Think Denmark

White papers for a green transition

SUSTAINABLE URBAN DRAINAGE SYSTEMS

Using rainwater as a resource to create resilient and liveable cities

INSIDE THIS WHITE PAPER

WATER IN URBAN AREAS
CLIMATE ADAPTATION AND INNOVATION

State of Green
Join the Future. Think Denmark

SUSTAINABLE URBAN DRAINAGE SYSTEMS
Using rainwater as a resource to create resilient and liveable cities
Version 2.0
Printed in May 2016

Front page photo
Cover photo showing climate adaptation solutions at Taasinge Plads in Copenhagen
Photo: Kontraframe

Editor in Chief
State of Green

Technical Editors
Danish Technological Institute / Water in Urban Areas: Hanne Kjær Jørgensen, hakj@teknologisk.dk
Danish Technological Institute / Water in Urban Areas: Ulrik Hindsberger, uhi@teknologisk.dk

Contributors
Aalborg University: Birgitte Hoffmann, bhof@plan.aau.dk
Aarhus Water: Anne Laustsen, ala@aarhusvand.dk
Aarhus Water: Inge H. Jensen, ihj@aarhusvand.dk
ALECTIA: Jan Jeppesen, jaje@alectia.com
Amphi Consult: Lars Briggs, lb@amphi.dk
Bonnerup Consult: Arne Bonnerup, arne@bonnerup.net
Byggros: Louise Hansen, loh@byggros.com
City of Copenhagen (Skt. Kjelds Kvarter): René Sommer Lindsay, ZT2J@tmf.kk.dk
City of Copenhagen: Jan Rasmussen, jrasmus@tmf.kk.dk
COWI: Ulla Rose Andersen , uva@cowi.dk
DHI: Morten Rungø, mor@dhigroup.com
EnviDan: Mads Uggerby, mau@envidan.dk
Frederiksberg Utility: Henrik Bay, service@Frb-forsyning.dk
Genvand: Søren Quist Rasmussen, genvand@gmail.com
HOFOR: Martin Vester, mves@hofor.dk
NIRAS: Jens Christian Riise, jcr@niras.dk
Orbicon: Christine Krag Strømberg, ckst@orbicon.dk
Ramboll Studio Dreiseitl: Herbert Dreiseitl, herbert.dreiseitl@ramboll.com
SLA: Rasmus Astrup, ras@sla.dk
State of Green: Tanya Jacobsen, tja@stateofgreen.com
Technical University of Denmark: Karsten Arnbjerg Nielsen, kan@env.dtu.dk
The Climate City: Helle Baker Norden, hbn@klima-byen.dk
Tredje Natur: Flemming Rafn Thomsen, frt@tredjenatur.dk
University of Copenhagen: Marina Bergen Jensen, mbj@ign.ku.dk
University of Copenhagen: Rikke Juul Monberg, rjm@ign.ku.dk
WATER PLUS: Søren Møller Christensen, smc@carlbergchristensen.dk
Watercare: Henrik Eckhoff Rønnest, info@watercare.dk
Wavin: Thomas Milert, thomas.milert.hansen@wavin.com

For more information
To order copies of this white paper or receive information about other related publications, please contact State of Green at info@stateofgreen.com

EXECUTIVE SUMMARY

Population growth, increasing pollution of drinking water, floodings as well as more frequent and longer periods of droughts all encourage an optimised use of rainwater in cities. Traditionally speaking, climate adaptation seeks to lower the risks posed by the consequences of climate change, including flooding caused by extreme rain events. However, when approached holistically it can also be used to create synergies between a number of urban challenges by addressing several areas of urban development at the same time. In this respect, Sustainable Urban Drainage Systems (SUDS) can play a key role in urban water management and contribute to building cities that are attractive for people to live in.

This white paper features lessons learned from different Danish stakeholders within rainwater management and SUDS, supported by state-of-the art case examples showing how it is possible to use rainwater as a resource to create more resilient and liveable cities.

Multifunctional solutions create more resilient and liveable cities
A large number of synergies and cost-efficiencies can be achieved when rainwater management is integrated into the overall urban planning. Cities around the world are increasingly concerned with improving their resilience against the effects of climate change, including reducing the risk of flooding and rising temperatures. At the same time, many cities are focusing on securing sufficient supply of clean drinking water for a growing population. Denmark is working towards creating multifunctional solutions which – in addition to managing rainwater and reducing the risk of flooding – also create added value for cities as they contribute to keeping the city's overall water balance and result in new attractive recreational areas.

Find inspiration for your own SUDS projects
The content of this white paper is meant to serve as a helpful tool for international stakeholders who wish to gain insight into the many potentials of using Sustainable Urban Drainage Systems, get an overview of how solutions have been implemented in Denmark and around the world, or who are looking for Danish partners to collaborate with on projects in their own country.

We hope you will be inspired.

SHARING SOLUTIONS FOR SUSTAINABLE RAINWATER MANAGEMENT

"Denmark's experience shows that climate adaptation and rainwater management can be turned into an opportunity to create greener and more liveable cities"

Esben Lunde Larsen, Minister of Environment and Food

As the climate changes and the number and frequency of rainfall events increases, so does the need for intelligent rainwater management solutions. Like many other countries, Denmark has experienced the consequences of a changing climate first-hand. Over the past few years, we have witnessed extreme rain events that have caused flooding and damages to homes and infrastructure. According to the Fifth Assessment Report from the IPCC, we can expect even more frequent and more extreme weather events in the years to come. Finding new and innovative solutions to managing rainwater is therefore a focal point for Danish cities, water utilities and companies.

Increasing pressure on sewerage systems

Increasing precipitation caused by climate change is putting greater pressure on our sewerage systems. However, rather than simply replacing existing pipes with larger ones, benefits can be achieved by focusing on more intelligent rainwater management which detains the rainwater in existing structures or distributes it to areas where it creates the least damage. Efforts to create more climate resilient cities in Denmark are well under way with a national action plan for a climate-proof Denmark and there are many good examples of green, innovative solutions.

Sustainable urban drainage systems

More and more Danish cities and water utilities are looking into managing rainwater as close to the source as possible and diverting it away from the sewerage systems and wastewater treatment plants, thereby bringing down the risk of combined sewer overflows.

Solutions that manage increasing volumes of rain span from hydraulic models for the planning phase to solutions for local retention of rainwater such as subsurface infiltration beds, green roofs and permeable paving, to drainage solutions such as separate sewers for rainwater and sewage water as well as local rainwater treatment via roadside infiltration beds etc.

Danish solutions to global challenges

The best examples of climate adaptation projects succeed in solving more than one problem at the same time. Such holistic solutions, however, requires close collaboration between authorities, utilities, organisations, private companies and individuals. Denmark has a long tradition of such collaboration. This has brought us far. We are proud of our results and solutions. And we are eager to share our experiences and lessons learned with other countries.

INDEX

1. FROM CLIMATE ADAPTATION TO GREEN URBAN DEVELOPMENT

Using rainwater as a resource

"In Copenhagen we always try to find solutions that do not just solve the problem but also create a better quality of life for the citizens of Copenhagen. We incorporate climate change adaptation at all levels of city planning and prepare comprehensive solutions for the entire city"

Morten Kabell, Mayor for Technical and Environmental Affairs, City of Copenhagen

Many factors such as population growth, increased pollution of available drinking water, floodings and more frequent periods of droughts encourage an optimised use of our rainwater. In addition, there is an increased focus on reducing the urban heat island effect by cooling the cities locally and on reducing pollution of surface water, securing sufficient drinking water supply and building cities that are attractive for people to live in.

According to the projections from the UN's Intergovernmental Panel on Climate Change, Denmark – as well as multiple other countries – will experience a change in precipitation over the coming years with more frequent rain of high intensity and longer periods of dry weather. When combining these projections with the fact that many cities are covered with extensive areas of impermeable surfaces, the need for infiltrating or delaying rainwater at the source becomes even more urgent to reduce the risk of flooding.

In this white paper, we will present the various possibilities of using rainwater as a resource as opposed to considering it as something that simply needs to be hidden in sewers. The aim of using rainwater as a resource is partly to reduce the risk of flooding by optimising the rainwater management and partly to contribute to creating more green and liveable cities. In this sense, adapting to a changing climate and developing attractive urban spaces for people to enjoy become two sides of the same coin. As illustrated by the many case examples, there are many synergies and cost-efficiencies to be achieved if rainwater management is integrated into the overall urban planning. The key is to have the right tools and models to ensure the right prioritisation of efforts and sufficient designing of the various rainwater management solutions as well as involving the right stakeholders at the right time throughout the process.

Several benefits can be achieved by using rainwater to help cities keep a sustainable water balance through various treatment technologies. These ensure proper treatment of rainwater to allow for infiltration to the groundwater aquifers or discharge into the local water environments such as lakes or streams. Finally, in areas suffering from water scarcity, local rainwater harvesting and recycling can be a valuable source of non-potable water which can be used for watering plants, flushing toilets or washing clothes instead of using the precious drinking water.

Copenhagen Cloudburst Management Plan, Copenhagen, Denmark
Copenhagen has experienced a number of extreme rainfall events since 2010 and these types of events are predicted to recur increasingly in years to come. As extreme rainfall events present enormous challenges which vary from area to area, they cannot be solved by a single initiative such as upgrading the sewerage system. For this reason, the City of Copenhagen decided on a coordinated and consolidated action combining the solutions appropriate to each area. The result was the launch of a Cloudburst Management Plan in 2012.

