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Urban water management

Creating climate-resilient cities

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Our Future Water

IWA DENMARK
the international water association

URBAN WATER MANAGEMENT

Creating climate-resilient cities

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Our changing climate and transition

BY SEBASTIAN H. MERNILD, PH.D. & D.SC., PROFESSOR IN CLIMATE CHANGE AND GLACIOLOGY AND HEAD OF SDU CLIMATE CLUSTER. MERNILD WAS LEAD AUTHOR ON THE IPCC'S SIXTH ASSESSMENT REPORT (AR6/WG1)

Observed warming is driven by emissions from human activities. Stated by IPCC (Intergovernmental Panel on Climate Change), it is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, and biosphere have occurred.

Each of the last four decades has been successively warmer than any decade that preceded it since 1850, where the global surface temperature was 1.09°C higher in 2011–2020 than 1850–1900, with larger increases over land than over the ocean. The temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years. Temperatures during the most recent decade exceed those of the most recent multi-century warm period, around 6,500 years ago.

Also, the globally averaged precipitation over land has likely increased since 1950, with a faster rate of increase since the 1980s. The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis. It is likely that human influence contributed to the pattern of observed precipitation changes since the mid-20th century.

Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation, and, in some regions, agricultural and ecological droughts. With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves, and heavy precipitation.

When it comes to a climate-related challenges – e.g., sea-level changes – the global mean sea level changes have increased by 0.20 m between 1901 and 2018, covering significant regional variations. The average rate of sea level rise was 1.3 mm per year between 1901 and 1971 increasing to 3.7 mm per year between 2006 and 2018. Human influence was very likely the main driver of the increases since at least 1971. Stated by IPCC, we except that the global mean sea level will continue to rise over the 21st century: and over the next 2000 years, global mean sea level will rise by about 2 to 3 meters if warming is limited to 1.5°C and 2 to 6 meters if limited to 2°C.

The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years. Further, the climate system is today in a situation, where the atmospheric CO_2 concentrations is higher than at any time in at least 2 million years, and concentrations of CH4 (Methane) and N2O (Nitrous oxide) is higher than at any time in at least 800,000 years.

We are facing a global challenge when it comes to human influence on the climate system. The average annual greenhouse gas emissions during 2010–2019 were higher than in any previous decade, but the rate of growth between 2010 and 2019 was lower than that between 2000 and 2009. The fact that the rate of growth has fallen on average over the past decade can be interpreted as one flimsy and initial sign that the green transition – in a global perspective – is showing its incipient effect.

Foreword

BY FINN MORTENSEN, EXECUTIVE DIRECTOR, STATE OF GREEN

Water is fundamental to all aspects of life. Representing a crucial vein to well-being in all societies, water resources underpin economic growth, environmental sustainability, and prosperity. The severe water challenges facing today's world require an unprecedented global response – but it also represents tremendous potential.

With collective action, climate-resilient water management can boost livelihood and liveability in urban areas all over the world. As such, this publication gives first-hand insights into how some of Denmark's leading companies, cities, utilities, and universities are working to deliver state-of-the-art water solutions for a sustainable future. By sharing Danish experiences, we hope to spur a global culture of innovation and joint leadership to enable the radical transformations required.

Collective action to common challenges

Denmark wants to reduce its greenhouse gas emission by 70% by 2030 compared to 1990 levels. While Danish emissions only account for 0.1% of worldwide emissions, we believe that it is essential to set an example for other nations to be inspired by. This, to a great extent, goes for the Danish water sector.

Together with leading public and private players, the Danish water sector has set an aspiring goal to become energy and climate neutral by 2030. This is an ambitious, yet realistic target. Danish water utilities are already world leaders in efficient supply of drinking water, and wastewater treatment plants are being turned into energy and resource recovery facilities, providing urban areas with green energy. With many of the needed solutions at hand, the time is ripe to scale solutions and share ideas offering equal opportunities for green growth.

Welcoming IWA's World Water Congress in Copenhagen

Standing on the shoulders of a long tradition of developing and implementing urban water and climate adaptation solutions applicable to more than one challenge at a time, Danish water solutions are found far and wide. We have close partners all over the world, and we continue to reach out for new ways to expand and deepen these relations.

In September 2022, the International Water Association's (IWA) World Water Congress & Exhibition comes to Copenhagen. As a global showcase of how we may shape tomorrow's cities, the World Water Congress comes at a crucial time. Finding new and innovative solutions to managing extreme weather conditions, flooding, and water scarcity is a top priority for cities all over the globe. Therefore, professionals from more than 140 countries will use Copenhagen as a backdrop to explore smart, holistic, and liveable solutions that empower cities to adapt to a changing climate, whilst improving the quality of life and well-being of our societies.

I hope that the IWA's World Water Congress & Exhibition, and this white paper alike, will serve as inspiration on how to improve climate-resilient water management around the world.

