Sustainable Urban Drainage Systems
- 8 case studies from the Netherlands

2BG
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Introduction

This working paper presents observations and experiences from a study trip to the Netherlands carried out during 23 – 26 April 2008 as a part of the Black, Blue and Green PhD course in sustainable urban drainage provided jointly by the University of Copenhagen and the Technical University of Denmark.

The study trip included visits to Leidsche Rijn (Utrecht), Eva-Lanxmeer (Culemborg), De Vliert ('s-Hertogenbosch), Monnikenhuizen (Arnhem), Haaksbergen (Twente), Ruwenbos (Enchede), Stad van de Zon (Heerhugowaard), and Westerpark (Amsterdam).

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Case 1: Leidsche Rijn, Utrecht

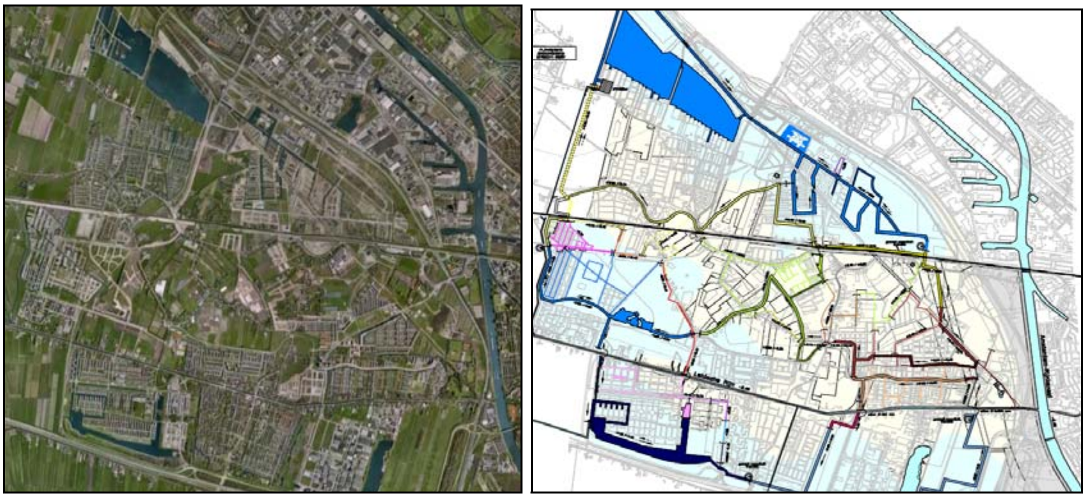


Fig. 1. Left: Orthographic photo of Leidsche Rijn. Elevation 10 km © Google Earth. Right: Map of the water system (Ingenieursbureau Utrecht 2007)

Leidsche Rijn is the largest ongoing housing development project in the Netherlands located in the western part of Utrecht. The project was founded in 1995 when a master plan for the whole area was set up, and is estimated to be finished by 2015. It will then contain some 30,000 houses that can accommodate up to 80,000 inhabitants. The area comprises 2100 hectares of land of which approximately 11 % is covered by surface water. The district is being built neighborhood by neighborhood ascribing different identities to the different neighborhoods.

As shown in figure 1 the area of Leidsche Rijn is divided into two hydrological different parts (white and light blue). The topography varies with relatively high grounds in the central parts of the area to lower lying areas along the perimeter. The higher grounds mainly consist of sandy soils facilitating stormwater infiltration, whereas the surrounding lower grounds are loamy and thus not (or far less) suitable for infiltration. Stormwater is infiltrated in the centre, overflow is led to the free water surface canals, before being retained in the large lake in the northwestern part of the area. The lake has direct contact to the groundwater, and here the water is stored, used for recreation and as an ecological habitat. In the north, the canals are deeper with steeper slopes and a high flow rate to transport the water to the lake. In the southern part, the slopes of the canals are less steep and infiltration of the water is possible.

Hydrology

One of the key features of this area is its stormwater management system, which is mainly made as an open system, visible to the citizens in order to improve the quality of life for the inhabitants.
Stormwater is managed in a closed loop system intended to retain water in the canals year round, to prevent the occurrence of flooding incidents and with as little intake of water from the surrounding area as possible. The reason for this is that stormwater is regarded as a source of non-polluted water, whereas the water in the neighbouring Amsterdam-Rhine Canal and the water from the surrounding agricultural areas are high in phosphorus concentration, which will lead to algae growth in the system. In order to have sufficient water in the system during dry periods it is therefore important to keep the stormwater in the area. This is achieved by a comprehensive closed canal system in which water is pumped from lower to higher grounds in order to maintain flow in the canal system. The stormwater collected from roofs and small streets is conducted through a network of wadis (wide infiltration trenches) and canals, and ends up in a 40 m deep lake on the northwestern edge of Leidsche Rijn. The wadis located in the drier parts of the area also

contribute to infiltration and replenishes the groundwater. In addition to this, many low-traffic roads and yards are equipped with permeable pavement that lets the stormwater runoff percolate to the subsoils.

This stormwater system was established due to problems in the past, when Leidsche Rijn was an agricultural district. Normally the groundwater levels in the region are higher in winter and lower in summer. Agricultural activities require fairly stable groundwater levels, and therefore a lot of groundwater was drained out from the area during winter, whereas water had to be supplied externally from the nearby Amsterdam-Rhine Canal in the summer. The water in the canal was relatively polluted compared to the water within the area, and thus the idea of storing superfluous water from wet periods for use during dry periods arose.

The current stormwater system helps keeping the stormwater within the area by infiltration and by using the lake as a buffer between wetter and drier periods. Under normal circumstances there will be no need for extra water supply, which minimizes the pollution from external sources. The groundwater level in the area is regulated and allowed to fluctuate a maximum of 30 cm between seasons. However the lake has an extra buffer of 100 cm, in order to avoid flooding problems in case of 100-year rain events.

Water quality management

In order to keep the open stormwater system clean and avoid stagnation of water, the water is continuously being pumped from low to high areas, which results in constant circulation. Within this closed loop, in the north-western corner of the district, a so-called vertical flow reed bed is incorporated (although the amount of reed is very sparse), where phosphates are held back (fig. 2). The main purpose is to maintain the P level of the surface water below 0.15 mg/l. The filter matrix consists of sand enriched with limestone (calcium carbonate) and iron oxides. The water taken in from the Amsterdam-Rhine Canal and some of the circulating water from the closed system runs through this treatment facility. The filter is currently in a trial period where various setups and parameters are tested to obtain the most efficient treatment. In the near future the system will be implemented at full scale expected to cover an area of approximately 6 hectares. The low technology nutrient removal combined with the constant flow in the canal system should keep the surface water free of algal bloom and potential odor problems.

Fig 2. Water filled (rightr) and empty (left) basin at the treatment facility.

There is not a big concern about groundwater contamination by infiltration in the area because the groundwater is only used for drinking water purposes after further infiltration and treatment. In the urban stormwater management system there is a distinction between water which is considered clean and water considered dirty, where dirty water is led to the sewer. Runoff from roofs is considered ‘clean’. Road run-off was originally categorised as (i) less than 500 cars per day, could be infiltrated without prior treatment, (ii) between 500 and 5000 cars per day, should be infiltrated through a wadi, (iii) more than 5000 cars per day, is considered dirty and should be led to the sewer system for municipal treatment. It was assessed that this distinction was too hard to manage, and in practice the distinction was made based on a judgement by the engineers on the size of the roads, where runoff from local roads were infiltrated through wadis while runoff from the bigger roads were led to the sewer.

Wadis

In order to improve the quality of the runoff before discharge to the canals, infiltration through a so-called wadi is used. A wadi is a grass-covered suppression in the landscape, with a top layer designed to retain pollutants (covered with grass), and a soak away pit or good infiltration potential underneath. The wadis at this site are constructed with a mixture of sand and humus in the top layer, which will remove a wide range of pollutants which is found in stormwater (PAHs and other hydrophobic compounds and heavy metals). Underneath the top soil there may be plastic boxes/trenches, storing the water while it infiltrates into the ground.

In areas with low permeability (clay ground) and high groundwater levels, the wadis function more as reservoirs in extreme events because of the low infiltration potential. Here there is a drain pipe in the bottom of the wadi leading to the open water canal system. A wadi and the infiltration trench underneath is shown in figure 3.

Fig. 3. Left: a wadi. Centre: Infiltration trench underneath the surface of the wadi. Right: Small stormwater infiltration area with compacted soil due to car parking.

In Leidsche Rijn, different types of wadis have been implemented over the last 10 years and varying experiences with their operations have been made. Most of the wadis in Leidsche Rijn are covered with grass and some are additionally escorted by trees alongside. A few wadis are also planted with perennials and used as small “rain-gardens”. These wadis are liked by the inhabitants and are well functioning. They provide seasonal colourful impressions for the neighbourhoods.

The experiences with maintenance of the wadis show, that only large dimensioned and long wadis are recognized as such and therefore maintained well. Experiences with the infiltration boxes installed in the wadis show that they are clogging and a proper maintenance of them is not possible. Therefore new wadis in the area of Leidsche Rijn are now built without infiltration boxes.

