Coping with climate change in Amsterdam – a watercycle perspective
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ABSTRACT

Amsterdam has the ambition to develop as a competitive and sustainable European metropolis. Water and Amsterdam are closely related, and water and climate change are closely related. Therefore, to be sustainable and economically strong, it is necessary for Amsterdam to anticipate the changes in climate that will take place in the Netherlands during the coming decades. Waternet, the watercycle company of Amsterdam and surroundings, has built a response strategy focusing on water management to contribute to the aim of making Amsterdam ‘waterproof’ for the next decades. This response strategy has two building blocks: adaptation and mitigation. With respect to adaptation the focus is on safety against flooding, discharge of rainwater without nuisance for the public, ecological healthy water in compliance with the European Water Framework Directive, a reliable drinking water supply in compliance with the Dutch Drinking Water Regulations and the European Drinking Water Directive, and an efficient and effective wastewater treatment in compliance with the European Urban Wastewater Treatment Directive. With respect to mitigation the focus is on energy recovery from the watercycle and nutrient recovery from wastewater. The strategy is carried out in close cooperation with partners on a regional level and a national level.

Key words | adaptation, energy, mitigation, water, water management, watercycle

INTRODUCTION

Amsterdam is the capital of the Netherlands. It has an important economic function, and is characterized by intensive spatial dynamics. Urban densification is an important development. According to the vision of the authorities of the city of Amsterdam (City of Amsterdam 2008), Amsterdam has to be a strong and sustainable city in 2040. Amsterdam continues to develop further as the core city of an internationally competitive and sustainable European metropolis. To be a sustainable city, it is important to anticipate climate change.

In the Netherlands, the KNMI (Royal Dutch Meteorological Institute) has developed four climate change scenarios based on IPCC reports (KNMI 2006). Variables in these scenarios are the extent of temperature rise, 1 °C or 2 °C in 2050, and the change in wind pattern in Western Europe. In all four scenarios, it is expected that the temperature will rise, resulting in milder winters and warmer summers. The winters will become wetter with more extreme precipitation while the number of extreme rain events in the summer will increase, accompanied by a decrease in rain days. The sea level will rise with an absolute rise in 2050 between 15 and 35 cm, an effect that is enhanced by land subsidence in the western part of the Netherlands. Climate change will also affect the city of Amsterdam. Water is present everywhere in and around Amsterdam. Amsterdam is surrounded by water and is partly located below sea level. Amsterdam has organized its water management very well but, looking to climate change and the effects, is Amsterdam ‘waterproof’ for the future?

Waternet, the first watercycle company in the Netherlands (van der Hoek et al. 2011), is responsible for the water management in Amsterdam. The activities of Waternet concern drinking water supply, sewerage, wastewater treatment, surface water management, groundwater...
management, control of the canals in Amsterdam and flood protection. Waternet has developed a response strategy to cope with climate change.

In management concepts, a strategy is related to the mission and vision of an organization (Rampersad 2002). While a mission describes the reason of being and a vision the long-term purposes of an organization, a strategy is a sort of action plan of how to realize these purposes. The mission of Waternet is to control and manage the water cycle in an integrated and societal responsible way. Integrated means that attention is given to all activities of Waternet and that coherence is strived after. Societal responsible means that a long-term perspective is taken into account focused on sustainability, and that all relevant partners are involved.

These starting points are reflected in the response strategy of Waternet of how to cope with climate change. First, in the strategy all activities of Waternet are considered and balanced. Attention is given to coherence between actions and synergy between actions. Second, Waternet cooperates with other partners in the development and implementation of this strategy. As an example, the Physical Planning Department of the city of Amsterdam is an important partner as spatial planning is closely related to water management, especially in an urban environment. Also with neighbouring municipalities, there is close cooperation, and the strategy is also attuned to national policies. To incorporate scientific knowledge in the strategy cooperation is also established with universities and knowledge institutes. Third, long-term decisions on this strategy are made at the Waternet management level and at the City Council level to guarantee a coherent strategy for the city. As climate change is characterized by a high uncertainty the strategy is periodically on the management agenda to anticipate new developments and insights.