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Climate resilient water supply

In a time where climate change, extreme weather conditions, water scarcity and droughts are increasing, a holistic understanding of various water supplies and their vulnerabilities is ever more critical. Whether relying on a groundwater supply entirely or as a supplement to surface water, its potential as a climate resilient water supply is considerable.

Climate variability threatens both water supplies and sanitation, with floods damaging water infrastructure and reducing water services. Increasing droughts reduce the availability of surface water, increase water source pollution, and as a result, increased abstraction reduces replenishment of groundwater sources. For communities to be resilient to climate change, the water system must be able to survive shocks and stresses, people and organisations must be able to accommodate these stresses in their day-to-day decisions, and institutional structures must continue to support the capacity of people and organisations to fulfil their aims.

Developing climate resilient water supply involves implementing strategies to mitigate the risks of floods and ensure adequate water supplies. For example, Managed Aquifer Recharge (MAR) consists of water management methods that recharge a groundwater aquifer using either surface infiltration ponds or directly through injection wells. The stored groundwater is available for use in dry years when surface water supplies may be low. MAR can be used as a drinking water supply, as process water for industry, irrigation, and sustaining groundwaterdependent ecosystems. Resilience to droughts can also be enhanced through demand management, making better use of existing water supplies through water conservation and water efficiency measures before attempting to increase water production further.

In Denmark, almost all drinking water is based on groundwater. As a result, the country has, over the past decades, amassed some of the world's most extensive expertise on sustainable groundwater management. However, all countries have different local conditions, which must be considered when planning for long-term water supply. It is estimated that there is approximately 60 times more groundwater than fresh surface water from lakes and rivers on earth, highlighting the tremendous potential to be leveraged by managing this vital source of drinking water. Whether it is the sole source of drinking water or a supplement to other sources, utilising groundwater holds a multitude of advantages

CHAPTER 1

Exploring groundwater as an option

A groundwater reservoir, known as an aquifer, is a hidden subsurface water resource and offers an opportunity to store water for future supplies. This is particularly important to secure reliable drinking water provisions in a time with more extreme weather conditions.

The source of water supplies varies across the world. In some places, surface water is the major source of water, supplied either from natural lakes and rivers or from water stored in dams. In other places, the water supply is based on groundwater. The advantage of using groundwater as a single source or supplementing other water supply sources is that the aquifer is less sensitive to seasonal changes in water consumption and variations in climatic conditions. Aquifers used for abstraction are often thought to be thoroughly protected from pollution, however if pollution does occur, restoration of the aquifer is often a complicated process as damages are long-lasting. Therefore, groundwater has to be managed sustainably. Performing Managed Aquifer Recharge, recharge of surface water into the aquifer, to obtain a balanced water account is an increasingly common practice and can play a significant role for some countries when considering sustainable groundwater management. Typical considerations include locating optimal sites for water infiltration, understanding where the infiltrated water might flow and if there are any threats to the water quality. By sustainably managing and recharging the aquifer, the otherwise vulnerable surface water is stored in the more protected aquifer 'savings account', rendering it reliably withdrawable. Withdrawn sustainably as part of a general supply operations or when prolonged droughts pose a threat to the surface water supply.

Collecting data and generating knowledge is key
The first step towards sustainable groundwater management is to obtain enhanced knowledge and understanding of the aquifer system such as the extent of the aquifer, whether the conditions present in the aquifer naturally protect against pollution or leave the aquifer vulnerable to land activities on the surface. Generally, available knowledge of aquifers is limited and mostly based upon borehole data. In some countries, borehole information, the only direct, in-depth source of information, is treated as private information and therefore not publicly available. In addition, most boreholes are drilled for the purpose of water abstraction and completed at a depth within the aquifer, where it is expected that the desired amount of water can be abstracted. Consequently, information about the underlying and deeper geology is not available and it is impossible to see the full picture. The geological information attained from boreholes can be lacking, as the level of detail in well completion reports vary immensely. Finally, while boreholes provide information at a specific location, they are usually sparse, missing crucial information about the extent and continuity of the aquifer units in hydrogeological modelling.

Improving hydrological model
Although the quality of the well completion reports can vary, a great deal of valuable information is hidden in the reports that can help improve our understanding of the aquifer system. The first step towards improved hydrological modelling is quality control and digitisation of existing well data, including lithological and geophysical wireline logs. Conducting geophysical investigations can play a key role in characterising the sedimentology of the aquifers and delineating groundwater infiltration and flow paths. This provides more accurate input to a hydrological model, improves understanding of the spatial distribution of the aquifer's hydraulic conductivity and supports sustainable groundwater management by allowing decisions to be made based on the most accurate available knowledge. Combining well completion reports from drilled boreholes with geophysical investigations allow for better modelling and as a result, more qualified knowledge. When decisions are to be made regarding sustainable groundwater management, this type of qualified knowledge forms the best practice, to base those decisions on. Whether it includes adding Managed Aquifer Recharge to the management portfolio, or managing the current groundwater level without this practice, cross-correlation of several datasets will aid in securing qualified decisions on reliable water supply.