Cars parking on wadis are another problem occurring regularly when wadis are built close to houses and along streets. Cars that park in the wadis cause soil compaction, which decrease the permeability. Therefore the water stays too long on compacted soil and inhibits the growth of grass or other plants. This problem needs to be solved by provident planning. Visible kerbstones (not hindering water from entering the wadi) and enough regular parking lots available close by could help to prevent this problem.

Other problems found within the construction of wadis are the need of very precise management of elevations at the the site. Examples of drainage pits that are implemented so high that no water will ever drain in can be seen in the area. Or large differences in terrain/ steep slopes which cause dry areas uphill and too wet areas on the ground of the wadi. This again leads to problems in plant growth.

Altogether the experiences with the planning and building of wadis are still relatively limited. Further experiences and research (!) will help to improve the technology and its usability for stormwater infiltration and storage.

Text box 1. Wadis at Leidsche Rijn

The smaller local roads from which direct infiltration of runoff is considered as safe practice are covered with permeable pavement. The roof runoff from adjacent buildings is led through downpipes and spouts onto the street to either infiltrate or run as surface runoff directly to the nearby canal or wadi.

Permeable pavement
Non visible, but effective for the purpose of infiltration is the permeable paving, used in the neighbourhood streets of Leidsche Rijn. Unfortunately the paving is not always functioning well. In streets with high traffic load, tire particles tend to clog the infiltration pores. Close to gardens, humus particles of garden soil can cause the same effect. This could only be prevented by a regularly cleaning of the pavement. This is commonly done by industrial vacuums that suck up all the sediment. This technique is cost intensive and not done in Leidsche Rijn yet. Here enough other infiltration capacity is available and infiltration through the pavement is therefore not crucial in relation to flooding problems.

Fig. 4. Wadi between roads and tiled pervious surfaces. Roof runoff is led onto the street to infiltrate or flow on the surface to the wadi.

Text box 2.Permeable pavement at Leidsche Rijn

In order for the water quality to remain satisfying, important measures concerning the behavior of the citizens is being implemented. Pesticides and salt for de-icing in the winter is banned, carwash and walking the dog is only allowed in special sites, and other innovative methods are implemented to elucidate the citizens on these matters are being used, e.g. a computer game about "dos and don'ts" in the area. It is not reported how well this ban works, but there are campaigns in order to get people to obey the restrictions. There is a risk though, that as time goes by people will forget about the regulation and this could cause problems in the system.

Monitoring of the water quality consists of monitoring the wadis and the efficiency of the removal of phosphorus from the vertical sand filter. The performance of the wadis is monitored on a yearly basis by collecting samples from various soil depths underneath the wadis and analyzing for 10-15 common pollutants, but mainly focusing on the heavy metals. This way, the wadis can be maintained when the need is there (the top layer of the wadi is replaced with a new layer with new sorbing capacity). There is no monitoring of bacterial contamination in the system. This could pose a risk to the inhabitants because of the closeness of the water and inhabitants built into the system.

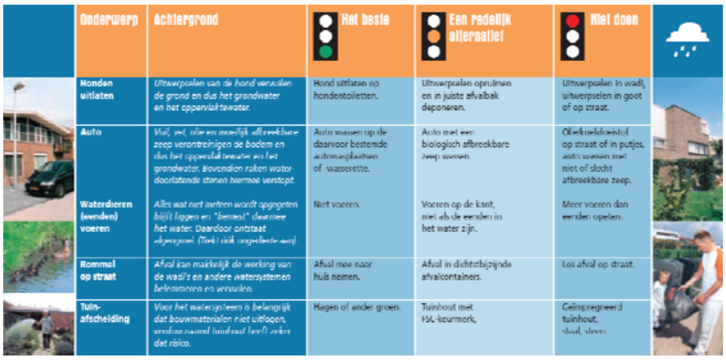
Planning and design

The canals do not only transport the water, but provide a strong structure to the neighbourhood of Leidsche Rijn. Visible water everywhere forms the special character of the area.

The stormwater management in the area of Leidsche Rijn aims to handle the accumulated stormwater on site. The stormwater is with few exceptions detached from the sewer system. Besides the technical solutions for infiltration, transpiration and storage of the water, the stormwater is also used for the design of the neighbourhood. The elements for stormwater management, like wadis and canals are communicating with the inhabitants and visitors. Even though the stormwater is not always visible, the elements give a special structure and arouse associations of water. The elements show the ecological standard and give an identity to the area.

With the steady growth of the area, more and more people are living in the new city district. One of the problems of the area is the absence of schools, cafés, neighbourhood centres etc. The shortage of these institutions results in missing social structures. The people's identification with the area is developing slowly and the inhabitants complain of a lack in life quality.
In this situation, the stormwater management system was used as a tool to build up a local identity.

One exemplary project to improve the situation is a local photo competition. The inhabitants were asked to take pictures of the water system and the pictures were shown in a small exhibition. This way, the people started to inform themselves about the water system and told their neighbours about it. As a result, people got aware of the special structures in their neighbourhood and took over responsibilities for it. Along with this the inhabitants got in contact with each other and social structures started to grow. This small successful project shows the social potentials within a new sustainable stormwater management system as well. Besides this little example, the information centre of Leidsche Rijn informs the people very detailed and in many different ways. Brochures, information materials and a game are available to teach the people how to behave in the sensitive environment of stormwater infiltration areas (fig. 5).



Onderwerp	Achtergrond	Het beste	Een redelijk alternatief	Niet doen
Honden uitlaten	*Uitwerpselen van de hond vervuilen de grond en dus het grondwater en het oppervlaktewater.*	Hond uitlaten op hondentoiletten.	Uitwerpselen opruimen en in juiste afvalbak deponeren.	Uitwerpselen in wadi, uitwerpselen in goot of op straat.
Auto	*Vuil, vet, olie en moeilijk afbreekbare zeep verontreinigen de bodem en dus het oppervlaktewater en het grondwater. Bovendien raken water-doorlatende stenen hiermee verstopt.*	Auto wassen op de daarvoor bestemde autowasplaatsen of -wasserette.	Auto met een biologisch afbreekbare zeep wassen.	Oliekoelvloeistof op straat of in putjes, auto wassen met niet of slecht afbreekbare zeep.
Waterdieren (eenden) voeren	*Alles wat niet meteen wordt opgegeten blijft liggen en "bemest" daarmee het water. Daardoor ontstaat algengroei. (Trekt ook ongedierte aan).*	Niet voeren.	Voeren op de kant, niet als de eenden in het water zijn.	Meer voeren dan eenden opeten.
Rommel op straat	*Afval kan makkelijk de werking van de wadi's en andere watersystemen belemmeren en vervuilen.*	Afval mee naar huis nemen.	Afval in dichtstbijzijnde afvalcontainers.	Los afval op straat.
Tuin-afscheiding	*Voor het watersysteem is belangrijk dat bouwmaterialen niet uitlogen, [illegible] dat risico.*	Hagen of ander groen.	Tuinhout met FSC-keurmerk,	Geïmpregneerd tuinhout, [illegible]

Fig. 5. Left: Table from an information brochure in Leidsche Rijn. Right: Physical model at the Leidsche Rijn exhibition centre.

In terms of organisational set-up, conflicts of interest have been identified between different stakeholders. The Water Board has been concerned with ensuring and protecting water supply interests, the urban drainage department has been concerned with run-off and flood protection, the urban planning department has focused on land use (i.e. the provision of green space, open water surfaces – igniting discussions whether or not, or to which degree, wadis should be identified as green space, thus compromise the provision of other park areas).

Study area, Terwijde

Fig. 6. Orthographic photo showing the 8 enclaves along the west side of the island. Elevation 1 km © Google Earth.

As Leidsche Rijn is a large scale project with several neighborhoods of different ideas and designs the case study is carried out for a local residential area in Terwijde in the northern part of the Leidsche Rijn district. The houses in this area are situated in 8 well structured clusters with green grass covered areas in between, and surrounded by a larger canal system (fig. 6).

Fig. 7. Left: Common court yard. Right: Green space.

Each enclave is arranged with buildings framing a common court yard dominated by hard surfaces. On the rear side of the buildings the soft surfaces dominate with private gardens overlooking the public green space (fig. 7). These green areas are topographically lower than the inhabited areas by up to approximately 0.5 meter (fig. 8).

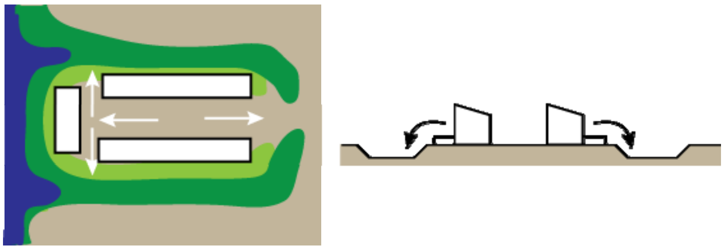


Fig. 8. Left: Illustration of the lake, public green space dividing enclaves and light green representing private gardens and semi-private buffer zone. Right: conceptual section of green space and elevated enclaves.