The plan outlines the methods, priorities and measures recommended for the area of climate adaptation, including extreme rainfall. It designates 7 water catchment areas and has resulted in a catalogue of approx. 300 surface projects which will be implemented over the next 20 years. When prioritising which projects to initiate, the city considers factors such as the hydraulic aspects in establishing the sequence of projects, where the risk of flooding is greatest, where it is easy to start, where other construction work is under way and where synergies with urban development are possible. (Courtesy: City of Copenhagen)

2. SUDS AS AN ALTERNATIVE TO TRADITIONAL SEWERAGE SYSTEMS

Introduction to Sustainable Urban Drainage Systems

The common term for rainwater management that takes place as close as possible to the source is SUDS – Sustainable Urban Drainage Systems. This is also sometimes referred to as Green Stormwater Infrastructure, Water Sensitive Urban Design (WSUD) or Local Rainwater Harvesting. In general, SUDS elements address one or more of the following functions: Infiltration, transportation, storage, delay or evaporation of rainwater. Examples of typical SUDS elements are defined on page 9.

Taking the pressure off the sewerage system

Due to the large areas of impermeable surfaces in the cities, the runoff from a city is different from the runoff pattern before urbanisation. In the hyetograph below, the impact of urbanisation is shown. The runoff from a city covered with impermeable paving will result in quick and very high runoff. As runoff from several catchments arrive at the same time to certain places in the sewers, bottlenecks are created in the sewers, causing a high risk of flooding at these bottlenecks.

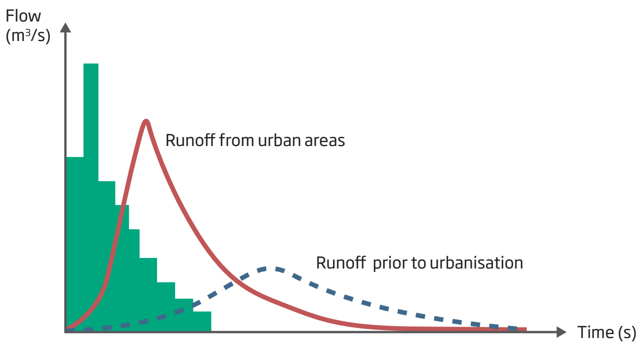
When considering the runoff from areas, which are completely or partially designed with permeable surfaces, the maximum and total runoff will be reduced, and the peak will be delayed. Runoff from the catchments will now arrive at the places that used to be bottlenecks at different times. When delaying and reducing the maximum runoff, the risk of flooding can in many places therefore be minimised. Considering SUDS as an extension of the traditional sewerage system, the aim of SUDS is to smoothen the runoff hyetograph and thus reduce pressure on the sewerage system.

Designing SUDS to handle different types of rain events

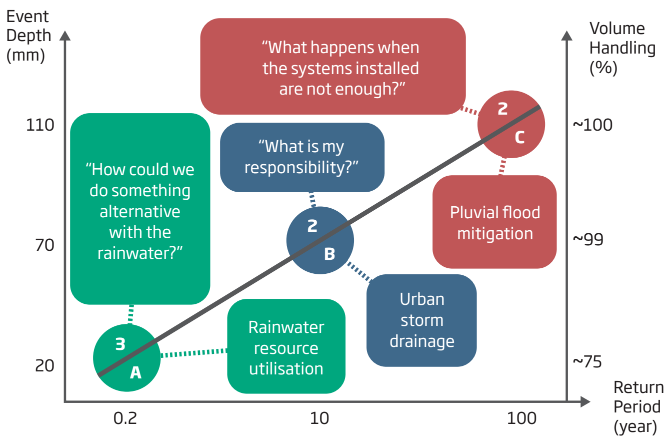
In Denmark, there is no standard definition of how to design SUDS. In practice, the recommendation is that every time you design a SUDS-system, you need to consider everyday rain, design storms and cloudbursts (as illustrated in the 3 points approach method below). Often professionals and stakeholders tend to focus on only one type of rain event. But there can be many problems in an area related to both everyday rain, design storms and cloudbursts. It is therefore very important to focus on all types of rain events when designing solutions. SUDS are particularly efficient for solving everyday rain challenges (point 3/A in the figure below) but when used carefully SUDS can also contribute substantially to solving some of the problems related to design storms and cloudbursts.

Testing SUDS elements to meet international standards

When developing new or using existing climate adaptation products, there is often a need for full-scale testing, optimisation and documentation of the product before implementing the solution in the field. The product might be subject to a European Standard and thus needs to meet certain specific requirements. Or the producer might need to document the water balance of a new SUDS element or document the permeability of a specific pavement etc. Denmark has more than 30 years of experience testing traditional components in sewerage systems and today it is also possible to test new climate adaptation products in a certified lab where tests are run in a full scale, using up to 30 l/s. The lab can also be used by companies from other countries. Read more about the climate adaptation lab facilities at www.climateadaptationlab.dk.



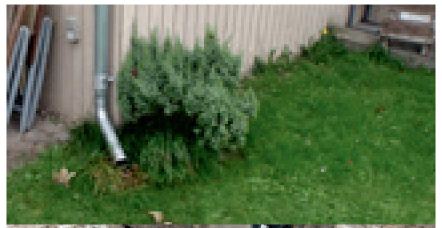
Hyetograph: *The aim of SUDS as an extension of the sewerage system is to smoothen out the hyetograph, reducing and delaying the peak maximum flow whereby a more natural water balance is restored.*



The 3 points approach-method: *Every time you design a SUDS-system, you need to consider everyday rain (80% of all rain volume), design storm (19% of all rain volume) and cloudburst (1% of all rain volume).**

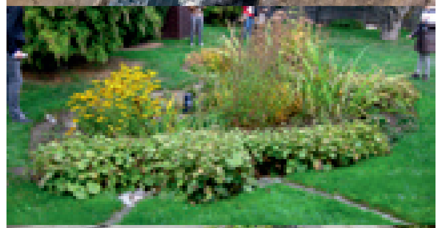
** Sørup, H.J.D, Lerer, S.M., Arnbjerg-Nielsen, K., Mikkelsen, P.S. and Rygaard, M. (in preperation): Efficiency of stormwater control measures under varying rain conditions: Quantifying the Three Points Approach (3PA).*

EXAMPLES OF TYPICAL SUDS ELEMENTS:

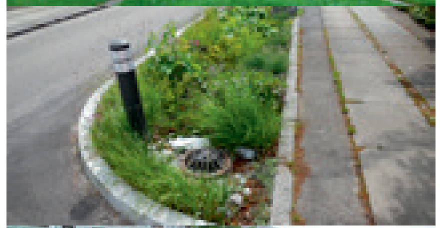


Infiltration from surface
Infiltration from surface occurs when disconnecting the downspouts and discharging the rainwater on the permeable surface.

Soakaway or infiltration trench
A soakaway (dry well, infiltration well) is a pit in the ground, stabilised with a porous material wrapped in geotextile and covered with topsoil and vegetation. An infiltration trench is a soakaway shaped geometrically like a trench, for example, 60 cm wide, 1 m deep and several metres long.



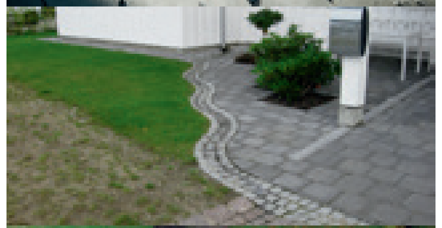
Rain garden
A rain garden is a depression in the terrain designed to receive, store and filter runoff from roofs or surfaces and is also designed as a specially planted area with selected plants that can cope with dry and with wet conditions.



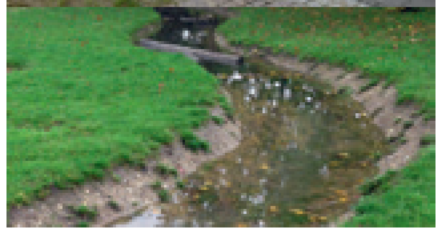
Swales
A swale is a rain garden placed in the side of a road, with a soakaway underneath. Typically, the swale also serves as a traffic harassment.

Green roof
Green roofs are roofs covered with a multi-layer system consisting of: growth medium, drainage layer and water-proof membrane. Green roofs delay runoff from roofs, and the total runoff volume is less than that from conventional tiled roofs. The degree of delay and volume reduction increases with the thickness of the growth medium. Green roofs insulate buildings against warming and can provide a habitat for certain insects and birds. Retained water evaporates.

Permeable pavement
Permeable pavement provides a horizontal surface suitable for walking or driving but also allows rainwater to infiltrate. The infiltration capacity of the permeable pavement depends on the design and on the hydraulic capacity of the base course and the soil underneath and alongside.



Trenches
Trenches are used for transporting water above ground in places where open trenches do not inconvenience road users. Trenches can be a recreational element in an urban landscape.



Ditches
A ditch is a narrow channel dug in the ground, typically used for drainage alongside a road or the edge of a field.

3. CROSS-DISCIPLINARY COLLABORATION IN CLIMATE ADAPTATION

Creating synergies and saving costs through collaboration between different stakeholders

"Experience from Danish SUDS projects shows that when city planning, construction, environmental issues, financing mechanisms and stakeholder relations are all addressed early in the development process, projects are more likely to become successful"

Jens Christian Riise, Market Director, Climate and Resources, NIRAS

Rainwater crosses both administrative and geographical borders. Danish experience shows that collaboration across disciplines and institutions can create valuable synergies, resulting in greener and more liveable cities with a higher degree of recreational value for the local community. The collaborative approach is, however, challenged by the fact that the different parts of the water cycle, i.e. sewage, rainwater, rivers, lakes and groundwater are often regulated by different legislative bodies.