Image credit: Niras

Surveying and 3D-mapping groundwater resources

In South Africa, even large metropoles like Cape Town have challenges supplying sufficient water. To secure a reliable water supply for the future, the local Saldanha Bay municipality, which is located north of Cape Town, has taken several strides towards incorporating groundwater into their water supply mix. The search for and use of groundwater resources has often been hindered by the fact that most of South Africa's groundwater is stored within fractures in the bedrock, making it difficult to map and reach.

In the Saldanha Bay municipality, they are currently mixing surface water from the Berg River with groundwater from three wellfields and have further plans for managed aquifer recharge and desalination. To sustainably manage groundwater resources in combination with existing water supply sources, while protecting the Laangebaan/Saldanha Bay area ecosystem, the municipality is aware that germane data is the basis for all decisions. To obtain knowledge about the geology and groundwater resources in finer detail, they engaged groundwater mapping experts to survey and provide 3D mapping of a 2400 km^2 large area. SkyTEM Africa performed the data collection, employing its proprietary airborne electromagnetic geophysical method. Data were analysed and modelled to locate groundwater resources and inform the management of these resources in a sustainable manner.

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Mapping sediments in infiltration ponds

Dating back to the 1930s, Orange County Water District (OCWD) has engaged in aquifer recharge to manage the local groundwater basin sustainably. This includes infiltration of multiple water sources, including surface water from the Santa Ana River. Water from the Santa Ana River is diverted to multiple recharge facilities, including off-river channels for infiltration. To maintain and optimise infiltration in the off-river Location, the upper sediment layer is continuously removed, at a cost. Over time, OCWD has conducted a number of investigations to obtain further knowledge of the topsoil conditions. These have primarily consisted of costly borehole and labour-intensive excavation investigations, providing only partial understanding. To be able to interpolate the spatial distribution of the shallow sediments, OCWD had an off-river infiltration basin mapped. The mapping was performed by an electromagnetic geophysical survey, which offers detailed mapping of the soil's electrical resistivity in the top eight meters. Together with the previously obtained borehole information, the result from the geophysical survey provided detailed and elaborated insight into what areas of the off-river channel the majority of water infiltrates and how water infiltration rates can be enhanced by trenching.

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CHAPTER 2

The liveable city is basin-connected

To secure water supply for people, protect water quality in and beyond the city and prepare the city for extreme weather events, it is important to understand that cities are closely connected to their surrounding basins. A city is not an island and overcoming challenges in urban water management can be done through a basin-wide approach.

Securing water for a growing urban population
More than half of the world's population now lives in cities and often cities do not have sufficient water of adequate quality within the city limits to secure water for consumption. This can be a serious constraint on the health of the population and economic growth. In order to secure availability of water, many cities need to take action by bringing in water from outside the city limits. In Denmark, national action has been taken to secure knowledge of water resources and since 2000, mapping of groundwater resources has been the backbone of groundwater protection plans, partly financed by a tax on drinking water. Data from water planning, monitoring and risk assessment are freely available in Denmark which supports a shared and basin-connected effort on groundwater protection.

Cooperation with stakeholders at basin scale is necessary in order to harvest the benefits from the shared information about the quality and availability of surface and groundwater and to share the resources between the different users in the basin, while also ensuring a sufficient amount of water in natural water bodies such as rivers, lakes and wetlands.

The International Water Association (IWA) has developed an Action Agenda for Basin Connected Cities. The Action Agenda builds on IWA's 17 Principles for Water-Wise Cities. It highlights three risk factors that need attention by urban stakeholders:

1 To secure water for consumption and production in cities
2 To protect water quality
3 To prepare for and respond to extreme events

Water does not respect administrative borders
This is a very simple principle, yet often difficult to follow in daily water management practice. To ensure proper water quality, urban water managers need to pay attention to the basin area the city is connected to and where the city gets its water from. In Denmark, there is a tradition for cooperation between different stakeholder groups across administrative borders as a means to secure a healthy water environment and protect boreholes and water abstraction areas, whether the water source is based on surface water or groundwater, as is the case in Denmark.


Image credit: VCS Denmark

Wastewater management in a basin perspective
Basin-wide cooperation on managing and treating wastewater from all polluters such as households, industries and agriculture is also important. It paves the way for the most efficient treatment solutions in a cost-efficient manner. It is important to ensure that wastewater is treated in the whole basin area. Otherwise, it may harm surface or marine waters near other cities and communities. If the treatment is inefficient, it will have severe consequences for the whole basin area and the environment, fisheries, and bathing water quality. It will also become more expensive for water consumers to clean up the environment after the damage is done.