METHODS

For a strategy to be effective, it is important that it can be implemented. Therefore, Waternet has operationalized the response strategy by identifying two specific building blocks. The first building block is adaptation to climate change. As Waternet is a watercycle company, this building block covers all elements of water management. The second building block covers mitigation. The mitigation strategy focuses on the reduction of greenhouse gas emissions and the recovery of energy from the watercycle as a compensation measure. Greenhouse gas emissions have been calculated based on the international Greenhouse Gas Protocol (WRI & WBCDS 2004). This protocol was applied to calculate the emissions by Waternet (Janse & Wiers 2006, 2007; Wiers et al. 2009).

RESULTS AND DISCUSSION

Adaptation strategy

The adaptation strategy to cope with climate change in Amsterdam focuses on five aspects:
1. safety
2. discharge of rain water
3. ecological healthy water
4. drinking water
5. wastewater treatment.

Safety

This concerns protection against flooding. The Netherlands is located in a river delta and the western part of the Netherlands is below sea level. Due to climate change the discharges of the rivers Rhine and Meuse will reach more extreme values (de Bruijn & Mazijk 2003; Doomen et al. 2006) and rainfall will become more intensive (KNMI 2006).

At the moment, Amsterdam is relatively safe against flooding (City of Amsterdam 2010b). However, flooding will have a huge economic impact and as it is the policy to further develop Amsterdam as a competitive sustainable European metropolis (City of Amsterdam 2010a), effects will become more dramatic.

Amsterdam already uses a multi-layered safety approach in the protection against flooding (Koeze & Van Drimmelen 2012). In the concept of multi-layered safety (van den Brink et al. 2011), shown in Figure 1, the first layer is flood protection and the implementation of (new) safety standards by taking technical and spatial measures. The second layer involves sustainable and ‘climate proof’ spatial planning to
reduce the economic damage and the number of casualties in case of flooding.

The third and final safety layer involves disaster management aimed at bringing people and animals to safe locations and to restore the damage. At the moment, Amsterdam updates the multi-layered approach because of the intended growth of the economic value of Amsterdam, because of spatial developments and urban densification close to dykes with a too low safety standard, and because of some weak spots in the protection system. Waternet together with the Physical Planning Department of the City of Amsterdam are the initiators and have the lead in the update of the multi-layered safety approach. In this context two pilots are carried out in Amsterdam. On a national level, there is close cooperation with the Ministry of Infrastructure and the Environment.

Discharge of rainwater

With respect to discharge of rainwater, it is important to realize that climate change will result in an increased frequency and intensity of extreme precipitation events. This may lead to problems with stormwater handling in cities (Nilsen et al. 2011). In Amsterdam, the effects of urban densification include reduced infiltration, increased volumes of runoff and higher and earlier peak flow rates. These result from the increased percentage of impervious surfaces. The city of Amsterdam intends to take measures based on the principle of retaining–storing–discharging to cope with more intense rainfall (City of Amsterdam 2010b). With respect to discharge of rainwater through the sewers, innovative sewer networks will be introduced based on real-time control to optimize and balance storage capacity of the sewers and pumping capacity of the boosters, resulting in an equalized flow to the wastewater treatment plants (de Korte et al. 2009). In urban areas the purpose is to delay the discharge by introducing green roofs and by introducing infiltration ponds in the green suburbs, where space is available. Also, the discharge of rainwater directly to surface waters, abundantly present in Amsterdam, is considered. In the public space, new gutters and storm drainage collection systems will be introduced in the streets that can temporarily store rainwater without being a public nuisance.