The green areas form wide swales which are able to store significant amounts of stormwater without putting the buildings at risk, and there may be further storage below ground in the form of infiltration trenches or other porous material. However, this local area is supposedly built on the clayey soils of the Leidsche Rijn district and it is most likely that the water is stored, evaporated or discharged into the nearby canal system, which are in direct connection with the green areas. Rainwater from roofs is transported via downpipes below ground. The downpipe material is unknown, but seems somewhat metallic by the looks of it even though it has been painted black. The roof material is also unknown. It is uncertain whether the water is infiltrated into the soil near the houses or if it is transported into the green areas via underground pipes. All hard surfaces in the inhabited areas are permeable to some extent consisting only of tiles and stones. The stormwater which is not infiltrated is transported via open drains in the middle of the roads to the green areas. The area is deliberately turned into a low traffic area with most parking spaces situated furthest from the canal system to ensure maximum treatment of this water before discharge.

Infiltration beds in local streets

In the case area stormwater infiltration beds are implemented in local streets. By differences in the terrain, the stormwater is led to the beds and infiltrated through grass covered soil. Probably due to lack of awareness among residents in the observed area, one of the beds was used as a small garden area (fig. 9). The bed was filled with garden soil and different herbs and flower planted. By this use, no stormwater infiltration is possible. This example shows the importance of adequate information provided for all residents and the need for new stormwater management systems to be supported by the residents.

Fig. 9. Infiltration bed filled and planted by the residents

Text box 3.Infiltration beds at Leidsche Rijn

Provided that the roof and downpipe materials are not zinc, copper or otherwise pollutant releasing materials and that the inhabitants follow the environmental guidelines provided by the municipality there seems to be no incentive for further cleaning of the rain runoff from this particular area.

Case 2: EVA-Lanxmeer, Culemborg

Fig. 10. Buildings and stormwater retention pond at EVA-Lanxmeer

EVA-Lanxmeer is a residential area developed by a group of ecologist from the EVA-foundation and is designed to house about 250 people. The project is designed as a demonstration project integrating multiple aspects of urban ecology including landscape based stormwater management, grey wastewater treatment and infiltration, passive solar heating, non-motorized transportation and the use of environmentally friendly construction materials (fig. 10 and fig. 12).

Hydrology

EVA-Lanxmeer is located at the edge of a water protection area. It focuses on approaching a closed hydrologic cycle and small scale solutions. This includes for instance rainwater harvesting and re-use, wastewater treatment and local infiltration. The involvement and motivation of inhabitants in the area is a highly prioritized area, since improper use or disposal of the water resources may cause a risk of groundwater pollution, which in turn can affect the drinking water. Consequently, learning and playing with the water seems to be an important factor in the design of the EVA-Lanxmeer as well. One can find a groundwater level indicator, a small water playground and a fountain.

Wastewater management is divided into 4 different flows; (i) run-off from roofs and vegetated areas collected in free-water surface ponds, (ii) road run-off and (iii) grey wastewater collected and treated in a constructed wetland before being infiltrated through the soil matrix, and (iv) sanitary wastewater collected and managed in conventional sewers (fig. 11).

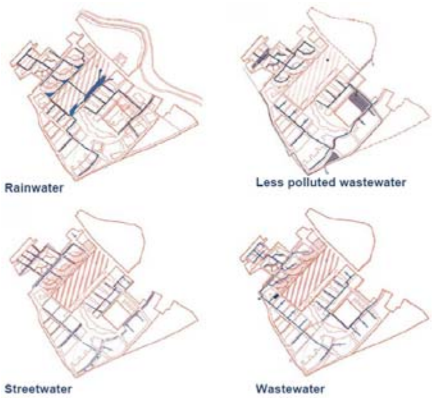


Fig. 11. Diagram of the 4 flows of wastewater at EVA-Lanxmeer

The stormwater from the roofs is collected in ponds located within the area. Much of the precipitation that falls on the roofs is however retained and/or detained by the many green roofs in the area, which also contribute to increased evapotranspiration. Stormwater runoff from streets and paved surfaces is led to wadis where it is allowed to infiltrate. Extra storage capacity is provided by restored riverbeds to prevent flooding during intense precipitation events.

When the project was launched the water supply to each house consisted of two separate pipelines: one for drinking water and one for household water. Household water was collected rainwater as well as wastewater from the cleaning process of filters at the local water plant. The household water was used for toilet flushing and washing machines. This practice was, however, later prohibited by the government authorities and the pipelines for household water are currently disconnected.

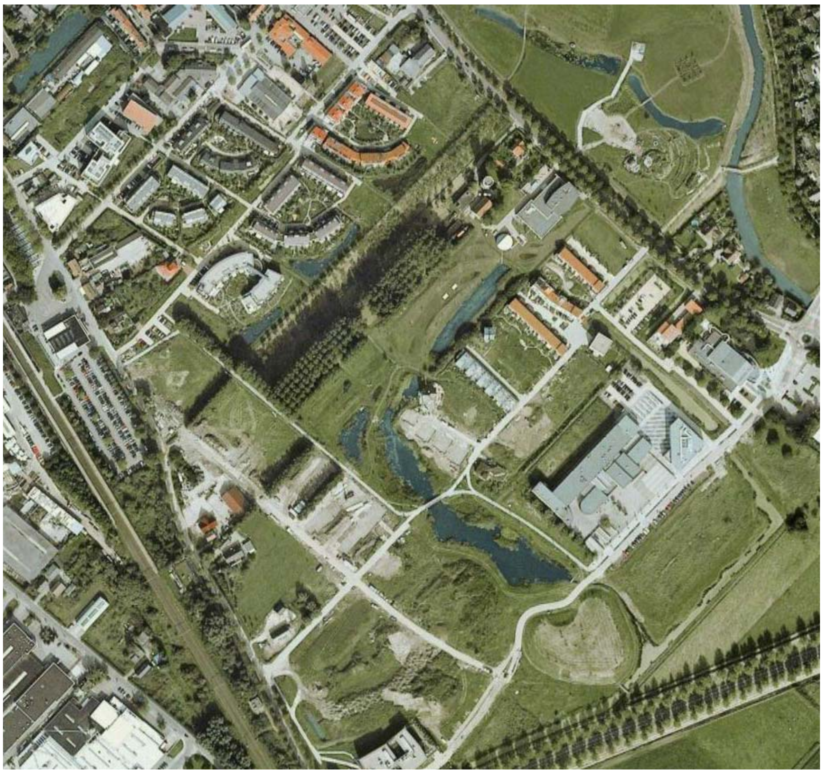


Fig. 12. Orthographic photo showing EVA-Lanxmeer during construction. Note the lakes, the forest strip, the intimate gardens in top and the constructed wetland immediately next to the big building to the East. Elevation 1 km © Google Earth

Water quality management

The fact, that the settlement is a pedestrian only area, reduces the pollution of the stormwater, contributes to a high quality of the collected rain runoff in the surface ponds and minimizes the need for larger paved areas. Lots of small pathways connect the houses and gravel materials are used frequently. This concept minimizes the stormwater runoff from the start and there is no strong need for runoff treatment before infiltration.

Another measure taken to approach a closed hydrologic cycle is the local treatment of household greywater, such as effluents from kitchen and laundry. The treatment is made by a reed bed located on the terrain. There are 3 local facilities for treatment of grey wastewater in the vicinities of the EVA-Lanxmeer area. No available documentation for the performance of these particular facilities has been found. However, it is well-known that such facilities require environmental awareness from the citizens of the area in order to maintain a satisfying degree of purification.
One of the grey wastewater treatment facilities is a sand filter/gravel filter at a central location immediately next to a school/office building. The wetland is fenced off by approximately 2 meter

high metal bars, restricting access. But the facility is still used, thus providing treatment at a satisfying level with an acceptable level of odorous and aesthetical nuisance.

Other types of wastewater from households, such as blackwater, is led to sewers and treated externally, due to the risk of groundwater contamination.

Planning and design

With the exception of the lakes providing aesthetic character to the area and reflecting the buildings, the integration of landscape based urban drainage principles is difficult to comprehend when visiting the site. Downpipes end below the soil surface and the separation or combination of flows in subsurface pipe systems is not immediately identifiable. Run-off from walkways and vegetated surfaces, however, flows by gravity to wet swales along the perimeter of local allotments.

The very individually build houses are build thoughtfully in the existing landscape. Old tree lined ditches still exist and give character and structure to the landscape. In addition, the estate exemplifies a high level of community involvement and commitment, which for example is indicated in the well maintained community gardens.

Case 3: De Vliert, ’s- Hertogenbosch

Fig. 13. Orthographic photo of De Vliert, ‘s-Hertogenbosch. Green spaces to the north and south, and heavily trafficked roads in the centre and to the west. Elevation 1 km © Google Earth

The De Vliert area in ‘s-Hertogenbosch was constructed more than 60 years ago, and originally had a combined sewer system. In the 90’s, there was an urgent need of reparation of the sewer system, and along with this restoration the stormwater was disconnected from the sewers and local infiltration was promoted.