Adapting to a changing climate in and outside of the city
Climate change has an impact on nearly all cities as many can look forward to more extreme weather events in the future. Cities will experience more heavy rainfalls and/or flooding from rivers and streams or rising sea levels and storm surges. Activities in the open land outside the city will have an enormous impact on how the city will be affected by flooding. It may be wiser to manage heavy rain on farmland than by flooding cellars in residential areas. Nature-based solutions allow local drainage of rainwater and may offer better room for water storage in rivers and streams than concrete canals and paved areas.

Enabling trust and joint decision making
Aligning basin management with the development of liveable cities depend on a strong cooperation between all basin stakeholders. A common vision combined with trust, reliable water resource information, planning tools and digital solutions enable joint decision making across different stakeholders in the basin.

For Denmark, basin-wide approaches are related to the demands from the EU Water Framework Directive calling for adoption of River Basin Management Plans in EU-countries and for transboundary basin areas. Accordingly, Denmark has been distributed into one international and three national river basin districts.

Furthermore, the UN Sustainable Development Goals state that all countries have to implement calls for integrated and basin-wide approaches to water management. It even has a dedicated target (SDG 6.5) which aims to implement integrated water resources management at all levels by 2030, including through transboundary cooperation as appropriate.

A basin-connected approach to sustainable groundwater abstraction

As in the rest of Denmark, the production of drinking water for the greater Copenhagen area is based solely on groundwater. The abstraction of approx. 55 mio. m^3/year takes place from 54 well fields located across 21 municipalities. Consequently, the water supply to the Greater Copenhagen area depends on a close and trustful collaboration between the water utility and these basin-connected municipalities in terms of licensing and groundwater protection. Behind the licenses to abstract groundwater lies years of negotiation and joint planning between HOFOR (Greater Copenhagen Water utility) and the municipalities. Through the water tariff, the consumers in the Greater Copenhagen area finance groundwater protection measures such as afforestation, regulation of the use of pesticides and information campaigns. To a certain extent, groundwater abstraction affects surface ecosystems, water flow in streams and the groundwater quality. A sustainable abstraction of groundwater is thus important to reduce these impacts. At the same time, consumers expect a stable and safe supply of drinking water. HOFOR therefore carries out comprehensive monitoring and risk assessment in close dialogue with the municipalities to secure a stable, healthy and sustainable supply.

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LOCATION

Greater Copenhagen

Increasing flooding calls for immediate cross-municipal cooperation

With its 160 km, Gudenåen is the longest river in Denmark and runs through seven municipalities. Climate change has led to an increase in precipitation and flooding which calls for increased cross-municipal cooperation in order to create holistic, long-term solutions. This includes engaging with a diverse set of stakeholders ranging from landowners to museums to help identify challenges and create new climate adaptation solutions. A hydrological model and warning system covering all 160 km's has been developed in order to inform stakeholders and produce future climate adaptation scenarios. Furthermore, a mapping of the local stakeholders, their interests and objectives has been carried out. The purpose of this was to involve stakeholders and get an overview of their experiences with flooding and possible solutions. This is important as future climate adaptation solutions should not only aim to reduce flooding but also create a common understanding of the river system as one system and develop climate adaptation solutions which resonate with the local stakeholders. The aim has been to create more holistic solutions with added value for the various stakeholders along Gudenåen.

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LOCATION

Central Denmark Region

CHAPTER 3

Efficient and safe drinking water in cities

A sustainable and liveable city requires safe, efficient and sufficient drinking water supply. While growing populations challenge the supply of sufficient clean drinking water for cities around the world, the Danish model for urban water supply may offer inspiration on how to supply high-quality water in a transparent and democratic manner.

Population growth and urbanisation is increasingly putting pressure on urban water supply. By 2025, half of the world's population will be living in water-stressed areas according to estimates by the United Nations. Furthermore, the recent global health crisis due to COVID-19 underscores the importance of access to clean water to ensure a healthy population.

Groundwater as a sustainable drinking water resource
In order to overcome water stress in rural and urban areas all over the world, knowledge of quantity and quality of available water resources is important. Groundwater is available in many countries but is often not used or overexploited due to lack of knowledge or poor management. Drinking water supply in Denmark is based entirely on groundwater, which is a sustainable, high-quality source as it is less susceptible to short-term changes in rainfall patterns than surface water. This has led to the implementation of intensive groundwater mapping, monitoring, and protection programmes. Denmark is relatively densely populated with very intensive farming activities, causing a range of challenges in terms of groundwater contamination and eutrophication. An emerging challenge is finding a wide range of both known and new pesticides in groundwater. This confirms the need for both a robust monitoring system and for developing competencies to handle pesticides, which is therefore areas of great focus. At the same time, long-term efforts with targeted information campaigns have created a strong awareness of the origin of Denmark's drinking water. This strengthens national willingness to protect this precious water source.