Legislation and financing mechanisms in Denmark

The responsibility of climate adaptation is divided between municipalities, water utility companies and private property owners. Danish municipalities must include climate adaptation plans in their local development plans. In helping them do so, the Danish Nature Agency has developed a set of guidelines for climate adaptation plans on how municipalities can manage climate adaptation as part of their overall planning for construction.

In correlation with the Danish Water Sector Act, expansions of sewerage systems are managed by water utility companies and financed through water tariffs. Due to a 'co-financing regulative', water utilities are allowed to co-finance climate adaptation projects above surface carried out by municipalities or private owners, which involve roads, water courses and recreational areas. As Danish water utilities have a monopoly on managing water and sewage, their activities and investments are closely monitored by the Water Utility Secretary under the Danish Competition and Consumer Authority.

Early stakeholder involvement

Using a cross-disciplinary, cross-institutional and watershed based multiple stakeholder approach can increase the sense of ownership of the solutions such as SUDS. And by using this holistic approach, solutions often have a higher degree of synergy with other activities in the municipalities. The results are often more liveable cities with a higher degree of recreational value for the local community.

Experience from Danish SUDS projects shows that when city planning, construction, environmental issues, financing mechanisms and stakeholder relations all are addressed early in the development process, SUDS projects are more likely to become successful. It is thus crucial to identify all relevant stakeholders and invite them to a dialogue as early in the process as possible.

To create the necessary momentum and ownership of the climate adaptation projects, urban planners, environmental managers and engineers from the municipal departments often join forces with engineers and planners from water utilities at an early stage. To ensure buy-in from the local community local citizens, property owners, local businesses and environmental NGOs are also involved later in the process, when the different solution proposals are discussed and selected.

By applying cross-disciplinary and cross-institutional approaches to collaboration, climate adaptation becomes an opportunity to create synergies between several projects at the same time.

Cross-disciplinary collaboration in Denmark

Water in Urban Areas (established in 2010) is an innovation network consisting of 150 knowledge institutions, government agencies and municipalities, utilities and private companies (tetra-helix structure). The purpose of Water in Urban Areas is to develop, document and present climate adaptation technologies and associated planning tools for transformation of existing urban areas in Denmark. All information and experience with SUDS systems in Denmark have been compiled on the website: www.sudsindenmark.dk.

Engaging and mobilising the local community in creating a Climate City, Middelfart, Denmark

Covering an area of 450,000 m², "The Climate City" project in Middelfart demonstrates how to integrate climate adaptation with urban development. Through a dialogue based co-creational process, the municipality and wastewater utility have worked closely together with landscape architects, engineers, local citizens and other stakeholders in developing the project. From the programming phase, through the architectural competition process and the subsequent project development and detailed project design, citizens have actively contributed with local knowledge, comments and ideas. The Climate City project, which focuses on climate adaptation through urban design of public areas, also functions as a driving force, which inspires local house owners to manage rainwater within their own gardens. Thus, The Climate City is to a great degree about mobilising the local citizens to become an integrated part of the project. The Climate City is a partnership project between Middelfart Municipality, Middelfart Wastewater Utility and the philanthropic organisation Realdania. (Courtesy of Middelfart Municipality, Middelfart Wastewater Utility, Realdania, Bascon, Orbicon, GHB Landscape Architects and ADEPT)

Separating rainwater from wastewater in existing living areas, Aarhus, Denmark

Sewer separation projects are often conducted by establishing separated piping systems for rainwater and wastewater, respectively. In the neighbourhood Risvangen in the city of Aarhus, however, no rainwater pipes are dug down. Instead, all rainwater is handled on the surface using various SUDS elements. The local citizens can either choose to handle rainwater on their own plots and in return receive a financial reimbursement of the connection costs, or to lead the water to a nearby public area via the surface, where the local water utility, Aarhus Water, handles it. Getting the citizens on board the project was a difficult, yet crucial task. While some house owners embraced the new recreational solutions, the project was also met with some resistance from more sceptical citizens. The project team therefore had to be very thorough and convincing in their approach and extensive efforts were made to make sure the citizen involvement process was steered in the right direction. A combination of workshops, extensive FAQ's and even individual advisory sessions on private plots were conducted to ensure a successful implementation. (Courtesy: Aarhus Water and EnviDan)

4. SUDS IN SIMULATION MODELS

Assessing the impact of different rain events through simulation models

By using simulation models, decision makers are able to better prioritise their efforts as they can see the effects of their investments beforehand

Morten Rungø, Head of Department – Urban Water, DHI
Jan Jeppesen, Head of Development – Climate Adaption, ALECTIA

A simulation model can serve as an important tool when decision makers need to decide and prioritise their efforts as the models help quantify the effects of investments. Denmark has been a pioneer and first mover in simulating flow and water depth in pipes and manholes of traditional sewerage systems. Back in 1985, Denmark produced the very first simulation model of the sewerage system, and the commercial software has been sold worldwide ever since. The models replaced calculations previously carried out by hand or in excel-sheets and made it possible to calculate the capacity of pipes and basins in the sewerage systems.

Today, the models are able to simulate the water cycle in detail. It is now possible to choose the hydraulic view modelling flow and water depth in pipes in manholes, or to choose the hydrological view focusing on the natural infiltration. It is also possible to combine the two types of models. The two types of simulation models will each be explained in the following.

Hydraulic model of SUDS elements as extensions of sewerage systems

When using simulation models, it is possible to quantify the effect of SUDS, bigger pipes or traditional basins in a sewerage system. The models simulate the impact of different, historical rain events calculating water depth and flow in the sewers and manholes related to different rain events – and also calculate flooding at the terrain. The models can simulate where overflows and flooding will occur and which effects the different solutions – both grey and green solutions – will have on the water level, the overflows and on the risk of flooding as well as the extent of the damage.

The latest model, named MIKE URBAN, makes it possible to create an overall hydraulic assessment of implementing different green solutions in a catchment, such as rain gardens, infiltration trenches, permeable pavements, barrels and green roofs as an extension of the existing sewerage system.

Lately, it is possible to simulate single SUDS-elements such as swales. To model the swale in MIKE URBAN, you need to define a soakaway with a certain geometry, filling material and infiltration capacity throughout the bottom and the sides of the soakaway. It is possible to connect the soakaway into the sewage system through overflows, pumps, sewers and a water brake. Besides the hydraulic simulation it is possible to simulate the water quality and the effect of different kind of water treatment using an additional model (ECO Lab).

Modelling the urban hydrology and SUDS

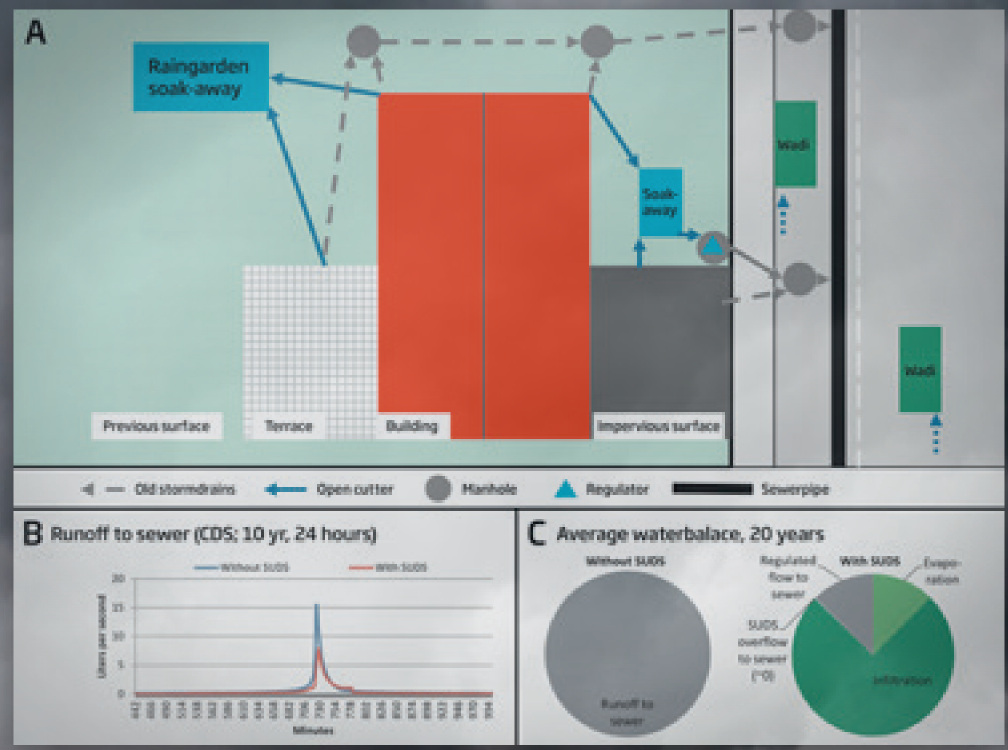
The other type of simulation model 'MODFLOW-LID' focuses on the entire urban water cycle and the consequences of applying SUDS instead of sewer based drainage systems. The model can simulate typical SUDS features such as green roofs, rainwater tanks, swales, infiltration devices, flow regulators and overflow from one SUDS-feature to another. Other significant processes in the urban water cycle are simulated, i.e. runoff from semi- and impervious surfaces, infiltration through the unsaturated zone to groundwater, groundwater flow within hydrogeological layers and groundwater related interactions with wells, rivers, channels as well as suburban infrastructures such as leaky sewer pipes, foundation drains and infiltration trenches.