Hydrology

The design of the stormwater handling is based on small localised solutions. Stormwater from the roofs is infiltrated individually in the gardens either on the ground or below, in rainwater tanks, infiltration ponds, trenches or similar, thus every household has the responsibility for their own runoff. Water from the roads with a low traffic load infiltrate through an infiltration trench under the road (run-off from roads with heavy traffic is collected in the sewer system). This system is supplemented with porous pavement and in case of wet weather and large flow an overflow from the infiltration system to a trench through a specially designed playground incorporating the stormwater and/or discharging to a nearby watercourse to the north and south (fig. 13 and fig. 14).

Fig. 14. Playground with stormwater overflow.

Water quality management

According to one of the key consultants on the project, Govert Geldof, stormwater quality has not been given a lot of consideration, because water from the roofs is seen as 'clean'. At the playground children are encouraged to play in/with the water. Even though this could be a potential cause of concern, there has been no complaints or worry by the inhabitants or the designers of the system.

Planning and design

Fig. 15. Permeable road pavement and run-off to park area at De Vliert.

De Vliert shows how unspectacular the renewal of an old sewer system can look like. Most of the roof runoff is handled in the backyards and not seen from the outside. The solutions for infiltration and use of the stormwater are mostly simple and long-known technologies. One can find elements like rain butts or little rain gardens to handle the stormwater on site.
The interesting aspect of this project is the use of the sewer renewal as a driving force for other purposes and the successful renewal of a whole city quarter.

The district of De Vliert represents an urban renewal project where landscape based urban drainage played an integrated part in line with traffic safety improvements, rehabilitation of recreational spaces (parks and playgrounds) and upgrading of the urban design including new pavement and street furniture (fig. 15).

During the planning process every resident had to be spoken with and every house needed its own special solution. This process was time consuming and exhausting for the planners, but it paid off and led to a new identity for the neighbourhood and the growth of a social community.
Inhabitants were involved in the planning process and took part by designing single items like the manhole covers and parts of a new playground. Govert Geldof, stresses the importance of public involvement for the success of urban regeneration projects. In his opinion support is wide spoken, when people are thoroughly informed about the objectives of the renewal process, when local ideas are integrated in the project and information provided along the way.
The design for stormwater infiltration systems sometimes leads to strange solutions, such as the water playground at De Vliert where there is only water when it rains. This design solution does not make much sense and dramatically reduces the number of days where active interaction with water is possible.

At De Vliert the designers operated with 3 concepts:

(i) the heroes, being the aesthetic landmarks and the resource persons,
(ii) the rituals, being the collaboration with end-users and end-user practice and awareness building, and

(iii) the symbols, being custom designed manhole covers or pumps at playgrounds referring to the design and presence of the special drainage system (fig. 16).

Fig. 16. Left: Custom made manhole covers indicate that the water here is infiltrated. Right: A pump at a playground included in the project.

In the case of De Vliert the urban retrofit was more expensive than just implementing a larger pipe where capacity problems occurred. In addition, and as a general premise, rehabilitating existing areas does not provide as ‘exceptional’ design solutions as seen in new urban development projects. However, with an integrated approach, more urban environmental quality and social gains such as a growing community feeling (and growing trust in the city administration) is obtainable.

Case 4: Monnikenhuizen, Arnhem

Fig. 17. Orthographic photo of Monnikenhuizen in Arnhem. Note the forests to the west and south. The slope descends from north to south. The lake is seen in the triangular arrow-shaped green space in the centre of the plan. Elevation 1 km © Google Earth

Located on a hill and surrounded by forest the site of Monnikenhuizen in Arnhem provides exiting and challenging topographic and contextual conditions for the utilization of landscape based urban drainage as an integrated design element in the development and branding of the area (fig. 17).

Monnikenhuizen consists of 204 residences and is distinguished by 3 special characteristics; gabions, water system and plantation.

Planning and design


Fig. 18. The Lake (left) and the River (right) as two dominant design elements at Monnikenhuizen

Two key design elements are identified; the River and the Lake (fig. 18). The River, being the gutter in the centre of the main access road, dynamically accentuates the meandering curves and the slope of the street, with a reference to more mountainous regions. Located in the valley at the bottom of the hill, the lake/pond forms the mental focal point of the plan, the communal meeting

place for residents, and the welcoming gate for visitors. The fluctuating water levels in the pond reflects the seasonal precipitation levels and uses the dynamics of water as an asset in the development of an ever changeable transitional space.
In addition a second river or 'waterfall' is used as a design element along the eastern part of the site. Both the river and the waterfall remain dry in periods without precipitation - as in nature.

Hydrology

Fig. 19. Left: Green roof with zinc edges. Right: Visibility of stormwater and zinc 'down-pipe'.

Monnikenhuizen provides a broad scope of inspiring solutions for stormwater management from small to large scale. On the small scale can be mentioned the green roofs retaining water (fig. 18), permeable parking lots (fig. 20), down pipes irrigating vegetated gabions or connected to infiltration boxes below ground and gutters reducing traffic speed or delineating private and semi-private (parking)spaces. On the bigger scale, water from the roads and overflow from the infiltration boxes are led via open, wide and shallow gutters in the middle of the streets to an infiltration and storage pond in the center of the area.

The bottom of the infiltration basin is covered with loam, which prevents (or significantly slows down) infiltration through the bottom. Thus, the pond will never dry out completely. During wet weather the water level will rise and infiltration take place through the sides of the basin. The pond also has an overflow which lets water out to an ecological corridor in case of extreme events.

A problem which has been observed at the site is clogging of the underground infiltration boxes. Therefore it is a problem that there is no access to the infiltration system when the construction is finished.

Monnikenhuizen is implemented in year 2000 and is at that time relatively unique in terms of using landscape based urban drainage systems as an asset. At present, according to the landscape architects, infiltration of rain water is the standard design solution in the Netherlands. Municipalities have developed guidelines for urban stormwater management (e.g. the "yellow book" by the City of Arnhem).

Fig. 20. Permeable parking lots.

Water quality management

All hard surfaces except from the roofs consist of more or less pervious material such as tiles, flagstone or pebbles partly facilitating infiltration. Some roofs discharge the runoff onto the streets and the open wide gutters which transport the stormwater downhill to the lake. Other roofs lead the runoff into infiltration trenches in the gardens and again, some roofs exploit both options simultaneously.

There are green roofs in the area as well as zinc roofs. It is well known that zinc roofs and downpipes have the potential to release zinc ions to the flowing stormwater and accumulation may occur in soils that infiltrate the water. There are, however, no measurements of the zinc concentrations in the lake water or sediment to reveal whether this is the case for the metal materials of Monnikenhuizen.

Zink is an important element in the design of the houses (fig. 19). It can therefore be expected that the run-off will contain considerable concentrations of zink. There have been no measurements on the water quality (i.e. concentration of zinc) or toxicity of the water and this was of no concern in the design of the project. Zink is only toxic in very high concentrations, so it is not clear if there could be adverse effects by the concentrations at the site.

Case 5: Lankheet, Haaksbergen

Fig. 20. Artists impression (left) and photo of the constructed wetland park as built at Haaksbergen (right).

At the Lankheet site located a forest area close to the town of Haaksbergen, in the East-Holland region of Twente, river water is treated in a constructed wetland system. The system combines treatment with reed production, land art and a recreational park, thus layering and intensifying land use in a multi-functional green space (fig. 20).

Fig. 21. Orthographic photo of the wetland system at Haaksbergen during construction. The canal runs to the east. Two of the intimate spaces are identified as ponds to the west. Elevation 1 km © Google Earth

The project site is divided into two large open plains combined with 3 smaller and more intimate spaces (fig. 21). The plains contain grids of wetland cells, each approximately measuring 40 x 40 m. The wetlands are lowered from the level of the walk paths and designed with a small moat restricting public access onto the wetland cells. Wetlands are covered by reeds, which are harvested for thatching (fig. 22), and the changing heights of the plants change the intimacy/openness of the walkways and reflect the seasonal changes. An artificial hill divides the two plains, frames the space, and provides the option for more perspective and an overview of the site. The intimate, somewhat meditative, spaces have open water surface accommodating direct interaction with water.

Fig. 22. Close-up of reed bed at Lankheet, Haaksbergen.

Hydrology and quality control

The system of reed bed infiltration basins are used to infiltrate and treat water from surrounding agricultural area. It can thus not really be considered a stormwater system since it is located in a relatively rural area in the outskirts of Haaksbergen. However, the project indicates the potential and necessity of multi-functional green space in the vicinity of urban areas to meet stormwater treatment demands at large scale.

When visiting the site, the purpose of treatment and the flow of water is relatively difficult to identify. The meandering river along the eastern edge of the site is expected to be the source. Whether treated water is discharged back to the river downstream, or water is infiltrated in the surrounding farmland or forest is unclear. Whether the reed beds function according to the intention and how clean the outflowing water is, is also unclear.

Planning and design

At first glance the location and scale of the plains makes it hard to differ the park from the surrounding production landscape. To underline the presence of a public accessible park land art is used to provide landmarks, mark the gateways and make the intimate spaces contrast the relative homogeneous context.

Fig. 23. Concrete stepping stones in a pond in Haaksbergen.