Ecological healthy water

Due to an increase in temperature, the surface water temperature will rise with negative consequences for algal growth and botulism. To retain ecological healthy water in the canals of Amsterdam, the water in the canals is refreshed with water from the IJ-lake and Markerlake several times a week. In this case, ecological healthy water is defined as surface water which complies with the European Water Framework Directive (European Union 2000). This fresh water is also used to flush the regional water system north of Amsterdam to prevent this system from becoming brackish. As a result of droughts, fresh water will be less available. Thus, there is competition between these two applications of this fresh water. For that reason, an experiment is being carried out in which the canals are only flushed based on oxygen depletion in the canals, saving water from the IJ-lake and Markerlake (Korving et al. 2012). The water quality in the canals has improved substantially in the past years by reducing emissions to the canals from sewers and house boats, improving wastewater treatment and moving the emission of wastewater treatment plant effluent downstream.
of the canal system. First results show that flushing from a two to four times a week routine can be changed to an approach in which the actual oxygen concentration in the canal system determines the need for flushing. In 2010 this resulted in flushing only during the summer period and, in 2011, no flushing was needed.

In addition, the European Water Framework Directive (European Union 2000) is used as a tool to improve the ecological water quality with structural measures. These measures are described in more detail in the Dutch River Basin Management Plan Rhine, western part (National Authority 2008; Regional Policy Council Rijn-West 2011) and in the Water Management Plan of the Water Authority Amstel, Gooi and Vecht (Water Authority Amstel, Gooi and Vecht 2010). These measures mostly include steps to improve the ecological infrastructure. Considering the effect of heavy showers due to climate change and the anticipated stormwater overflows, it is important to know that 75% of Amsterdam is equipped with a separated sewer system, so stormwater overflows are not a problem in relation to ecological healthy water. A further reduction of emissions from the wastewater systems (sewer and sewage treatment) is not necessary yet.

### Drinking water

With respect to drinking water, Waternet operates two production plants to supply drinking water to Amsterdam. Figure 2 shows the infrastructure.

The Dune plant uses water from the river Rhine. The water is abstracted from the river Rhine in the centre of the Netherlands, pretreated in Nieuwegein (WRK station near Utrecht), transported to the dune area west of Amsterdam for artificial recharge and finally post-treatment is carried out. The Lake plant uses seepage water from the Bethune polder north of Utrecht. After coagulation, sedimentation, reservoir storage in Lake Loenderveen and rapid sand filtration the water is transported to a post-treatment plant south-east of Amsterdam. The total production is about 86 million m³/year, of which 70% is produced at the Dune plant and 30% at the Lake plant.

Both sources have been evaluated for quantity and quality (de Bruijn & Mazijk 2003; Bernhardi & Van den Berg 2006; Doomen et al. 2006). To date, at the raw water intakes of Waternet these sources are not in danger, either by quantity or by quality. This implies that with these two sources and treatment plants a reliable drinking water supply is guaranteed, i.e., the drinking water demand can be fulfilled and the drinking water quality complies with the Dutch drinking water regulations (State Journal 2011) and with the European Drinking Water Directive (European Union 1998). Recently, the National Institute for Public Health and the Environment RIVM concluded that due to climate change the quality of surface water in the future may deteriorate to such an extent that by 2050 it will be unsuitable for drinking water production (Wuijts et al. 2012). The results apply to almost all locations in the Netherlands where surface water is abstracted for drinking water (abstraction points).

To anticipate climate change, new sources are considered. The focus is on sources free of anthropogenic substances and sources with a constant quality to facilitate relatively simple treatment. For this reason, water reuse and water recycling is not seen as a future drinking water source. In a case study for the city of Amsterdam it was concluded that under normal conditions drinking water that meets the Dutch drinking water quality standards could be

![Figure 2](https://iwaponline.com/jwcc/article-pdf/5/1/61/374961/61.pdf)
produced from treated wastewater effluent, but additional redundancy should be built in to meet the standards under extreme operating conditions (Rietveld et al. 2009). In addition, extensive risk assessment and risk management are required to safeguard a reliable drinking water supply at any time, using this source. Also, the application of a dual water supply system is not a viable option. In such a system household water with a lower quality for other purposes than human consumption, and drinking water for human consumption are supplied simultaneously. Waternet experimented with such a system in the new housing estate ‘IJburg’ in 1998–1999, but the results were not successful related to the economics and sustainability of the system (van der Hoek et al. 1999). In addition, in an evaluation of several pilots with a dual water supply system in the Netherlands, it was concluded that the health risks of these systems are very difficult to manage (Oesterholt 2003) and in the Dutch drinking water regulations (State Journal 2011) these systems are not allowed.