A key model characterisation is the detailed simulation of SUDS on allotment scale, and the upscaling to neighbourhood and city level scale. Thereby, the effect on the groundwater table from many infiltration devices can be simulated and used to analyse the risks of a shallow water table which may mobilise pollutants, cause damage to building foundations, basements, etc. Catchment runoff (i.e. stormwater runoff, foundation drainage and overflow from SUDS-structures) can be given as input to sewer pipe models to simulate the hydraulic consequences from SUDS on sewer overflows and flooding events. The model can thus be used in the planning of sustainable SUDS strategies for neighbourhoods and reduce the risk of poor investments strategies.

Simulation of sustainable stormwater infiltration strategies in Odense, Denmark

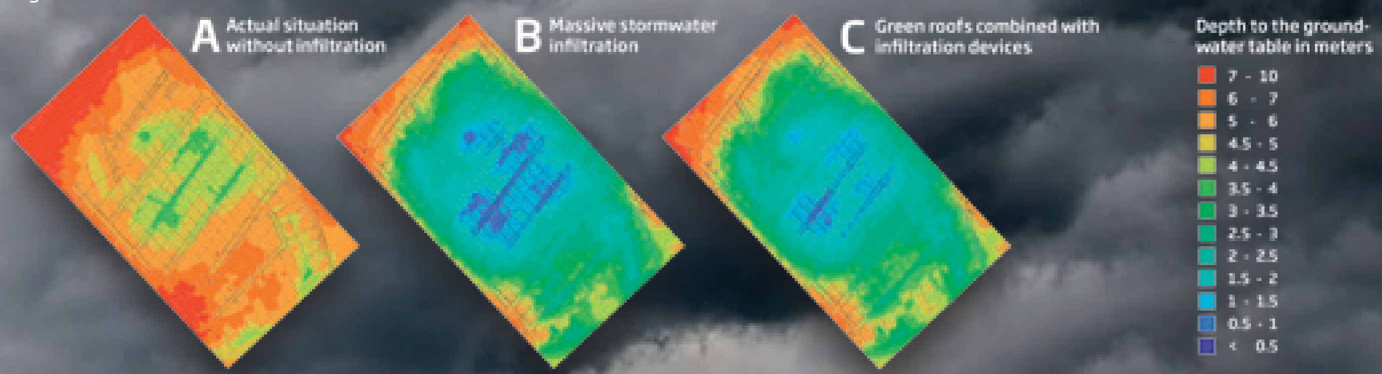
The developed urban hydrology model 'MODFLOW-LID' was demonstrated for case-areas in the city of Odense. Different SUDS-strategies were simulated on detailed scale (Figure 1) and upscaled by the model to neighbourhood scale (Figure 2). SUDS-strategies included the use of rainwater tanks, green roofs, raingardens and soakaways on private parcels as well as swale-trench systems with water brakes and overflow to the existing sewer system underneath roads. Special attention was given to the simulation of rainwater harvesting (rain tanks) and green roofs in combination with infiltration devices to manage sustainable infiltration strategies in terms of both maximising the infiltration, minimising the risk of a shallow groundwater table underneath buildings and delaying stormwater runoff to the existing sewer system. As the illustration in figure 2 shows, the model was used to simulate different stormwater infiltration strategies and the associated depth to the groundwater table in a residential area: (a): actual situation (baseline scenario) without stormwater infiltration; (b): massive stormwater infiltration leading to a critical shallow groundwater table in low-laying parcels; (c): the use of green roofs to reduce stormwater infiltration volume leading to less critical depth to the groundwater table. (Courtesy: The Foundation for Development of Technology in the Danish Water Sector - VTU, ALECTIA, VCS Denmark, Municipality of Odense, Aarhus University, GEUS)

Figure 1:



Simulation of a SUDS-strategy on allotment scale:
(A): Drawing of SUDS elements and the direction of stormwater;
(B) Simulated accumulated runoff to the sewer system in a 10 Yr design storm;
(C) simulated average water balance.

Figure 2:



5. BREAKING THROUGH THE SURFACE

Handling rainwater in densely populated areas with impermeable paving

"It makes no difference that the base course is completely soaked with water, because it is still carrying the weight needed - it is still functional"

Kim Falkenberg, Sales Manager, R&D products, IBF

Due to the large and increasing areas of impermeable surfaces in cities, the runoff from a city differs from the natural runoff pattern before urbanisation as explained in chapter 2. When impermeable surfaces are primarily used, the runoff from several catchments will arrive at the same time in certain sections of the sewers, where the capacity of the pipes is lower than the accumulated flow. The lack of capacity creates bottlenecks in the sewers, causing a high risk of flooding. When establishing SUDS solutions, maximum runoff is delayed and reduced, which will probably minimise the risk of flooding.

Replacing impermeable pavements but preserving the carrying capacity

When establishing SUDS in the densely populated city, it is of importance that the functionality of the base course - including the carrying capacity - is preserved. This is possible when paving roads or streets using permeable asphalt, or when using permeable tiles in the pavement or at the parking lot. Permeable paving allow transportation, storage and delay but in general there is no evaporation.

Considering infiltration from areas with permeable paving, experience from Denmark shows that it is possible to construct permeable paving both with - and without - infiltration. If, for instance, the municipality is worried about the water quality of runoff from a bigger parking lot, it will be possible to construct the permeable paving with a membrane underneath and to lead the runoff through pipes into a sampling well. When sampling in a certain frequency, determined by the municipality, it will be possible to document the quality of the runoff from the parking lot and from this, assess whether it is possible or not to allow infiltration of the runoff in the long run.

Green roofs as SUDS in densely populated areas

Green roofs are also suitable as SUDS in the densely populated cities. Green roofs allow transportation, storage, delay and evaporation but no infiltration. When establishing a green roof, the functionality of the roof is preserved as the area now has a dual function (i.e. roof and storage of water). The choice of each green roof depends on what weight the building is able to carry, the price and the strategy for the green roof. It is also possible to choose plants, which will promote the biodiversity in the area. It is now possible for Danish municipalities to plan (through the local plans for residential areas) whether houses need to have green roofs to ensure climate adapdation. In general, the green roof is designed with an overflow into a rain garden, a soakaway or into the existing sewers.

Denmark has accumulated a lot of knowledge and experience in planning, financing, designing and establishing SUDS in densely populated cities and there is a great interest in sharing the lessons learned in this process with other countries.

Green roofs allow global healthcare company to handle rainwater locally, Bagsvaerd, Denmark

In a dense industrial area the global healthcare company Novo Nordisk A/S decided to transform more than 15,000 m^2 into one big green roof, creating a landscape on top of an underground parking facility. Instead of using the traditional sedum roof, a variety of grasses and meadow species - all wild native plants - were chosen. The green roofs extend all the way to the ground and blend the roofs and the ground perfectly together, thereby creating a spectacular starting point for increasing biodiversity. At the same time, the solution also allows the company to handle all rainwater locally. A combination of steep roofs and a large roof area called for a customised solution. Byggros' system DiaCell was therefore adjusted to fit the special needs of this construction. Nonwoven geotextile was installed together with a Fortrac geonet for erosion control. Two layers of geocells, soil substrate for extensive roof gardens and finally a prevegetated sedum/meadow mat were also installed as part of the solution. (Courtesy: Henning Larsen Architects, SLA, Byggros A/S, Skaelskoer Anlaegsgartnere A/S)

Climate street absorbs rainwater, Copenhagen, Denmark

In an attempt to avoid floods caused by cloudbursts, one of Copenhagen's streets, Helenevej, has been transformed into a climate street with infiltration of rainwater. Asphalt has been replaced with tiles to allow rainwater to seep through the surface. The rainwater is thereafter infiltrated on its way to the groundwater aquifers. Gaps between the tiles transport the water below the road surface. The tiles and the joints are designed to infiltrate a maximum amount of water without losing its carrying capacity. There is a reservoir consisting of 40 cm of gravel beneath the tiles. In case of extreme rainfall, the water is retained in the reservoir beneath the surface. The gravel layer has a pore volume of 30% which means it can absorb up to 30% water. Along the road, the water can flow between four chambers. It is possible to connect the chambers to the sewerage system in situations where for instance the surface is frozen and therefore keeps water above surface. The road has proved able to handle large water volumes without problems during a cloudburst. (Courtesy: Frederiksberg Utility, Frederiksberg Municipality, NCC, IBF and University of Copenhagen)

Retention and filtration of rainwater at hospital, Horsens, Denmark

Horsens Hospital in the western part of Denmark recently installed a new underground parking lot. The new building was vulnerable to extreme rain events due to insufficient capacity of the public sewerage systems. With the purpose to protect the parking lot, the rainwater had to be diverted to other areas than the sewerage systems. The soakaways named Q-bic and Q-BB were installed to overcome the challenges. Through underground rainwater pipes, the water was transported from the roof of the parking lot and eventually diverted to a soakaway below the surface. With a capacity of nearly 700 m^3, infiltration and retention of the rainwater have reduced the probability of sewer overflows and thereby reduced the risk of flooding. (Courtesy: Wavin A/S)

6. SUDS AS A MEANS TO INCREASE BIODIVERSITY

Creating green corridors and resilient cities by integrating nature into urban life

Globally, biodiversity is under pressure and the majority of the dying species are threatened as a consequence of human activities. Important eco systems are weakened and food chains are destroyed. In Denmark, consecutive governments have worked to reverse the decline in diversity of the country's nature by creating contiguous and resilient areas of nature with improved living conditions for native animals and plants. Another benefit of such areas is the creation of better opportunities for outdoor experiences for the local community.