Securing high quality drinking water with low carbon footprint
The various protection measures in Denmark have resulted in high groundwater quality, which allows for production and distribution of drinking water without the need for disinfection. The groundwater is treated by aeration, followed by single or double rapid sand filtration, which includes an array of complex microbial processes that can remove contaminants such as pesticides. The water sector has an important role to play in reducing carbon emissions globally. Biological rapid sand filters – which have been used, refined, and optimised in Denmark for decades – are now receiving increased international awareness also due to their low carbon footprint. To maintain a high-water quality all the way from well to tap, the system has to be well maintained and constructed of high-quality materials. To support this, a management support system such as 'Water Safety Plans' (DDS), which all major water utilities in Denmark are required to use, is useful.

Reducing urban water loss to meet future demand
An important means to meet the rising demand for drinking water in cities is to reduce urban water loss and Non-Revenue Water (NRW). Today, 25-50 % of all distributed water worldwide is either lost or never invoiced. This poses both a threat to the environment – especially in areas with high water scarcity – and a threat to the financial viability of water utilities due to revenue losses and unnecessarily high operating costs. In Denmark, private-public cooperation has led to advanced non-revenue water technologies such as smart meters, valves, pumps, and pipes as well as tools and methods for planning, monitoring, and managing water loss. Together with an economic incentive for water utilities to reduce their water loss to less than 10 %, the country has achieved one of the world's lowest levels of NRW with a consistent national average of just 6-8 %.

Pursuing increased efficiency through data, digitalisation and innovation Danish water utility companies operate with a high level of transparency, and information on both water prices and water quality is publicly accessible. This transparency has migrated into development of advanced drinking water databases with information on e.g., water quality, daily operational data, distribution systems etc. Data availability sparks efficiency improvements through increased digitalisation, machine learning and data-based decision making. Furthermore, fast, and efficient exchange of data clears the way for public-private-partnerships on innovation.

Smart metering saves 4 million litres of drinking water in water scarce area

Saldanha Bay is located in a water scarce part of South Africa north of Cape Town. During 2017, the region faced one of the worst droughts in its history. The municipality knew they needed to start saving and managing water resources differently to ensure sustainability of their supply to the community. Along with severe water restrictions, the municipality decided to invest in a smart water metering solution with real-time data to bring down water loss. The project started in 2017 with a pilot in Vredenburg where a fixed network with one concentrator and 2,558 meters was installed. Today, the utility is notified by alarms from the meters whenever leaks or bursts occur in their distribution network. Within the first 30 days of operations, 317 alarms were identified and fixed within just hours of occurrence. The real-time monitoring of consumption and water balances has resulted in an immediate drop in the municipality's water loss – more than 4 million litres have been saved so far. After the successful pilot, 30,000 smart meters will be installed over the next years.

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LOCATION

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Reducing urban water losses with short return in investment

Reducing loss of drinking water is a national priority in China, where the Central Government has mandated cities to keep their NRW-levels at 12 % or less. In Changchun, Jilin Province, the Changchun Water Group (CWG) is dedicated to achieving this goal. In 2017, the CWG therefore initiated a collaboration with its Danish sister city, Hjørring and a number of Danish companies. To document the original level of water loss, online monitoring equipment was installed, and digital surveys of flow and pressure was carried out over a period of 11 months in two of the CWG's supply areas. This documented a total NRW-level of up to 35 % with commercial losses accounting for approx. 15 % and physical losses accounting for the rest. To reduce this level, a number of technology and service solutions – well-documented under Danish conditions – are expected to be applied. Reducing NRW to 12 % would lead to an annual value creation of approx. EUR 20 million. Based on experience from the two demonstration sites, the investment in NRW service and technology solutions would have a return on investment of around 3 years.

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LOCATION

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Resilient cities with nature-based solutions

In many cities, the most common means of mitigating the risks from climatic extremes has been increasing investment in conventional — or "grey" — infrastructure, such as dams and levees. However, engineers and decision-makers have come to realise the economic and environmental costs of these solutions. For example, economically, grey infrastructure is often capital-intensive in building, operating, maintaining, and replacing. Furthermore, as it is mainly built to address a specific water management problem, it can amplify risks downstream. Environmentally, grey infrastructure often degrades the quality and quantity of water supply, resulting in ecosystem degradation. As such, there has been a turn toward more long-term economically and environmentally sustainable nature-based solutions that provide equivalent or similar benefits to grey infrastructure. NbS are natural or semi-natural systems that utilise nature's ecosystem services to manage water resources and associated risks. NbS come in a variety of shapes and sizes and are implemented in a wide variety of contexts. For example, nature-based solutions can include green roofs that mitigate urban flooding while providing multiple co-benefits (including improving air quality, reducing the urban heat island effect, and providing a space for social activities). NbS also include constructed wetlands for naturally treating wastewater at the landscape level while lowering carbon emissions and providing a habitat for wildlife. Overall, nature-based solutions increase the water infiltration and storage capacity of soils to reduce the impacts of floods, help purify polluted water, mitigate droughts by releasing water from natural storage features, and appreciate over time with the regeneration of nature and its associated ecosystem services.