The use of brackish groundwater as a new drinking water source appears much more attractive. Brackish groundwater is free of anthropogenic substances and has a constant quality. Therefore, the use of brackish groundwater has gained much attention in the Netherlands (Oosterhof et al. 2009). A concept of brackish groundwater treatment is PURO (Figure 3), which is studied by Waternet and a colleague drinking water company, Oasen (Timmer et al. 2011). In this concept the brackish groundwater is desalinated by reverse osmosis at a low recovery, without the addition of chemicals. The membrane elements are placed in the groundwater wells. The concentrate is returned at great depth in an aquifer where the natural salt concentration is equal to that of the concentrate, so no salination takes place. The pressure required to force water through the membranes, about 8 bar, is naturally present at the depth where the membranes are placed in the well. As a consequence, the environmental impact of this process is very low.

**Wastewater treatment**

With respect to wastewater treatment, the wastewater treatment process itself is not really affected by climate change (e.g., heavy rainfall) as Amsterdam is supplied with a separated sewer system for 75%. However, by using wastewater treatment techniques able to comply with very stringent nitrogen and phosphorus standards for surface water, negative effects of an increasing water temperature on surface water quality (e.g., algal blooms) are avoided. Waternet operates two wastewater treatment plants in Amsterdam. Both plants comply with the regulations as described in the Urban Wastewater Treatment Directive (European Union 1991). In the period 2009–2011, the total nitrogen and phosphorus removal efficiencies of the plant ‘West’ were 85–88% and 91%, respectively, and the total nitrogen and phosphorus removal efficiencies of the plant ‘Westpoort’ were 88–92% and 93–94%, respectively. Both wastewater treatment plants are located in the ‘Western harbour area’, which is vulnerable to flooding. Because of the importance of this specific infrastructure for public health and ecological healthy water, local measures are planned to improve the water safety and to minimize the effects of flooding. These measures are raising the area, constructing...
small dikes around the area and implementation of crisis management (Koeze & Van Drimmelen 2012).

In addition, the wastewater treatment process is also used in the mitigation strategy, which will be discussed in the next section.

Mitigation strategy

In 2007 the International Panel on Climate Change recommended to strive for an ambitious reduction of carbon dioxide-equivalent (CO2) emission levels in order to stabilize global warming (IPCC 2007).

Activities in the watercycle in Amsterdam (drinking water treatment and distribution, wastewater collection and treatment, water management) contribute about 2% to the greenhouse gas emissions in Amsterdam (Janse & Wiers 2006, 2007). This is relatively low compared with other countries. For example, water-related greenhouse gas emissions in Australian cities represent 8% of the national greenhouse gas emissions with a range of 4–16% being possible for individual cities (Kenway et al. 2014).

Figure 4 shows the greenhouse gas emissions from activities in the watercycle in Amsterdam, and the required compensation to operate the watercycle climate neutral.

The year 1990 is the reference year. At that time the emission was 89,000 ton CO2-eq. In 2009, the emission has been reduced to 62,800 ton CO2-eq. This reduction has been realized through the purchase and use of renewable energy to an amount of 45,000 ton CO2-eq (‘green electricity’), through energy efficiency measures, and through process optimizations, especially with respect to the use of raw materials. The year 2020 is the target year to operate climate neutral. Assuming a steady purchase and use of green electricity, a compensation is required of 69,000 ton CO2-eq. For part of this, compensation can be reached through additional energy efficiency measures: 15,900 ton CO2-eq based on an energy efficiency improvement of 2% per year. The remaining compensation, 53,000 ton CO2-eq, may be realized through the production of renewable energy by Waternet. Of course, wind energy and solar energy are possibilities, but for Waternet, as a watercycle company, it is much more attractive and challenging to use the energy content of water. Waternet has developed initiatives to recover energy from surface water, wastewater, groundwater and drinking water to compensate for greenhouse gas emissions (Mol et al. 2011; van der Hoek 2012).