Bringing nature back into the cities

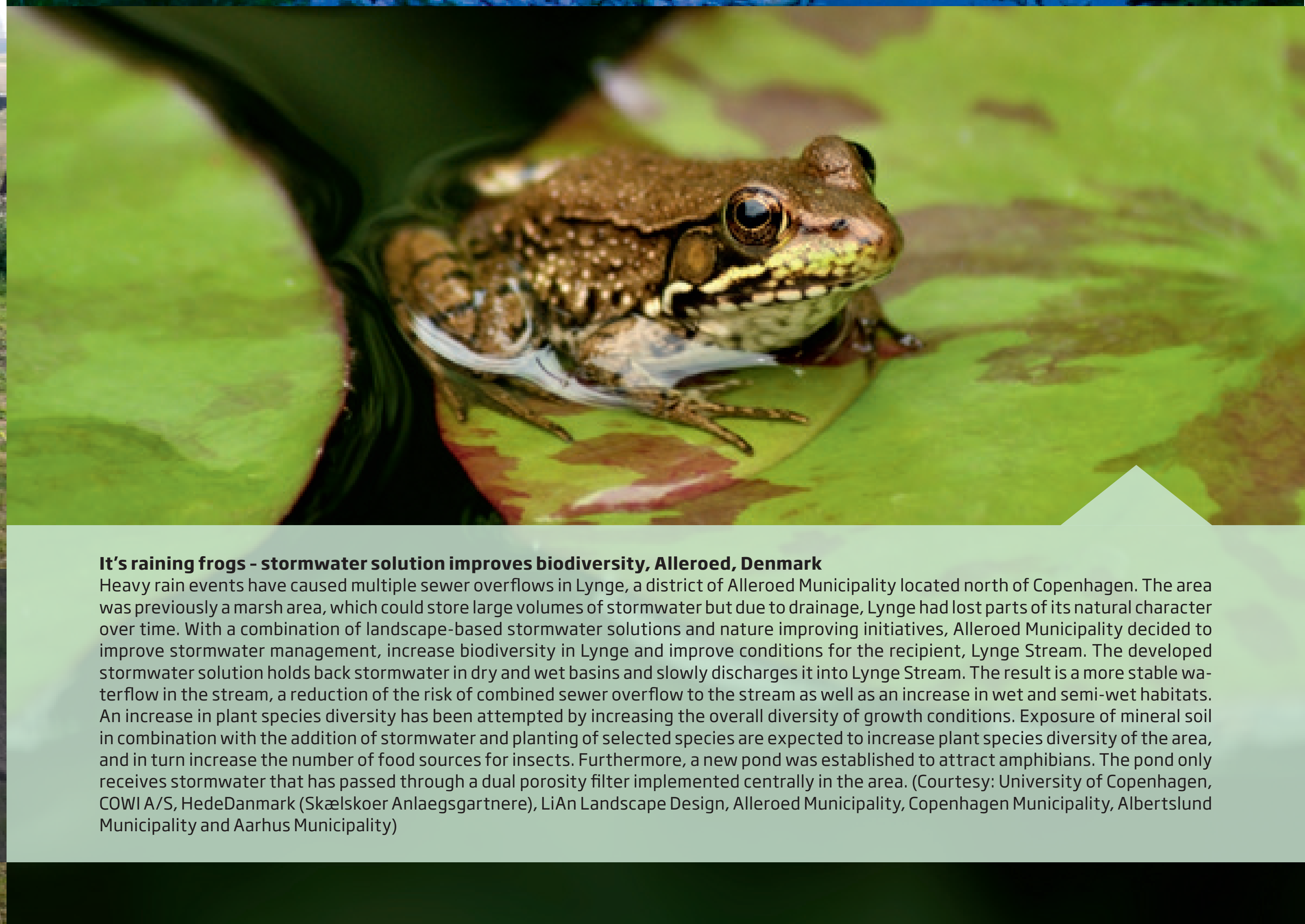
The occurrence of SUDS solutions such as green roofs, rain gardens and swales can contribute to increase biodiversity locally. The SUDS solutions and the water cycle is becoming the focal point when creating green corridors and resilient cities by integrating nature into urban life.

It is possible to choose a strategy for the chosen plants in SUDS elements to support certain insects (i.e. bees, butterflies) and thereby birdlife, amphibians and/or native plants. Denmark has experience with strategies of supporting native plants which serves as habitats for certain species - for example 'salt marsh' or 'meadow'. The concept is named 'Urban Green' where the plants are selected to ensure that the composition of the plants support each other like a 'symbiosis' between the wild plants. The concept is bringing nature back into the cities and creating wild, green and blooming lushness everywhere through rain gardens, swales and green roofs.

In addition to improving green corridors, SUDS also has a number of other benefits for urban life. For example, the so-called urban heat island effect - that is higher temperatures in cities compared to the surrounding countryside - is reduced locally when the number of green areas is increased. There is also a growing overall trend among architects and city planners to get inspired by nature and to consider both nature and wildlife when planning and designing new urban areas.

Water brings life to Bishan-Ang Mo Kio Park, Singapore
In 2006 the 'Active, Beautiful, Clean Waters Programme' (ABC Waters) was introduced in Singapore. The purpose was to transform the country's water bodies beyond their functions of drainage and water supply into lakes with new spaces for recreation. The Bishan park project is one of the flagship projects under this programme. The park was due for major refurbishment and the Kallang River, which at the time was more a concrete channel along the park edges, was also due for an upgrade in order to accommodate increasing volumes of rainwater runoff from the catchment due to urbanisation. Today, the 2.7 km long straight concrete drainage channel has been restored into a sinuous, natural river and 62 ha of park space have been redesigned to accommodate the dynamic process of a river system including fluctuating water levels, while at the same time providing maximum benefit for park users. Since the introduction of the naturalised river into the park, the park's biodiversity has increased by 30%. (Courtesy: Ramboll Studio Dreiseitl)

Restoring the village pond to prevent flooding and increase biodiversity, Radom City, Poland
Parts of Radom City in central Poland have suffered from almost annual flooding during heavy summer rains. In order to adapt to the climate change causing either flooding or extreme drought, a concept was formulated by Danish Amphi Consult and its Polish sister company FPP Enviro S.p.zoo. The concept included the creation of a new retention lake, a retention polder, a river meandering and the restoration of a 9 ha lake for recreation to secure that water coming from outside the city is kept under control, while at the same time contributes to recreational purposes and secures a habitat for animals and plants. Inside the city, examples of water retention measures for stormwater management such as swales, green roofs, permeable pavements and 12 'BIOWATER' ponds have been planned for schools, squares and housing areas. The BIOWATER concept is a new concept supported by the philanthropic organisation Realdania and combines rainwater management with recreation and biodiversity measures. The project in Radom is financed by a EUR 6 million EU LIFE grant for climate adaption and will be carried out from 2015-2020. (Courtesy: Amphi Consult, FPP Enviro S.p.zoo, Poland, Radom Municipality, Radom Utility Service, Lodz University, Aarhus Municipality, Danish Technological Institute, GHB Landscape Architects and Mangor & Nagel Architects)



It's raining frogs - stormwater solution improves biodiversity, Alleroed, Denmark
Heavy rain events have caused multiple sewer overflows in Lynge, a district of Alleroed Municipality located north of Copenhagen. The area was previously a marsh area, which could store large volumes of stormwater but due to drainage, Lynge had lost parts of its natural character over time. With a combination of landscape-based stormwater solutions and nature improving initiatives, Alleroed Municipality decided to improve stormwater management, increase biodiversity in Lynge and improve conditions for the recipient, Lynge Stream. The developed stormwater solution holds back stormwater in dry and wet basins and slowly discharges it into Lynge Stream. The result is a more stable waterflow in the stream, a reduction of the risk of combined sewer overflow to the stream as well as an increase in wet and semi-wet habitats. An increase in plant species diversity has been attempted by increasing the overall diversity of growth conditions. Exposure of mineral soil in combination with the addition of stormwater and planting of selected species are expected to increase plant species diversity of the area, and in turn increase the number of food sources for insects. Furthermore, a new pond was established to attract amphibians. The pond only receives stormwater that has passed through a dual porosity filter implemented centrally in the area. (Courtesy: University of Copenhagen, COWI A/S, HedeDanmark (Skælskoer Anlaegsgartnere), LiAn Landscape Design, Alleroed Municipality, Copenhagen Municipality, Albertslund Municipality and Aarhus Municipality)

7. SUDS AND TREATMENT OF RUNOFF

Improving the water cycle by ensuring an appropriate quality of rainwater runoff

"As groundwater is the source of all drinking water in Denmark, the level of treatment for runoff must be high"

Hanne Kjær Jørgensen, Senior Consulant, Danish Technological Institute

In order to protect the groundwater, runoff must be of an appropriate water quality. Especially runoff from streets needs some kind of treatment before it is infiltrated. The contaminants can be oil, heavy metals, environmentally foreign substances, endocrine disrupters or road salt.

The water quality of the infiltration runoff is subject to legislation in Denmark. The municipality will determine for each case whether treatment of the runoff is required and in some cases also suggest which type of treatment that should be applied. Factors that need to be considered include the source of the runoff (e.g. roofs, squares, roads etc.), if the area used for infiltration is an area with special drinking water interests, the distance to the recipients and/or water wells, the use of the area (industry, residence etc.) and what the intended use of the treated runoff is.