Denmark has experienced the consequences of changing climate like many other countries first-hand. Over the past decades, extreme rain events have caused flooding and damage to homes and infrastructure. With the expectancy of more frequent and more extreme events, all Danish municipalities must have a local climate adaptation plan addressing their area's specific climate change-related risks. Furthermore, Danish experiences combining climate adaptation measures with existing urban development show that multipurpose NbS contribute to making cities more resilient and attractive places to live.

CHAPTER 4

Water for smart liveable cities

Proper water management can make a difference for cities that are healthier to live in, resilient towards climate change and more sustainable overall. Digitalisation connects water management to the smart city agenda and increases transparency, innovation and liveability.

Today, more than half of the world's population live in cities. The United Nations (UN) estimate that by 2050, this will increase to 70 %. According to World Economic Forum's Global Risk Report 2020, water-related issues such as extreme weather, natural disasters, drought, and failure to adapt to climate change are among the greatest global risks to the well-being and prosperity of mankind.

Ensuring basic delivery of services for people and production, while at the same time protecting the surrounding water resources is a key task for urban water managers. This must go hand-in-hand with planning and managing well-functioning cities that are resilient, healthy and attractive places to live. Urban water managers all over the world share these challenges. In Copenhagen – the host city of the International Water Association's (IWA) World Water Congress & Exhibition in 2022 – and other Danish cities, water managers are constantly working towards creating better cities, and they are committed to sharing experiences with other cities worldwide.

Water governance, technology development and daily operations in Denmark is based on a high level of trust, engagement and enforcement of regulations which ensure public legitimacy. Over the past 50 years, a professional effort has been made to streamline and further develop the water sector to provide environmental benefits, effectiveness, and efficiency and to support sustainability efforts. And in recent years, to also contribute to an overall green transformation of society in a manner which promotes economic growth and employment.

Megatrends shaping the water sector
A call for **sustainability** is seen all over the world. Many of the Sustainable Development Goals (SDGs) directly or indirectly depend on finding sustainable solutions for water, and there is even a dedicated goal for clean water and sanitation (SDG 6). The SDGs are crucial to the overall vision of Water for Smart Liveable Cities.

A strive for **liveability** through use of multifunctional blue-green infrastructure, which offers many benefits to urban society, including improved local climate resilience through reduced combined sewer overflow and flooding, improved urban amenities, and decreased environmental life cycle impacts of water infrastructure. This strive is embedded in IWA's 17 Principles for Water-Wise Cities.

Digitalisation, which is currently transforming water systems from passive, single-purpose infrastructure elements into active and adaptive units that can respond differently according to situation and be planned, designed, and operated in an integrated manner. This connects the water sector to the broader smart cities agenda, which strives at increasing citizen involvement, and potentially contributes to making the water sector more efficient, more innovative, and more sustainable.

These megatrends are also reflected in the European Union's 'Green Deal', which aims to achieve carbon-neutrality by 2050 and sets ambitious targets for zero pollution, a cleaner environment and improved biodiversity. This is mirrored by the Danish Government's green transition policy which aims to reduce the country's total greenhouse gas emissions by 70 % by 2030 and sets a specific target for the Danish water sector to become energy and climate neutral by 2030.

Harbour baths as catalysts for urban development

The first swimming facility in the Copenhagen Harbour area opened in 1785 and throughout the 19th century several more were established. However, in 1954 the pollution level had increased which – combined with improved knowledge of bacteriology and viruses – let to a ban on all swimming activities in the harbour. The ban lasted until 2002 when the opening of the current harbour bath was made possible through improved wastewater management and the city's efforts to mitigate combined sewer overflows (CSOs). Underground detention structures were established and equipped with transmitters to indicate overflow into the harbour. The transmitters continuously send information to a central computer and based on 3D-modelling, the City of Copenhagen can determine whether the limits in the Bathing Water Regulation have been exceeded and a red flag should be hoisted at the swimming facilities. Citizens can access this information online or via an app. Today, more than 100,000 people enjoy a swim in one of the city's swimming facilities each year as well as participate in recreational activities such as kayak-polo, canoeing, kayaking, and fishing. The area along the city's inner harbour is now one of the trendiest spots in the city and property values have more than doubled.