In a first inventory, performed in 2010–2011, it was estimated that sustainable energy may be recovered from the watercycle (thermal energy from surface water, wastewater and ground water, and chemical energy from wastewater) up to an amount of 148,000 ton CO2-eq, which exceeds the required compensation of 53,000 ton CO2-eq (van der Hoek 2012). However, this study is concerned with just a first estimate without taking into account the technical, economical, managerial and political feasibility of the specific projects. In a more detailed study, all projects have been evaluated on their technical and economical feasibility (van Odijk et al. 2012). In addition, from a managerial and political point of view, not for all projects can the avoided greenhouse gas emission be accounted entirely to Waternet, as several parties are involved who also take their share in the targeted greenhouse gas emission reduction. This evaluation and specification resulted in a more detailed estimation. Figure 5 shows the results expressed as minimum and maximum scenarios. In both scenarios the specific projects are taken into account which are under consideration at the moment. Six categories are distinguished, either based on chemical energy recovery or thermal energy recovery from the watercycle. The energy recovery is recalculated in avoided greenhouse gas emissions.

In the minimum scenario, it is assumed that only those projects will be realized which are very cost-effective (very low costs or even cost savings to abate a set amount of CO2-eq. emissions), and that for several projects only 50% of the avoided greenhouse gas emission can be accounted.
to Waternet. In the maximum scenario, it is assumed that all projects will be realized and that 100% of the avoided greenhouse gas emissions can be accounted to Waternet.

In the minimum scenario, the energy recovery equals 27,300 ton CO₂-eq/year, in the maximum scenario the energy recovery equals 82,800 ton CO₂-eq/year. Realization of the specific projects may result in the required compensation of 53,000 ton CO₂-eq/year.

The city of Amsterdam has the ambition to reach a reduction of greenhouse gas emissions of 40% by 2025 (City of Amsterdam 2009), which implies a reduction of 3,100,000 ton CO₂-eq/year. This means that the watercycle may contribute 0.9–2.7% to this ambition.

The required greenhouse gas reduction of 53,000 ton CO₂-eq can be divided into three categories as defined by the Greenhouse Gas Protocol (WRI & WWBCDS 2004): direct greenhouse gas emissions (scope 1), indirect greenhouse gas emissions from electricity consumption (scope 2) and other indirect greenhouse gas emissions, e.g., greenhouse gas emissions related to the use of chemicals and raw materials (scope 3). For the Waternet case, the contributions of scope 1, 2 and 3 are 36, 4 and 60%, respectively (Klaversma et al. 2013). The measures described above are all related to energy recovery from the watercycle and focus on scope 1 and scope 2. The analyses show that it is not certain whether the required compensation can be met completely with these measures. Therefore, recently, measures have also been identified in scope 3, focusing on the use of alternative materials and chemicals in water treatment (Klaversma et al. 2013). Three measures have been considered: phosphate removal and recovery in wastewater treatment; pH correction with carbon dioxide instead of HCl in drinking water treatment; and change of materials for drinking water distribution pipes (ductile iron instead of PVC). Only the first measure, in which less FeCl₃ is dosed and struvite is recovered from wastewater with addition of MgCl₂, has a significant effect on the climate footprint. Introduction of this measure will reduce the greenhouse gas emission by 1,120 ton CO₂-eq per year. Hence, the mitigation strategy of Waternet is now based on measures that cover scopes 1, 2 and 3.

**CONCLUSIONS**

Amsterdam aims to develop as a competitive and sustainable European metropolis. Sustainability implies that Amsterdam responds to climate change. From a watercycle perspective, it is possible to contribute to this target. Waternet, the watercycle company of Amsterdam, is in charge of all water-related tasks in and around Amsterdam. By adaptation measures focusing on safety against flooding, discharge of rainwater without nuisance to the public, ecological healthy water, reliable drinking water and effective and efficient wastewater treatment it is possible to make Amsterdam ‘waterproof’ in the future. By mitigation measures focusing on energy recovery from the watercycle it is possible to operate the watercycle climate neutral and to contribute 0.9–2.7% to the target of reducing the greenhouse gas emission in Amsterdam by 40% by 2025.

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