As groundwater is the source of all drinking water in Denmark, the level of treatment for runoff is high. Most of the time, the treatment process is both mechanical and biological. A simple, mechanical process, which is used upstream (in the inlet of) every soakaway is a detention well collecting sand, gravel, leaves etc. The detention well is a simple but effective treatment element, which also makes it possible to maintain the soakaway and prolong its lifetime. The biological treatment is – parallel to a traditional wastewater treatment plant – based on the use of biofilm attached to elements such as calcium, pebbles or marble.

If the runoff is to be used as a resource e.g. for recreational purposes, a higher water quality is required than if the runoff is infiltrated back into nature. In Denmark, there is a rule of thumb saying that rainwater can be stored for a maximum of 24 hours when used for recreational purposes. If the treated runoff is to be sprayed or pumped for play and learning, the legislation in Denmark (the Drinking Water Ordinance) requires that the runoff is of a quality equal to drinking water quality. In this case, UV-disinfection might be necessary.

Treating rainwater runoff from industrial area, Kolding, Denmark
The local wastewater utility in the city of Kolding was facing the challenge of having to clean runoff from a highly polluted industrial area to protect the environment in a small river nearby. The river was polluted with oil and hazardous substances derived from the industrial area where trucks were being loaded and a variety of materials were stored outside on the storage yard. To solve this problem, they applied the HydroSeparator® which is an automated and effective solution to improve water quality in various recipients while minimising the need for retention basins at a much lower total cost of ownership. The maximum capacity of the HydroSeparator® was determined by the requirement of a maximum flow of 200 l/s discharges to the small river. It is built of two standard HydroSeparators of 100 l/s each, which can operate concurrently or separately. Today, the plant operates automatically with very low operating costs and can be monitored and controlled from the internet as well as the connected SRO-system from the wastewater utility Kolding Spildevand. (Courtesy: Bonnerup Consult, HydroSystems and Kolding Spildevand)

Treating rainwater through curb-extensions, Copenhagen, Denmark
On Lindevang, a street in Copenhagen, an unconventional management approach to rainwater from roads has been applied. A technology that is becoming more widespread in relation to cleaning dirty runoff water from roads is SUDS. By using alternative methods for handling road water, a double profit is gained in the form of a decreased load on the sewer system and a facility with recreational value. The curb-extensions on Lindevang are constructed by using a two-section system in which the first section collects fallen leaves and sand particles. The second section of the curb-extension infiltrates through a special type of soil which binds and delays organic and inorganic nutrients, through which clean water infiltrates into the groundwater aquifers. In the case of extreme rain events, the water is by-passed to underground infiltration trenches in order to use the full capacity of the system and then followed by discharge to the sewer. (Courtesy: Orbicon)

Treatment of road-runoff with Dual Porosity Filtration (DPF), Lynge, Denmark
In the last decades, there has been a tendency towards separating the discharge of rainwater and household wastewater. Although this was also the case in the project 'Lynge Nord', the Municipality of Alleroed north of Copenhagen also wanted to create a new blue and clean habitat with water from road runoff. Seeing as road water runoff is contaminated with fine particle materials as well as dissolved substances, a purification solution was necessary. The process, Dual Porosity Filtration (DPF), was developed and is now a well-documented technology with results from more than 40 stormwater events. The processes of purifying the water in DPF are sedimentation, adsorption, and biodegradation. Suspended solids (SS) less than 5 mg/l can be expected from DPF. Particles larger than 2μm will be removed, creating crystal clear water after the purification processes. The removal of heavy metals and phosphorus is significant compared to other solutions on the market. (Courtesy: Watercare, University of Copenhagen)

8. SUDS AND RECIRCULATION OF RAINWATER

Using rainwater harvesting to create a city in water balance

"A city in water balance relies on water resources available within the city limit. Rainwater harvesting, aquifer recharging and wastewater recycling allow for population growth"

Marina Bergen Jensen, Professor, University of Copenhagen

In many areas of the world, increasing water scarcity and drought is a paramount problem, forcing cities and countries to focus on how to harvest and optimise the reuse of rainwater. In Denmark, water scarcity has not yet been a serious problem but climate change predictions indicate that prolonged drought periods will occur more frequently in the future.

The water balanced city

A recurring objective for cities that invest in rainwater harvesting and recycling is often to ensure that the city is able to rely on the water resources available within the city limit. Many cities are faced with increasing population growth due to urbanisation and rainwater harvesting and recycling can thus contribute to allowing the city to keep its overall water balance in spite of its growing population size.

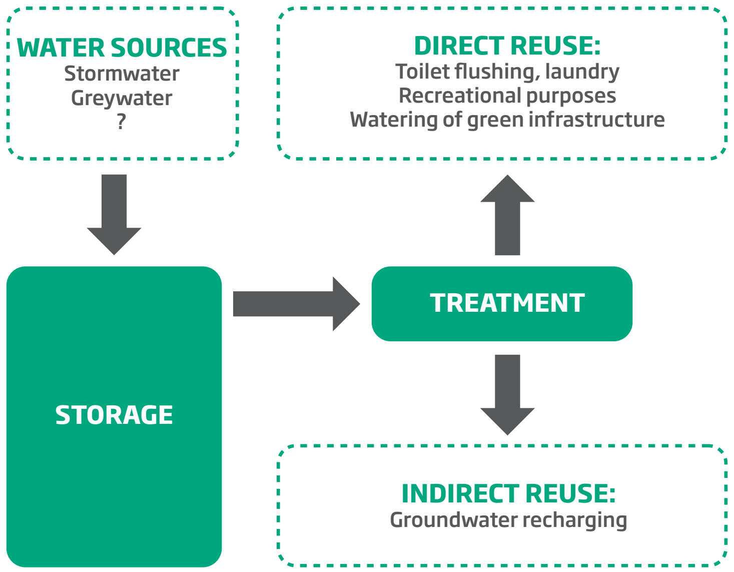
The Danish innovation consortium 'Cities in Water Balance' aims to provide urban climate adaptation options that address both the increased rainwater flood risk and the increased drought risk by means of linking rainwater management systems directly or indirectly to water supply systems and in this way progressing towards a closed urban water cycle. Based on the overall concept of the water balanced city, it is possible to customise concepts for areas where there is a great risk of water scarcity.

The focal point of the water balanced city concept is how to increase infiltration, evaporation and reuse of rainwater but the issue of leakages in the drinking water system should also be considered to reduce water loss. Finally, educating citizens on how to save drinking water and reuse rainwater should also be a part of the concept. A team is put together for each single case under the concept. Each team typically consists of a consortium of knowledge institutions (in charge of development of concept, documentation and teaching), consulting engineering companies (in charge of design) and contractors (in charge of establishing the system for collecting rainwater and performing the leakage detection).

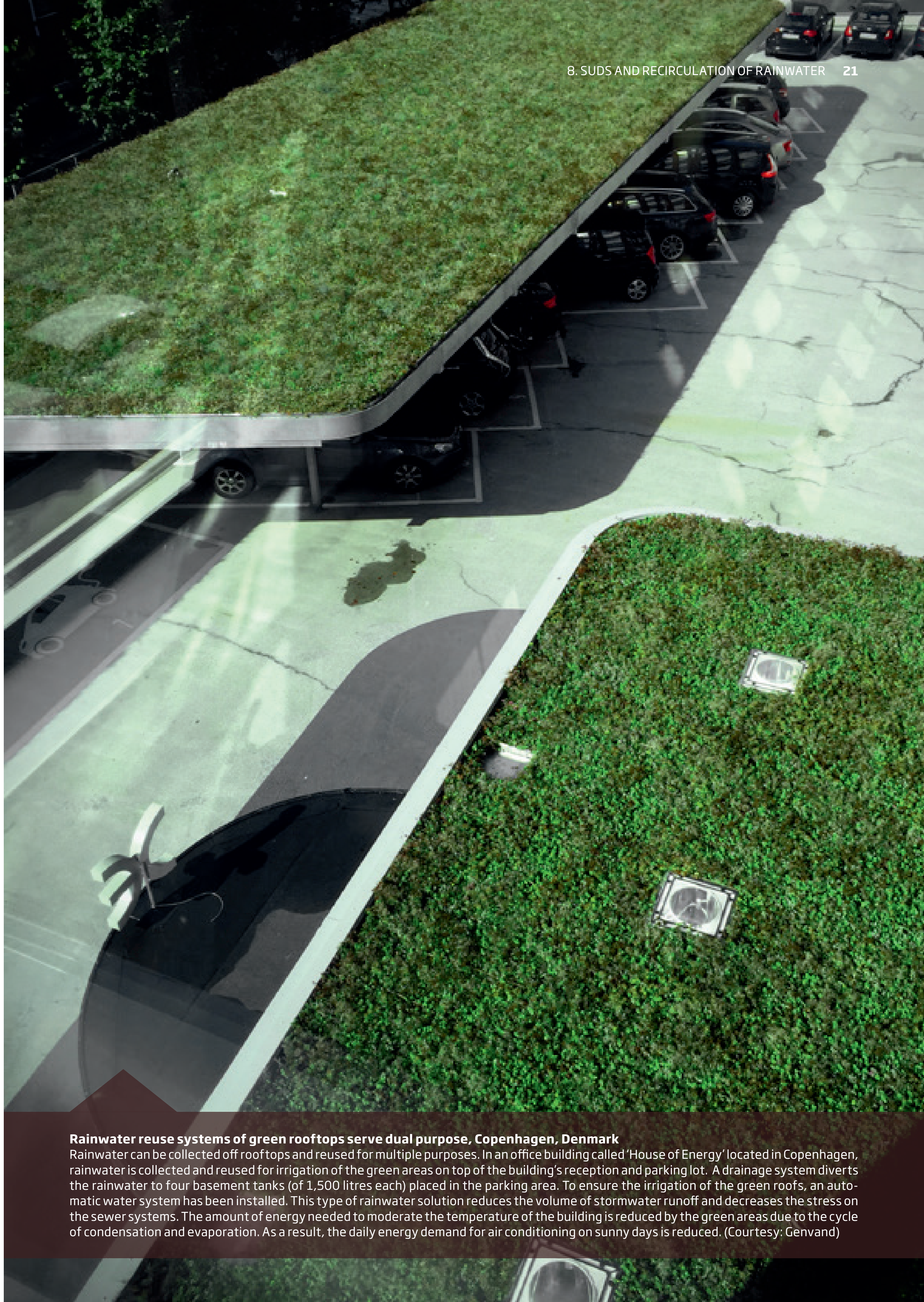
Safety issues when reusing rainwater

The legislation in Denmark for reusing rainwater is very strict, forcing companies to focus on optimal design and safety standards. It must be documented that there is no contact between the rainwater system and the drinking water system. Thus, there are two compulsory technical solutions to prevent the drinking water from being polluted; a physical gap between the two systems and a back security valve that prevents the drinking water from having physical contact with the rainwater.