One example for the combination of art and water treatment is the step stones found in the park (fig. 22). Amorphous formed concrete step stones invite the visitors to walk through one of the lakes. By walking over the step stones one experiences the water very closely. The surface levels in the two sides of the lake are different. The step stones are used as a barrier where the water is floating through. By the time of the visit, the overall water level was relatively low and only little water was streaming from one part of the pond to the other.
This caused accumulation of waste and dirt in the gaps between the stones. The nearly still standing water was smelly and the experience of the close water surface was not positive.

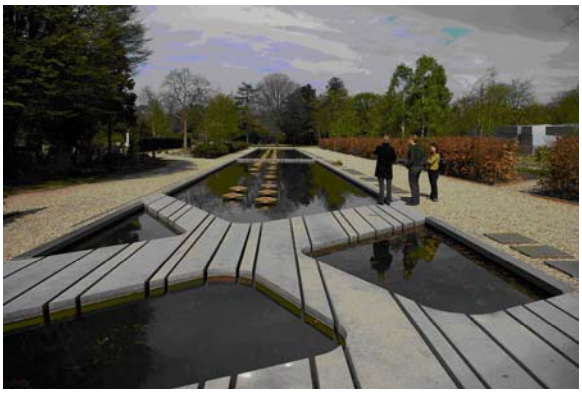


Fig. 23. Reference picture. Pond with concrete stones on the Nieuwe Ooster cemetery in Amsterdam

A better solution for the same effect was found in the Nieuwe Ooster cemetery of Amsterdam (fig. 23). Here the landscape architects Karres en Brands chose to build the concrete stones more formal and closer together. This solution seems to be less susceptible for dirt accumulation. Probably the cemetery is maintained more often than the step stones in the open landscape. Solutions for the open landscape need to be less fragile and easy to maintain.

Case 6: Ruwenbos, Enschede

Fig. 24. Photo of a wadi dividing built enclaves in Ruwenbos.

The district of Ruwenbos in Enschede has been developed during the last 10-15 years. As a consequence the area provides historic foot prints of the relation between the level of knowledge in and experience with landscape based urban drainage systems and the physically built environment. As counting tree rings the level of confidence in landscape based urban drainage can be read from one phase to another.

Hydrology

At the early stages stormwater is collected in a separated system and discharged to the green areas to the east and west of the enclaves. Here water seeps into wadis (fig. 24). Overflow is discharged to a retention pond to the south (fig. 25). The first phase was designed to be reversible to a conventional separated sewer system if the systems did not meet functional expectations.

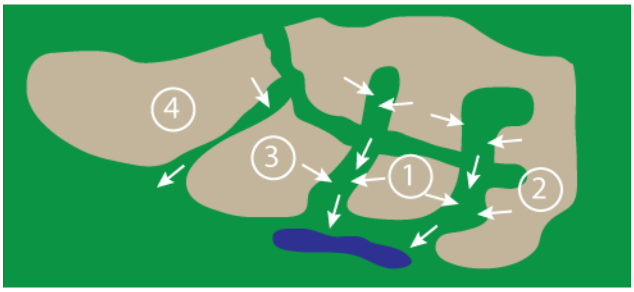


Fig. 25. Sketch of drainage system and design phases.

As time goes by and experience and confidence rises the design is more integrated and non-reversible. Landscape based urban drainage options are now integrated in the design from the start.

Water from paved areas and roofs are led via open gutters to the wadis. The residential area Ruwenbos in Enschede hosts the first wadi constructed in the Netherlands. At the time of construction there was thus little experience on the performance and design of wadis in Holland, which has resulted in wadis being over-dimensioned. However, this is not really a problem since they seem to function well and are appreciated by the inhabitants. The stormwater in the wadis will generally infiltrate in the underlying soils, or during intense precipitation events, flow out in a nearby pond and river.

There have been slight problems with clogging of the wadis in this area due to the presence of nearby oak trees. The leaves of oak trees are seemingly degraded very slowly and tend to pulverise which clogged the upper layers of the soil. So from time till time the citizens are actively removing the leaves that fall in the wadis.

Water quality management

The wadis of Ruwenbos were the first in the Netherlands and were a copy of the German Mulden Rigole (fig. 26). The roof runoff as well as runoff from the small local roads is transported via ditches to enter one of the three wadis traversing the area of Ruwenbos. The whole area is generally paved with more or less permeable surfaces such as tiles, flagstone and pebbles allowing for significant parts of the storm water to infiltrate even before entering the ditch.

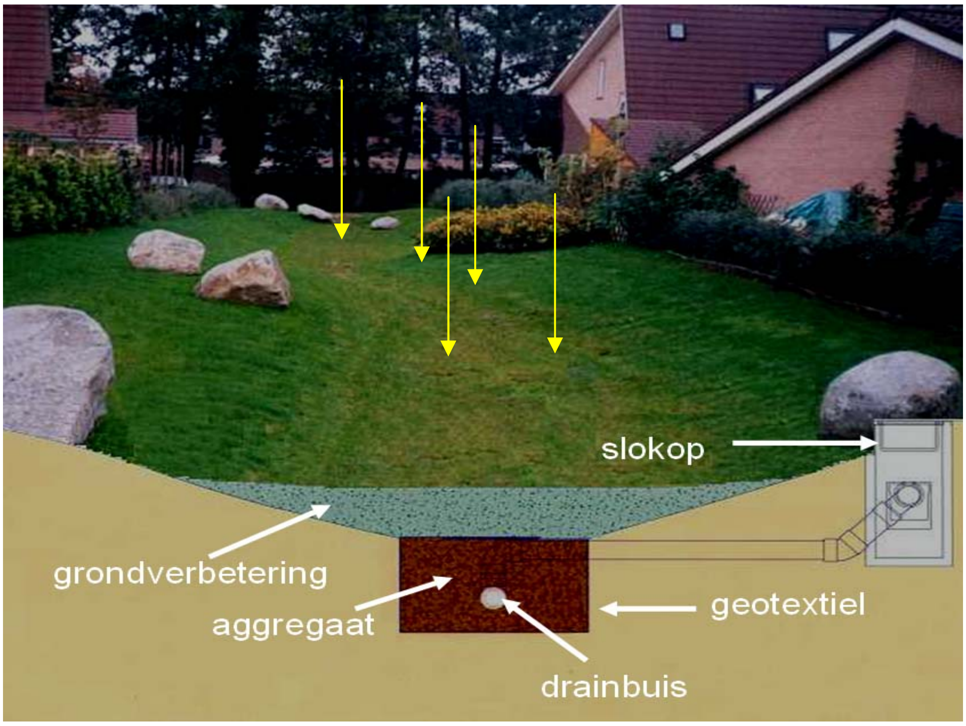


Fig. 26. Conceptual section of wadi at Ruwenbos, Enschede. Depression, filter substrate, infiltration box, drain pipe, geo textile and overflow structure (from Palsmaa, 2008)

An example of the importance of communication between the different partners in such a project is that the first houses built here were equipped with downpipes made of copper, which have the potential to release copper ions to the flowing rain water. This was based on a misunderstanding between the architects and the engineers designing the wadis. Problems with high concentration of copper in the soil can therefore occur. However, according to Govert Geldorf the wadis are being monitored on a yearly basis and to his knowledge no alarming accumulation of copper has yet been registered in the top soil layer. Monitoring is mainly concerned with heavy metals and is performed by taking out soil samples from different depths in the top soil of the wadis to register the rate of accumulation. Later in the building stage, the material was switched to something else, so that only the oldest houses still have copper pipes.

Planning and design

Fig. 27. Orthographic photo of the Ruwenbos district in Enschede. The enclaves are divided by green wedges predominantly north-south and one central with an east-western orientation. The retention pond and park is located next to the motorway and below power transmission lines. Elevation 1 km © Google Earth

The stormwater management system is well integrated in the green structure of the housing estate, with a visual reminiscence of the water from the streets via open gutters to green wedges, through wadis and into the retention pond in the local park (fig. 27).

The early wadis were over-dimensioned – by about 300%. This has increased the robustness of the technology, and has provided room for more multi-functional use of the urban green spaces. As an example the meandering curves and wadis are now doubling as popular bicycle race tracks for children. Govert Geldof, who has been involved as a consultant in the project, recommends large scale and robust wadis, in contrast to small systems squeezed in at marginal spaces.

The stormwater retention pond to the south is located under power transmission lines and next to the motorway, thus integrated in the planning of a multi-functional infrastructure corridor. As such, it is an example of actively including areas that would otherwise be left as wastelands. As a result of infiltration in wadis (due to the relatively good soil and ground water conditions) the stormwater retention pond turned out to be over-dimensioned and covering a relatively large area. Consequently the pond has been resized to provide more dry soil for park land. This exemplifies the appropriateness of over-dimensioning systems at the early pioneering stages of new technologies so that the flexibility of rehabilitation is maintained as an option if systems (does not) work better than expected.