CONTRIBUTORS

City of Copenhagen, HOFOR – Greater Copenhagen Water Utility, DHI, Krüger, Ramboll, COWI, NIRAS, JDS Architects and Bjarke Ingels

LOCATION

Copenhagen city harbour

Sønæs – climate change adaptation creates attractive park and water landscape

For years, a 10-ha recreational area on the edge of the Danish city Viborg was home to swamped football fields, and the adjacent lake suffered from high amounts of phosphorous and nitrogen. Today, the area has been transformed into a public park, protecting the city against damages from cloudbursts and reducing the amount of nutrients released into the lake. A purification pond was established to simultaneously retain large amounts of stormwater and decrease flood risks. The technical stormwater elements have been integrated in a soft, undulating terrain which retains the natural characteristics of the area. The utility's costs were the same as it would have been for a traditional stormwater project, but the multipurpose design meant that half of the utility's contribution covered elements which also had a recreational value. The municipality and a private funds financed the purely recreational facilities.

The project demonstrates how climate adaptation can accommodate both stormwater management and purification as well as social and recreational benefits. The successful integration of these features has transformed Sønæs into a key destination point for the region.

CONTRIBUTORS

Utility company 'Energi Viborg', Viborg Municipality, lytt and WSP with financial support from Realdania and The Danish Foundation for Culture and Sports Facilities

LOCATION

Viborg

CHAPTER 5

Creating resilient and liveable cities with nature-based solutions

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 maintaining a holistic view, the incorporation of various nature-based solutions can contribute to greener and more pleasant urban spaces with added benefits for the city residents.

Just a few decades ago, most cities in Denmark regarded rainwater as something to dispose of and hide in sewers – not as the valuable resource it actually is. Today the situation is quite different, as water is now recognised as an asset with enormous potential to enhance the daily lives of city dwellers. 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 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 nature-based solutions (NbS) are designed correctly, they can serve multiple functions beyond rainwater management and thereby play a key role in creating 'the liveable city'. This is also in line with the International Water Association's 'Principles for Water-Wise Cities' which among other things focus on Water Sensitive Urban Design that not only reduces the risk of flooding, but also enhances liveability though the presence of 'visible water' in urban design.

The key is long-term planning, as many projects are built to last for decades, or even longer. When deciding upon which projects to implement, city planners and other decision makers need to consider what kind of city they want to have in 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 a dawning understanding that the existing, expert-based service and the passive

citizen role is no longer adequate. 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?**
- **How can we work innovatively with climate adaption and develop new professional skills and approaches to planning?**

Estimating the economic value of NbS by thinking of the multiple uses 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 NbS elements with multipurpose 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. 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 the durability of the solution, the environmental effect(s), aesthetic and recreational aspects as well as possible synergies with other planned construction projects.

The second tool is called 'SPLASH' (in Danish: PLASK) and has been made available free of charge by the Danish Environmental Protection 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 reveals the economic gains from each suggested action on a long-term basis (e.g., the 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 (in Danish only) and can be used by Danish urban water managers to help them plan and prioritise their efforts.


Image credit: SLA

Copenhagen's first climate resilient neighbourhood

An existing neighbourhood in Copenhagen has since 2013 undergone a transformation to become more resilient to the effects of climate change such as strong and heavy rainfall. Once completed, 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 quarter in the North-Eastern part of the city is sitting on an incline, sloping down towards the harbour. Therefore, the main purpose is to retain surface water in the area and infiltrate as much rainwater to the groundwater as possible. Storage capacity is used during heavy rain and cloudbursts. 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 rainfalls locally. During cloudbursts, surface solutions are combined with a conventional split rainwater sewer system, ensuring a controlled transport of rainwater to the nearest harbour.

Taasinge Plads
The transformation of Taasinge Plads was completed in 2014. The area is now a green pocket park that demonstrates how to manage three different types of surface water fractions: Rainwaterfrom roofs, which is used for recreational use and play, rainwater from zero traffic areas, which is used for local infiltration and finally, surface water from roads, which is infiltrated through filter media. As salt is used as ice control in the winter, the road water does not infiltrate the groundwater, but is 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 was finished in 2019 and is a long stretch of road (34,900 m^2 and a roundabout), where green spaces, urban nature and linked surface water solutions have replaced asphalt and pavements. The applied urban nature is inspired by the characteristic wet/dry biotopes found in Copenhagen and uses their processes in a rational way to treat and retain rainwater. Surface water from roads is handled by first-flush solutions, which direct the polluted initial surface runoff (first flush) stemming from heavy rainfall to the existing sewer system, whereas the cleaner, 'second flush' is directed to green surface water solutions. This can be turned off in the winter to avoid salt intrusion into the green areas.

Both projects will be linked to the rest of the holistic system on the cloudburst branch, which will drain this specific area of Copenhagen.

CONTRIBUTORS

City of Copenhagen and HOFOR - Greater Copenhagen Water Utility. Strategic design advisors for the master plan of the area: THIRD NATURE. Advisors for Taasinge Plads: LYTT Architecture and WSP. Advisors for Bryggervangen & Skt. Kjelds Plads: SLA and NIRAS.