The design and safety regulations is described in detail in a manual which includes guidelines for designing all parts in the system, including fittings, filters, manholes, storage tanks, pipes and the back security valve. For instance, the size of the storage tank is designed though calculations of the consumption of water, the amount of runoff from the roof, and considerations of the residence time to reduce the growth of bacteria in the tank.



A city in water balance relies on water resources available within the city limit. Rainwater harvesting and wastewater recycling allows for population growth.



Rainwater reuse systems of green rooftops serve dual purpose, Copenhagen, Denmark
Rainwater can be collected off rooftops and reused for multiple purposes. In an office building called 'House of Energy' located in Copenhagen, rainwater is collected and reused for irrigation of the green areas on top of the building's reception and parking lot. A drainage system diverts the rainwater to four basement tanks (of 1,500 litres each) placed in the parking area. To ensure the irrigation of the green roofs, an automatic water system has been installed. This type of rainwater solution reduces the volume of stormwater runoff and decreases the stress on the sewer systems. The amount of energy needed to moderate the temperature of the building is reduced by the green areas due to the cycle of condensation and evaporation. As a result, the daily energy demand for air conditioning on sunny days is reduced. (Courtesy: Genvand)

9. CREATING RESILIENT AND LIVEABLE CITIES WITH SUDS

Using rainwater as a resource to create green urban spaces with added benefits

"We need to consider what kind of cities we want fifty years from now. Every project supports a pathway. We may support the traditional way. Or we may make innovative projects that open up for new ways to work with water in our cities"

Birgitte Hoffmann, Associate Professor, Aalborg University

Adapting to a changing climate with more frequent and more intense rain events also presents an opportunity to rethink urban development and gain greater value from investments. By keeping a holistic view of the situation, the incorporation of various SUDS elements can contribute to greener and more pleasant urban spaces with added benefits such as increased real estate values, increased biodiversity, increased traffic safety and more recreational opportunities for the local residents.

Just a decade ago, most cities in Denmark regarded rainwater as something to get rid of and hide in sewers – not as the valuable resource it actually is. Today the situation is quite different as water is once again seen as an asset with an enormous potential to enhance the daily life of people living in cities. This also makes investments in climate change adaptation projects easier to justify to the public. While choosing an integrated approach may initially be more complex as it involves a broad range of environmental, economic and social strategies, it is often more cost-efficient seen from an overall societal perspective.

Creating the liveable city
While there is no global definition of what makes a city 'liveable', various international rankings of the world's most liveable cities typically consider factors related to dimensions such as safety, healthcare, economic and educational resources, infrastructure, culture and environment. The best cities manage to create synergies between these dimensions. When SUDS projects are designed right, they can serve multiple functions beyond rainwater management and thereby play a key role in creating 'the liveable city'.

The key is long-term planning as many projects are built to last for decades or even longer. When deciding on which projects to implement, city planners and other decision makers need to consider what kind of city they want to have fifty years from now as decisions made today will have a significant impact on the city's urban structure for years to come.

At the same time, there is an increased realisation that the existing expert-based service and the passive citizen role is no longer adequate. As described in chapter 3, broad stakeholder collaboration and involvement is needed. When creating liveable cities, three consecutive challenges need to be addressed:

- How do we create climate resilient societies in practice and utilise the potentials to strengthen the sustainable transformation of urban and rural areas?
- How do we develop new types of interaction with the citizens of this work?
- How can we work innovatively with climate adaption and develop new professional skills and approaches to planning?

The lessons learned from Denmark in terms of addressing these challenges have been compiled in a 'Handbook for sustainable transition' published by the Danish innovation network Water in Urban Areas.

Estimating the economic value of green SUDS projects
By thinking in multiple use of rainwater, it is possible to create synergies from investments. In many cases surface solutions with multiple functions are actually cheaper due to lower construction costs. However, assigning economic value to green or dual-purpose solutions and the positive spillover effects from these compared to traditional basins or sewerage system expansions can sometimes be difficult.

In Denmark, there are no national guidelines for calculating the benefits and added values of green solutions that involve SUDS elements with multiple purpose functions. However, two different tools have been developed for this purpose.

The first tool is a method for comparing expenses for building 'grey' vs. 'green' solutions developed by Water in Urban Areas. The calculations in this method include the various types of costs (such as project planning, construction work, maintenance etc.), the frequency of each cost, who the cost bearer is and if there are any associated risks. Finally, it also takes into account parameters such as sturdiness of the solution, the environmental effect, the aesthetic and recreational qualities as well as possible synergies with other planned construction projects.

The second tool is called 'SPLASH' and has been made available free of charge by the Danish Nature Agency to help calculate the socio-economic consequences of specific climate adaptation measures in a local area. SPLASH calculates the size of investments needed to guard against a given rain event and shows economic gains from each suggested action on a long-term basis (e.g. reduced costs of flooding damages). The value of positive spillover effects such as increased green areas, reduced water consumption and increased CO_2 absorption etc. is also included.

Both tools are available online and can be used by Danish municipalities, utilities, consulting companies, architects, contractors and knowledge institutions etc. to help them plan and prioritise their efforts.

Sports center uses climate adaption as stepping-stone for new recreational facilities, Gladsaxe, Copenhagen
Extreme rain events have caused flooding on several occasions in the Copenhagen suburb Gladsaxe. To prevent future flooding, a large climate adaptation project was recently finished at Gladsaxe Sports Center. The sports center is situated on top of a large regional water system. By diverting rainwater through a series of ponds and canals, more capacity was therefore created in the sewerage systems both locally and in the low-lying areas between Gladsaxe and the sea. By choosing surface solutions with dual purposes rather than traditional underground reservoirs, the project saved approx. EUR 4 million, proving it a very cost-efficient solution. Keeping the rainwater above surface also became a stepping stone for creating new recreational areas and playgrounds. Eight different holes were constructed to function as different recreational areas when they are not used for collecting rainwater. For sports enthusiasts, the park has been turned into a concrete corridor for skate boarders and a paddle tennis field. As the holes have a more informal setting, the park now has a much wider appeal for the overall local community who is invited in for anything from jogging or playing, to dog walking or taking a Sunday stroll. (Courtesy: Gladsaxe Municipality, Nordvand, Bisgaard Landscape, Grontmij, Ohlers Design, WATER PLUS, Realdania, The Danish Foundation for Culture and Sports Facilities and the Danish Nature Agency)

The climate resilient school, Roskilde, Denmark
The vision for the climate resilient school in Roskilde is to handle all stormwater on campus. To ensure this, 1,100 m^2 of roof has been disconnected and runoff from the pavement infiltrates through permeable pavings. Runoff from the roof runs through trenches into a paddling pool shaped like the local bay which is also used by the schoolchildren for playing and learning. From the 'bay', the stormwater goes through an ACO trench into a soakaway. The soakaway has a membrane underneath, creating storage volume for stormwater. It is possible for the children to pump up the stormwater with old-school hand-pumps. The overflow goes into a raingarden and a ditch downstream through the raingarden. From the raingarden, the water flows into a multifunctional pump track lane with parkour-elements for street climbing. The multifunctional square is covered in permeable rubber and illustrates the meeting between coast and sea. The project demonstrates that SUDS are able to handle everyday rain, design storms and cloudbursts, when the different SUDS elements are connected to each other as pearls on a string. (Courtesy: Danish Technological Institute, Aalborg University, DHI, Gundsoe Entreprenoer Forretning, Thing og Brandt Landskaber, IBF, NCC Roads, ACO Nordic, Wavin, Nykilde, Amphi Consult, KLS Grafiske Hus, Municipality of Roskilde and Roskilde Utility)

Copenhagen's first climate resilient neighbourhood, Copenhagen, Denmark

An existing neighbourhood in Copenhagen is currently undergoing a transformation to become more resilient against coming climate changes like strong and heavy cloudbursts. The transformation will also result in green, beautiful urban spaces for the local residents to enjoy.

Principles
Unlike most of Copenhagen, the neighbourhood of Skt. Kjelds Kvarter is sitting on a slope, sloping down towards the harbour. The main purpose is therefore to retain surface water in the area and infiltrate as much rainwater to the groundwater as possible. Storage capacity is used during heavy rain. During cloudbursts the excess water is transported away from the neighbourhood to places where the risk of damage is minimised. The overall aim for the neighbourhood is to have flexible surface solutions that can manage daily rain locally. During cloudbursts, the surface solutions are combined with a conventional split rainwater sewer system which ensures a controlled transport of the rainwater to the nearest harbour.