Case 7: Stad van de Zon, Heerhugowaard


Fig. 28. Ortho photo of Stad van de Zon, Elevation 3 km © Google Earth

Stad van de Zon – City of the Sun – was constructed to meet the rising demands for housing in the Alkmaar region north of Amsterdam.
The city is located almost precisely between the North Sea and the IJmeer. As such the large pond with the iconic square island (fig. 28) - which is possibly 'visible from the moon' - is an integrated part of the overall regional blue structure linking the two major water bodies to the east and west (fig. 29).


Fig. 29. Orthographic photo of the pond and iconic square island in the centre. The North Sea to the west. The IJmeer to the east. Elevation 30 km © Google Earth

Stad van de Zon is the first city in Holland to be classified as "CO_2 emission neutral", which means that it does not contribute to global warming. Water is used as a crucial element in the branding of Stad van de Zon as a 'sustainable' the new city.

The site covers about 250 ha and is divided between the historical northeast axis with high trees framing the road and old thatched farmhouses located at the original Dutch polder level.

Hydrology
The new development consists of the pond, the square island, the labyrinth and the hills to the south, and is levelled about 60-80 cm above the polder system to prevent inflow of nutrient rich water from surrounding agricultural land. Consequently, the stormwater system is designed to be self-sustained in terms of precipitation, evaporation, infiltration, treatment and recycling at an annual basis. In addition, the system is prepared to manage 100-year rain events without flood risks.

Fig. 30. Orthographic photo of the southern part of Stad van de Zon, with the historical north-east axis, the labyrinth treatment canal and private residential islands linked to the central square. Elevation 1 km © Google Earth

The residential area is situated in the middle of an artificial lake, which is divided into two parts (fig. 30). The northwestern part of the lake is deeper, and the growth of aquatic plants is not promoted. This is also where a public beach is situated. The southeastern part is more shallow, and contains a "labyrinth"- designed as a free water surface flow constructed wetland with an average depth around 1 meter - with various aquatic plants, through which the water is led and being treated from nutrients and other pollutants at the same time. To secure continuous circulation stormwater is pumped counter clockwise around the pond a speed of 1200 m^3/hour.

The water system in Stad van de Zon and the surrounding Park van Luna is mainly focused on recreational values and water quality, and thus the techniques usually associated with sustainable urban stormwater drainage (such as infiltration devices etc.) are not being employed.

Water quality management

The pond includes a beach area, which demands high water quality standards.
The labyrinth in the southeastern part of the area acts as a treatment facility with the main function of removing nutrients from the lake water through uptake by plants, predominantly reed. Until now the system has been able to keep the lake sufficiently clean to ensure a good water quality for swimming. To our knowledge there is no particular monitoring program connected to this labyrinth wetland except for the monitoring of the water quality in the lake itself. As long as it purifies the water satisfyingly there will be put no more consideration into this facility. One of the concerns with respect to maintaining the high water quality is the presence of birds which may pollute the water. In case of the wetland failing to purify the water the possibility exists to bypass the wetland and run the water through a more technical treatment system.
Furthermore, in order to reduce contamination risks, road run-off is discharged to the polder system, thus excluded from the pond and the closed-loop stormwater management system.

Planning and design

The stormwater pond is utilised at many levels. As an integrated part of the regional blue structure, as a landmark branding and promoting the new area, as a swimming/surfing/fishing locale, and as a point-de-vue for the housing estates – most extraordinarily for the houses located on their own private island or peninsula in the pond. Generally spoken, the cost of houses immediately next to open water surfaces are approximately 20% higher than second row locations in the Netherlands.

The design of the wetland integrates landscape architectural concepts of a maze layout, a recreational play spot and a bird habitat, compromising strictly rational area and performance optimisations as suggested by the consulting engineers. However, if the future proves it necessary, the scale of the treatment plant is expected to provide good basis for rehabilitation works without dissolving the original landscape architectural idea.

Fig. 31. Conceptual sketch of Stad van de Zon presented by Jan Wijn, Dutch Water Board.

The project shows the importance of envisioning and communicating the potentials and qualities of utilising stormwater at many levels. The conceptual sketch of the Stad van de Zon uniting energies and themes at regional level (fig. 31), the iconic branding of the site, the recreational potential for residents and visitors, the sensitivity to historic buildings and the respect for protected areas along polders all communicate the intensions and unite stakeholders across disciplines. During the site visit, the project was presented with great enthusiasm by Jan Wijn from the Dutch Water Board. He showed a motivation to carry out very tedious and time consuming 'new' tasks (breaking with the everyday practice) in order to support the common goal of making the vision come true, for example securing high water quality in the pond to allow for swimming. This commitment makes all partners an asset working with, not against, the project. In other cases, some stakeholders/authorities/professions risk being regarded as stubborn and in opposition to new (less reliable?) solutions.

Case 8: Westerpark, Amsterdam

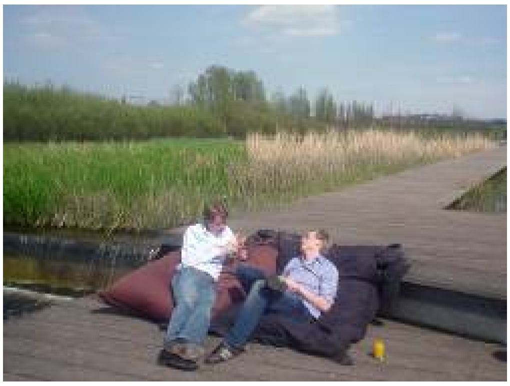


Fig. 32. Leisure activities on top of a wetland in Westerpark.

Westerpark in Amsterdam is a recently developed park located at a former gas works site (fig. 34). Stormwater plays an important role in the design and is an important element used to promote activities for the visitors of the park.
Two former gas tanks are transformed into ponds with seaweed, ducks and other birds, creating a strong contrast and co-existence of culture and nature in the park.
A bar is built next to and on top of a wetland and pond system, exemplifying the attraction of water, the cooling effect of trickling water, the sound of falling water, the reflection and glittering play of sunlight in the water surface, the sound of the wind blowing through the wetland plants (fig. 32). The wetland environment is used as a trendy attraction for young people – however, addressing the need of odour control and evaluating potential health risks.
Another site reflects the varying states and aesthetics of fresh water – clear, green, brown, still water covered with duck weed, cement slopes with varying water depths and temporary wet and dry surfaces reflecting the precipitation levels of the previous hours or days.


Fig. 33. Children playing in the urban beach environment.

Most families and sunbathers flock around the shallow pond where children are allowed to play in the water (fig. 33). The site works as an urban beach in the centre of Amsterdam, and beach life enfolds along the banks. Water is changed (recycled?) at a rate about 1 l/s, providing a small water fall at the outlet, which attracts and invites children to play.
The Westerpark is an inspiring site with multiple examples of the socio-cultural potentials of landscape based urban drainage. The legal and technical aspects of water quality control and odour control are yet to be identified in detail.

Fig. 34. Orthographic photo of Westerpark in Amsterdam. The older park inspired by the English garden tradition is located in the eastern part. Reminiscences of 3 gas tanks can be seen to the west. The triangular concrete pond is located to the north followed by ponds and wetlands to the west and north-west. Elevation 1 km © Google Earth

General reflections

Having visited the 8 case study areas in the Netherlands a number of issues seem to be parallel in the projects and might provide valuable lessons.

The systems tend to be closed loop systems, where water is collected, retained and recycled within the project site. Much attention is put into preventing inflow of relatively contaminated water from the rivers and polder systems. When water is retained and restricted from external water sources, the water quality is easier controlled.

Much attention is on preventing surface water from rivers and agricultural drainage systems from entering the closed loop stormwater management system. However, little concern seems to be given ground water sources. In EVA-Lanxmeer infiltration is allowed, despite ground water is extracted below ground (however 100 meters below ground). In Leidsche Rijn direct contact with ground water sources is allowed in the design of the 40 meter deep retention pond. In Ruwenbos groundwater is allowed to rise to ground level during winters. The lesson being that ground water, in the Netherlands, is not a major obstacle to locate areas suitable for stormwater infiltration.

Over-dimensioning the design seems to be an appropriate option in the start-up phase, when the confidence in the technology and the level of experience among contractors, designers, administrators and decision makers is still modest. This also shows the need for experiments, and the willingness among professionals and decision makers to implement pilot projects. The knowledge base and decision support tools might not be as comprehensive as conventional solutions, and the cost of customized projects might be more expensive than implementing pre-fab units by business as usual, but to generate knowledge and bring the sector forward, more experiments are needed. Ruwenbos has shown the process of trial and error. Most importantly it has shown the necessary maturing process for professionals to gain confidence in new technologies (in an iterative process influencing management practices, contractors' trust, legislation, public administration practices and so on).

It is recommended by Palsmaa and Geldof that wadis are designed as large systems included in the overall urban design. Small systems squeezed in at marginal spaces are not recommendable due to lower robustness and difficulties in maintaining and keeping an overview of the optionally multiple sites in need for continuous monitoring, operation and maintenance.

Landscape based stormwater management is not a utility network to be squeezed in at marginal spaces. It is not invisible, hidden underground. It must never be an ad hoc element to be elaborated by technicians just prior to the tendering process. For successful solutions in terms of flood control, pollution control, aesthetics and social inclusion water must be integrated and taken seriously from the earliest stages of the design process. Furthermore, for successful and integrated projects, designing is not a task for (landscape) architects alone. Projects must be developed in an interdisciplinary team of civil engineers, environmental engineers, hydrologists, biologists, chemists, social scientists, school and pre-school teachers, event makers, artists, entrepreneurs, contractors, architects, landscape architects, and of course local residents of all ages. It is not an easy task. It counteracts and challenges the planning autopilot. It takes more time. But the result is worth it. Jan Wijn from Stad van de Zon is a fully committed example of that.

Integrating water from the early stages might also - at least in new built areas – allocate the areas necessary for landscape based urban drainage systems. SUDS is not one solution, but (often) a series of technical solutions customized to the specific context.

This leads to the premise that in order to assess projects and evaluate the appropriateness of one technical solution to another one must start with the specific context. Asking oneself the questions: How is the topography? What is the soil condition? How high is the ground water table (during summer and winter)? Which types and which levels of contamination are visible/measured/ known/intended/allowed at this specific site? What is the history of the site? What is the level of local awareness? How is the level of commitment among residents, decision makers, professionals and other partners involved in the project? Having these answers at hand the basic premises for project evaluation and/or project design are in place. It is now reasonable to proceed.

Wadis with infiltration trenches are difficult to maintain and experience has shown their tendency to clog, which provide an extra expense to clean up. In the case of Leidsche Rijn experience has changed practice from inclusion to exclusion of infiltration trenches in the standard design of wadis. The experience from Leidsche Rijn is that the design parameter for wadis should be *infiltration* – not *retention*.
Govert Geldof criticizes the infiltration system at Leidsche Rijn as the wrong technology for the given location. Leidsche Rijn is located in a clay bed not suitable for infiltration. Implicitly Geldof stresses that one must always start with the specific contextual setting and premises before evaluating the scope of appropriate technologies. If technologies are not fitted to the specific setting, the design will ultimately fail. The experiences from Leidsche Rijn might prove him right.

Reviewing the project the successful projects seem to include a somewhat holistic approach. Not only approaching the issue of stormwater management (in the sense of flood protection and environmental conservation), but applying as many integrated aspects as possible. De Vliert, as an example, addressed problems with traffic, needs for better recreational facilities, community involvement and social inclusion, aesthetical upgrading etc. to the (otherwise technical and isolated) issue of sewer rehabilitation works. This way, the necessary public expenses for rehabilitating ageing infrastructures aimed at multiple societal benefits, also in the short run. EVA-Lanxmeer is another example showing that infiltration in a water reclamation zone is an option if properly addressed and planned from the start. Not least, if proper dialogue between stakeholders is initiated at an early stage.

Envisioning and communicating ideas is a powerful tool to gain support among stakeholders. In this sense participatory practices and residents' involvement must have a high priority. Stad van de Zon and De Vliert are two good examples on this issue.

Envisioning is one issue, a holistic approach another, round table discussions among multiple stakeholders a third. At the earliest stages operation and maintenance tasks must also be included. The oak leaves clogging the wadis in Ruwenbos, the destroyed grass pavers in Monnikenhuizen, the malfunctioning infiltration boxes and the clogged permeable pavements in Leidsche Rijn. They are all examples of systems that have broken down fully or partly or seasonally due to challenges during the ongoing operations and management duties. Keeping in mind that the blue print from the design office is first handed over to the contractor (who risk making mistakes during construction in the field, especially when new technologies are introduced), the contractor and consultant hands over the final drawings 'as built' (at least they claim to do so), the environmental management department at the local municipality takes over the drawings, ongoing maintenance work might be out sourced to a local contractor (who risk not report the changes to the municipal officer, who might not have the original digital drawing or who risks making mistakes when carrying out the updates etc.), years go by, new staff is taking over, the gap between the drawings and the built reality widens. At least 4 times the project drawings are handed over from one part to another. To secure functionality of the system, the design must be so robust and the drawings so clear, that the chain does not break somewhere along the way. In other words, the successful design must be very aware of and address all the weak links that can ultimately lead to the termination of the system. Starting over from scratch.

The robustness of the system is essential. Especially in the long run. The more complex the design, the more parameters can lead to malfunctioning. This does not equal ‘small is beautiful’, ‘less is more’ or other dogmas. Again, the choice of solutions and assessment of appropriateness rely on the specific context.

In the Netherlands residences next to open water surfaces are in general 20% more expensive than the neighbouring buildings in second and third row. This indicates clearly the value of water in an urban development process. But to secure the attraction and promote water in the real estate market, the stormwater management systems must be reliable. They must be beautiful to look at, they must not provide a health risk, they must not be a source for odour nuisance, they must not break down, they must not flood the basement or undermine the foundation structures. These aspects must be thoroughly assessed before implementing ‘alternative’ stormwater management systems.

To sum up, some of the general conclusions at this stage are:

- start with the context
- think holistically / in entities
- integrate water from the earliest planning and design stages
- envision and communicate the idea to all stakeholders
- allocate the necessary space for interlinked SUDS elements
- plan for operation and maintenance tasks from the beginning
- prioritize robustness
- utilise the financial potential of water in urban development projects
- respect that it takes time to gain confidence in new planning, implementation and maintenance practices
- allow for experiments

The Netherlands has about 10-15 years of experience with landscape based urban drainage systems. The history and evolution has influenced legislation and practice, which provides a valuable resource base for other countries evaluating the potentials, necessity and possible conflicts of landscape based stormwater management systems.

For Denmark, many lessons can be leaned and some mistakes can be prevented, by integrating thoroughly the experiences from the Netherlands.

Overview tables

The following section include overview tables of the case studies presented in previous chapters, including:

- Leidsche Rijn
- EVA-Lanxmeer
- De Vliert
- Monnikenhuizen
- Lankheet
- Ruwenbos
- Stad van de Zon
- Westerpark

Leidsche Rijn

	Work analysis	Evaluation	Questions
Hydrology	A closed water system is the aim at the site. Because of the geology at the site, the infiltrated water flows to the lakes in the area. Stormwater is infiltrated through grass covered wadis with infiltration soils. Problems with some wadis, clogging the infiltration boxes	On the whole the system seems to work well, but the infiltration trenches underneath the wadi's are not functioning as well as they were supposed to, due to clogging. The use of green roofs was not supported since the aim of the project is to keep water in the area and be self-sufficient in water supply, thus the increased evapotranspiration obtained by green roofs is not desired. Infiltration on clay soil is difficult	What are the soil types and related infiltration properties in the area? How much of the total precipitation is retained by infiltration? How much is ''lost'' by evapotranspiration? How much of the total stormwater volume is infiltrated/led to sewer systems?
Quality control	Water is circulated in the canals and lakes in order to avoid standing water. Phosphorus in imported water and in the system is reduced by vertical filtering in soil with iron oxide Water is kept in the area to minimize losses and to minimize needs for importing water No pesticides and salt are allowed in the area. Focus is on regulating and controlling the water levels and flow	There could be problems with getting people to obey the rules on not to use pesticides, only wash their cars at the car-wash etc. This would increase the risk of contamination of the system. There are no measurements on bacterial contamination in the system. This is a risk because of the close contact between water and inhabitants in the area.	Is there any monitoring strategy for the quality of the water in the system? What are the criteria for classifying water as 'clean' and 'dirty'? How is the quality of the groundwater at the site? Is it used?

Planning and design	Very large scale project The project integrates canals, wadis, lake Water is visible to citizens and stormwater management is very obvious in the area. New urban development Canals and wadis give a strong identity to the neighbourhoods. Canals have different profiles depending on their duties. Communicating and regulating aspects seem to be equally weighted in the area.	Focus of the whole project is to make water visible to the citizens Different architectural qualities in different areas Stormwater management as frame for a whole new city district. From the stormwater perspective altogether a successful project Social problems. Missing identity. Partly identified as starting problems Utilization of levelling promising	What is the main focus of the project – communicating / regulating? What are the single elements of the projects? Are the single elements working? (Problems with overflow, dirt, smell, life span…) What are the difficulties in the detailed construction of the elements? What kinds of materials are used? Are there special, smart solutions – good functioning, combination of several functions in one element, very beautiful solutions? Are stormwater management elements working as design features? How obvious is the stormwater management in the area? Is stormwater management able to give an identity to the area?

Table 1: Summary of the Leidsche Rijn project.

EVA-Lanxmeer

	Work analysis	Evaluation	Questions
Hydrology	Focus on closing the hydrologic cycle as much as possible Stormwater is infiltrated in infiltration trenches and ponds. Grey-water is collected and treated in reed-beds. Black wastewater is led to sewer.	Stormwater management not in the main focus, but part of an overall ecological concept.	What is the soil type/infiltration properties of the area? Is the treated water from household effluents also allowed to infiltrate locally after being treated or is it led someplace else? Problems with flooding?
Quality control	Protect drinking water resources Treatment of household wastewater (greywater)	No information on the efficiency of the system or monitoring programs. Groundwater pollution no major issue - no cars. In spite of the area being on the edge of a water protection area where drinking water is retrieved, local infiltration was permitted. This leads to the assumption that the infiltration time and depth to groundwater table are large enough to ensure proper “treatment” of the water. Furthermore it ought to imply that the water quality is being closely monitored, but whether these assumptions are correct is not known.	Are there any measurements on the efficiency of the grey-water treatment? Monitoring? How deep is the groundwater level/drinking water aquifer?