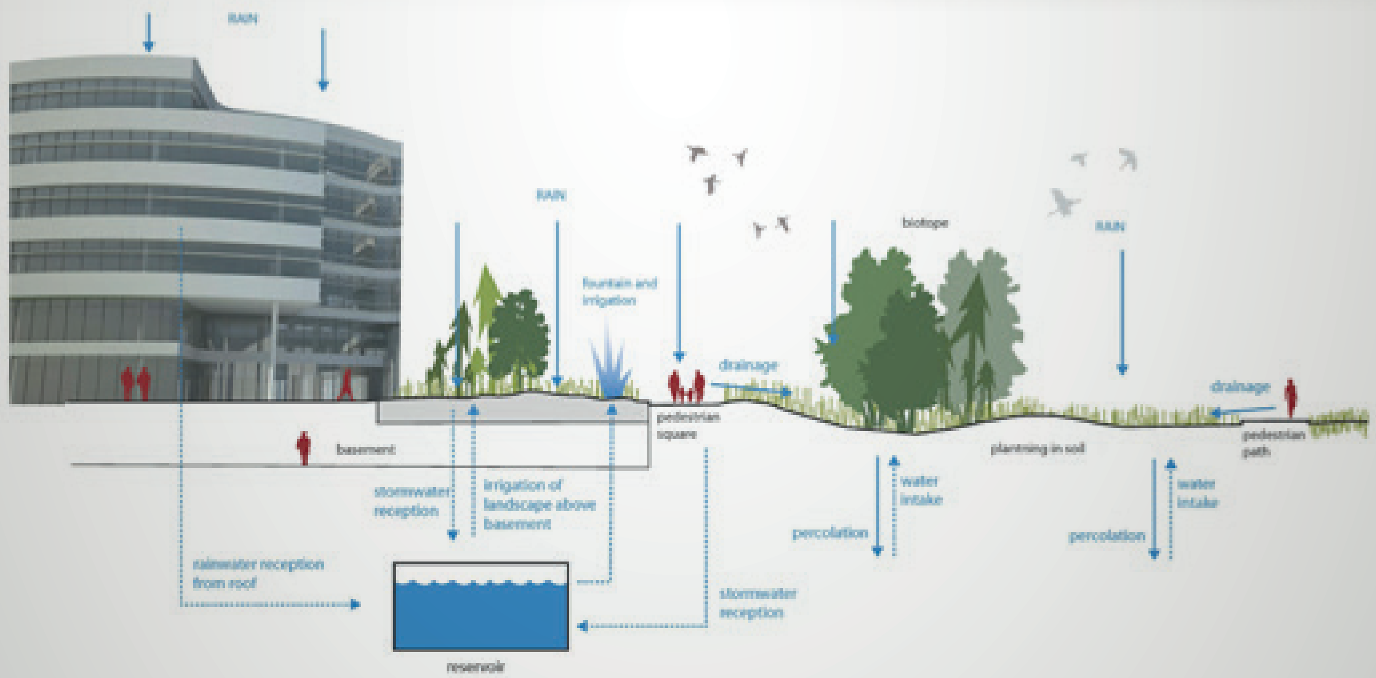
The transformation will be carried out in different sections – two of those sections are described here:

Taasinge Plads
The transformation of Taasinge Plads was completed in 2014 and the area is now a green pocket park that demonstrates management of three different types of surface water fractions; rainwater from roofs, which is used for recreational use and play, rainwater from none traffic areas, which is used for local infiltration, and finally surface water from roads, which is infiltrated through filtermedia (as salt is used for ice control in the winter, the road water is not infiltrated to the groundwater but transported to the harbour). During cloudbursts, an integrated open storage capacity is taken in use and works as a blue element in the pocket park.

Bryggervangen and Skt. Kjelds Plads
Bryggervangen and Skt. Kjelds Plads is a long stretch of road (34,900 m^2) where green spaces, urban nature and linked surface water solutions will replace asphalt and pavements. The applied urban nature will learn from characteristic wet/dry biotopes in Copenhagen and uses their processes in a rational way to treat and retain stormwater. Surface water from roads is handled by First-Flush solutions which direct the polluted initial surface runoff (First Flush) of a rainstorm to the existing sewer system, whereas the cleaner "Second Flush" is directed to green surface water solutions.

(Courtesy: City of Copenhagen and HOFOR (Greater Copenhagen Utility). Strategic design advisors for the master plan of the area: Tredje Natur. Advisors for Taasinge Plads: GHB Landscape Architects and Orbicon. Advisors for Bryggervangen & Skt. Kjelds Plads: SLA and ALECTIA.)

Cost-efficient climate adaptation and wetland restoration, Karlstrup Meadow, Denmark
Heavy rainfalls used to lead to severe flooding in the small cities of Greve and Solroed located south of Copenhagen. Today, the increased volume of rainfall is used positively in a restored river valley with an open pond and wetlands which provide both recreational value to the citizens and improved habitats for flora and fauna. A new pond purifies rainwater before it runs to the re-established river, allowing trout and other wild fauna better living conditions. At the same time, the water utility company now has access to 30,000 m^3 of rainwater storage during stormwater events. The Karlstrup Meadow project is a unique collaboration between Greve Solroed Utility Company and the two municipalities of Greve and Solroed and has created win-win solutions for everyone involved, including local sports clubs, farmers and bird watchers. In Karlstrup Meadow, climate change adaptation became a strong driver of sustainable and cost-efficient development as the project saved the water utility company construction costs for traditional urban retention basins. The holistic approach had a strong focus on stakeholder involvement, alternative financing mechanisms and not least technical solutions involving a new stream established through the local forest. (Courtesy: NIRAS A/S, Greve Solroed Utility Company, Municipality of Greve, Municipality of Solroed)



Functionality and aesthetics don't compete at Novo Nordisk Nature Park, Bagsvaerd, Denmark
Novo Nordisk Nature Park is the first Danish domicile park with a 100% water balance. The park's topography and plantation are carefully designed to handle even 100 years of torrential rainfall without directing any water into sewers. The functional solutions have given the global healthcare company Novo Nordisk full refund on its sewer taxes and the solution goes hand in hand with the creation of lush nature, including great variety of dense biotopes which maximise environmental sustainability, recreational value and optimal conditions for innovative outdoor meetings and creative walk-and-talks. Rainwater from pavements and roofs on the site is collected in an underground water tank. It is later used for irrigation of the green roofs or led to the different biotopes via underground reservoirs. These create perfect conditions for the wetland biotopes such as the alder biotope which is rarely encountered in urban contexts and which provides new experiences through its unfamiliar expressions. Any excess water is infiltrated. (Courtesy: Henning Larsen Architects, SLA A/S, SKAG and Orbicon)

10. DENMARK KNOWS CLIMATE ADAPTATION

Having experienced floods from cloudbursts and storms, Denmark has felt the consequences of a changing climate first-hand. However, the Danish experience also shows that climate adaptation can present an opportunity to rethink urban development and gain greater value from investments. Rather than coming at the expense of urban living, climate adaptation can contribute to greener and more livable cities. Sustainable urban drainage systems are part of the solution and Danish cities are increasingly optimising their rainwater management and diverting rainwater away from the traditional sewerage system.

Denmark has a long tradition of public-private collaboration and national government agencies, municipalities, water utilities, companies and local citizens are working together on numerous projects to prepare our cities for a changing pattern of precipitation. In Denmark, we believe that knowledge is power and we look forward to sharing our lessons learned from planning, constructing and implementing climate adaptation solutions.

Explore, Learn and Connect Online
Stateofgreen.com is the official platform for Denmark's green solutions and knowhow and offers an online entry point for all relevant information about Danish companies and institutions and their expertise within water and climate adaptation as well as other green strongholds.

Come visit us in House of Green
House of Green is an interactive visitors' and exhibition centre located in the heart of Copenhagen. House of Green uses a combination of guided storytelling and self-exploration to showcase green Danish integrated solutions and scenarios, as well as an overview of the combined Danish story within energy, climate, water and resources. Danish representatives act as hosts that both inspire and inform delegations before they move on to on-site visits. For more information about House of Green, please visit www.houseofgreen.com.

Experience SUDS solutions live in Denmark
A cornerstone of the Danish vision is to inspire others and demonstrate how a green society is both possible and profitable – and we invite people to come see for themselves. Through State of Green Tours we offer commercial and political decision makers and journalists around the world a chance to take advantage of the lessons learned by leading Danish companies and institutions within the fields of energy, water, climate adaptation and environment, and to experience Danish green solutions – live. For more information about State of Green Tours, please visit:

www.stateofgreen.com/tours

About State of Green
State of Green is a public-private partnership founded by the Danish Government, the Confederation of Danish Industry, the Danish Energy Association, the Danish Agriculture & Food Council and the Danish Wind Industry Association. H.R.H. Crown Prince Frederik of Denmark is patron of State of Green. As the official green brand for Denmark, State of Green gathers all leading players in the fields of energy, climate adaptation, water and environment and fosters relations with international stakeholders interested in learning from the Danish experience. Connect through: www.stateofgreen.com /climate-adaptation

Learn more about Danish climate adaptation solutions, find more cases from around the world and connect with Danish expertise at:

stateofgreen.com/climate-adaptation

State of Green is a non-profit, public-private partnership founded by:

Confederation of Danish Industry

Danish Energy Association

Danish Agriculture & Food Council

Danish Wind Industry Association

Ministry of Foreign Affairs of Denmark

Ministry of Business and Growth Denmark

Danish Ministry of Energy, Utilities and Climate

Ministry of Environment and Food of Denmark