Planning and design	Medium scale project Community driven Central pond and community gardens core of plan Includes design elements like main pond, old ditches, green roofs, fountain, small gravel pathways – less imperious paving Both communicating and regulating aspects can be found in the area. Often the functions of elements are not visible. Pond clear without algae Fountain not working Old ditches need to be maintained. Paving done by recycled materials (old concrete plates), gravel, wood chips The stormwater management is not the single driving force for the area. Other aspects of an ecological life style seem to be as important. (solar energy, eco materials, gardening…)	Strong emphasis on ecological living, high life quality – individual wishes and visions for living can be fulfilled. Communicating water elements do not, fulfil their purpose. Water system relatively invisible (for a demonstration project). The narrative of water difficult to read – competing with passive solar heating, eco-friendly materials, gardening, ‘life quality’ No visible structure for the stormwater management, but good atmosphere.	Why is the fountain not working – too little stormwater? See table 1.

Table 2: Summary of the EVA-Lanxmeer project.

De Vliert

	Work analysis	Evaluation	Questions
Hydrology	Urban retrofitting. Renewal of drainage system led to separated systems Disconnection of individual house lots Stormwater from roofs is infiltrated in the individual gardens. Individual solutions for every house. Little infiltration depressions, rain gardens, water butts etc. Stormwater from roads it is led to an infiltration trench with overflow through a playground. Stormwater from major roads is led to sewers	The infiltration solutions were chosen individually for each house, and consist of for instance infiltration beds, rainwater harvesting cisterns, etc. Thus to quantify e.g. infiltration rates each individual solution has to be taken into account and considered.	Has the local infiltration led to a change in groundwater levels and/or variations compared to pre-SUDS levels? Is the water mainly infiltrated or is it also being used for e.g. toilet flushing?
Quality control	No treatment component is highlighted	Potential risk to the children in close contact with the runoff water from the roads.	Is there any concern about water quality in relation to the close contact with children?

Planning and design	Medium scale project Rehabilitation of area from WW2 Urban renewal project integrating water, traffic and recreation. Public participation in focus. Main difficulty in this project is the contact to the inhabitants and their cooperation. Play & lean features included Regulating aspects are in focus of the project. Some communicating elements like special designed manhole covers are added to communicate the new system to the people. The stormwater management is not very obvious in the area, even though it is used as a driving force for the renewal of the district.	Stormwater management is used to lift a whole city district. Stormwater management not visible but well functioning. Process as the most important result – not the best design results, but increasing awareness and responsibility of residents. Community accept and awareness counteract piracy - washing machines no longer discharge to the drainage system This project shows the chances lining within new stormwater management solutions.	See table 1.

Table 3: Summary of the De Vliert project.

Monnikenhuizen

	Work analysis	Evaluation	Questions
Hydrology	Project aims to expose stormwater in public Stormwater is infiltrated near the houses or led via gutters in the road to an infiltration basin.	The water system of this area seems to be more of an architechtural/aesthetical feature rather that hydrological, although of course it also affects the hydrology.	Where is the groundwater level in relation to the infiltration basin? Is it possible for the infiltration basin to dry out completely during dry periods? How much stormwater runoff (return period) can the area accept before infiltration basin is flooded?
Quality control	Best practice guidelines distributed to inform residents	There could be contamination of the infiltration basin by zink, which could influence the ecosystem.	Has the water quality in the infiltration basin been measured? How high levels of zink are present?

Planning and design	Medium scale urban transformation project Traffic shares the public space with stormwater The system is working well and after 8 years still in a good shape. Both communicating and regulating aspects work hand in hand. Elements include stormwater infiltration pond, gutter along the streets to collect and transport the stormwater, green roofs, brick paving, gabions, grass pavers, small gravel foot paths. Infiltration pond with variable surface level (water temporarily covering grassland) an important feature Stormwater management visible (especially the gutter) and important for the local identity, Other elements like gabions and recurring materials are of the same importance for the appearance of the area. Use of the gutter as traffic block to slow down the speed of the cars and to structure the streets. Residents complain about the depth of the gutter. Plastic grass pavers are destroyed by frequent parking – replaced by concrete grass pavers.	Good quality of planning and design work Stormwater used as an asset to brand the estate Water integrated as element from detail to master plan level After eight years no major vandalism or problems in function. Nice atmosphere, high quality of living. Terrain/topography important for stormwater system and the design of the settlement. The use of good suitable materials pays of over the years.	See table 1.

Table 4: Summary of the Monnikenhuizen project.

Lankheet

	Work analysis	Evaluation	Questions
Hydrology	Infiltration/water treatment ponds with reed vegetation.	The impression from the study visit is that the system mainly affects water quality rather than quantity, even though it may result in increased infiltration to some extent compared to other rural areas. However the information was very scarce and it is difficult to draw any certain conclusions both on purpose and effects of the project. Difficult to identify water flow (from where to where?)	What kind of water is being received by the ponds? Is it only direct infiltration to groundwater or are there drainage pipes underneath?
Quality control	Treating contaminated water from agriculture/ polluted river by infiltration in ponds planted with reed.		

Planning and design	Large scale project located in rural farmland Integrated river treatment, public park, and reed production It is a landscape based solution with natural materials (grass covered dikes, reed). Wooden entrances, concrete step stones were added to highlight the recreational value. Area with stepping stones provides aesthetic value to the area Both communicating and regulating aspects can be found. It seems that the project started of with the regulating entitlement. Communicating aspects where added on to make the project visible and to develop a recreational value on top. The horizontality and homogeneousness of the geometric fields is counteracted/articulated by land art	The use of a large scale, landscape based water treatment area for recreational purposes is an interesting approach. The added design feature, like the wooden archways are used to mark the area and wake the interest of visitors. It is questionable if this approach fits to the surrounding. Layering/intensifying land use Indicates the potential or need for multi-functional green space in peri-urban areas Hidden site.	See table 1.

Table 5: Summary of the Lankheet project.

Ruwenbos

	Work analysis	Evaluation	Questions
Hydrology	First wadi in the Netherlands Wadis are working well, they were over-dimensioned from the beginning. Therefore no flooding problems occur.	Since the wadis are over-dimensioned compared to normal stormwater volumes, it is likely that the wadis have a relatively high capacity for infiltration	Are the wadis capable of infiltration all year around (or are there wetter periods when water stays in the wadi)?
Quality control	Wadis are used for infiltration of stormwater In early stages architects used ‘wrong’ materials for the down pipes.	Copper was used for down-pipes in the area, which results in contamination of the soil in the wadis.	
Planning and design	Medium-large scale project. 15 years of development - from differentiated to integrated design Design elements include wadis, small scale streets, gutters in the streets Both communicating and regulating aspects were probably source of motivation for the planning. Except of the wadi areas, only little communicating elements can be found. Wadis function as frame for the neighbourhood, other stormwater management elements are not very visible. Softly curved green spaces divide built enclaves Surplus capacity in retention pond -> more park area	Early project, still functioning well. Some mistakes to be learned from. Wadis over-dimensioned, take lots of space, but by this give quality to the neighbourhood. Stormwater management integrated in green structure though in itself not too obvious. Cheep simple solutions that work. Describe evolution and iteration between level of knowledge and physically built environment Indicates feasibility of over-dimensioning in early stages	See table 1.

Table 6: Summary of the Ruwenbos project.

Stad van de Zon

	Work analysis	Evaluation	Questions
Hydrology	Self-sustaining closed loop system. Respecting / isolated from historic and contaminated river and polder system.	The flooding risk (return period) of the residential area is 100 years, which includes future climate scenarios. This, in combination that water is being kept within the area and that measures are taken to preserve a good water quality, leads to the conclusion that the stormwater system could be considered sustainable even though this may not have been a main objective when the area was established. The closed loop system is relying on heavy duty pumping	What is the flooding risk of the residential area? Has future climate scenarios been taken into consideration when calculating the risks?
Quality control	Water as a part of the city Water quality good enough for swimming and water activities Labyrinth integrates landscape, bird habitat, recreation and stormwater treatment	Open-ended design. The rehabilitation of the labyrinth is an option	
Planning and design	Large scale project Stormwater lake used as a brand for area and part of the regional blue structure CO_2-neutral urban development project Public beach included	Shows potential of stormwater pond as swimming locale. Attraction of water, e.g. with private residential islands.	See table 1.

Table 7: Summary of the Stad van de Zon project.

Westerpark

	Work analysis	Evaluation	Questions
Hydrology			
Quality control			
Planning and design	Medium scale project Integrated park, water treatment, trendy bars, play spots and urban beach Showing different aesthetics of water (clear, green, brown, duck weed, reed, dry cement)	Local government and professionals willing to use stormwater actively	

Table 8: Summary of the Westerpark project.