LOCATION

Copenhagen

Green climate screen

A neighbourhood in one of Copenhagen's most congested areas, with approximately 45,000 cars passing through on a daily basis, saw an improvement in both noise from traffic, its liveability factor and the at times, heavy rain runoff. Instead of constructing a conventional noise barrier out of e.g., steel or concrete, the vertical green climate screen is based on mineral wool, willow tree and vertically growing plants that specifically accommodate bees and other pollen-dependent insects. The 80 m long and 3 m high vertical green climate screen receives rainwater runoff from 240 m^2 roof surface, which evaporates over time, rather than increasing local groundwater levels or straining the sewers. The screen is sized to handle a 10-year rainfall event – the same as the public sewerage system. A yard-like space now provides the residents with a useable urban space; where thanks to reduced noise from traffic it is easier to conduct conversations and stay in the dry meadow between the apartment building and green screen. The multifunctional green screen aids better air quality, heat island mitigation and enhances urban space activation.

CONTRIBUTORS

Malmos, Aarsleff, TL-Engineering, Niels Lützen Landscape, 3B, AC-Steel, Pile-byg, Danish Technological Institute and University of Copenhagen

LOCATION

Copenhagen

Using rainwater to combat urban heat-island effect with green bus stops

Many cities today suffer from Urban Heat Island (UHI) effect and excess of rainwater runoff in the streets, creating challenges for liveability and causing costly damages to infrastructures. Four cities in Poland have chosen to use the Green Bus Stop as a nature-based solution to reuse rainwater as a resource and contribute to the reduction of UHI effect. The green roof of the Green Bus Stop can retain up to 90 % of the rainwater falling on its surface. The excess of rainwater falls into an underground rainwater container, where the rainwater can be stored and redistributed to the surrounding areas. Vegetated ground boxes around the bus stop can also retain rainwater and create steppingstone habitats for the local fauna (e.g., insects, birds). During intense rain events, the excess storm water is drained with patented internal vents, into the vegetated boxes containing optimised drainage layers. Any excess rainwater from the boxes is led to sewers or nearby green areas. Besides adding ecological connectivity and biodiversity to urban areas, the Green Bus Stop emits less heat than the traditional counterpart does, at times as much as 10°C less.

CONTRIBUTORS

Amphi Consult & FPP Enviro

LOCATION

Poland

Managing rainwater with nature-based solutions

Nature-based solutions is the tool for climate change adaptation and increasing urban biodiversity, supporting a triple bottom line of planet, profit, and people, where the aim is to heighten urban resiliency.

Nature-based solutions (NbS) are measures that encapsulate the notion of water as a resource. At times, NbS are rainwater management, inspired by nature's methods such as permeable pavement and underground storage; at other times the solution is nature-based elements that support biodiversity.

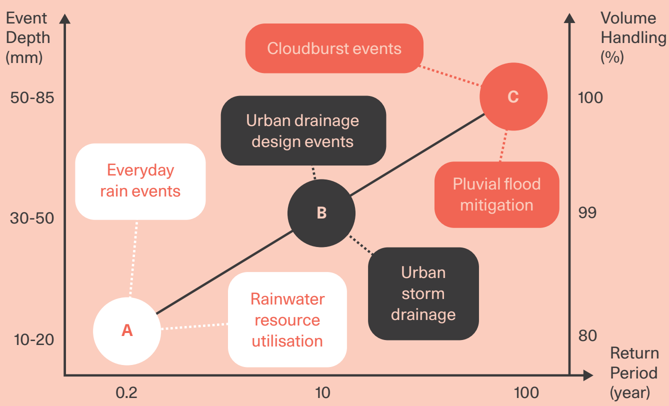
Taking the pressure off the traditional sewerage system
Due to the large amount of impermeable surfaces present in cities, rainwater runoff in a city differs from the runoff pattern that occurs prior to the urbanisation process. The hyetograph below reveals that urbanisation has an impact. The runoff from a city covered with impermeable paving will result in quick and high runoff. As runoff from several catchments arrive at the same time to the same places in the sewers, it creates bottlenecks, heightening the risk of flooding.

By viewing NbS as an extension to the traditional sewerage system, the aim of NbS is to smoothen the runoff hyetograph and reduce pressure on the sewerage system. Runoff from catchments will arrive at the usual bottlenecks at different times. By delaying and reducing the maximum runoff, it is possible to reduce the risk of flooding.

Designing NbS to handle different types of rain events
In Denmark, there is no standard definition of how to design NbS. In practice, the recommendation is that every time you design a NbS, you need to consider everyday rain, design storms and cloudbursts (as illustrated in the 3-point approach method). Often professionals and stakeholders tend to focus on one type of rain event. However, there can be numerous problems in an area related to the different rain events. It is therefore highly important to focus on all types of rain events when designing solutions. NbS are particularly efficient for solving everyday rain challenges but when used carefully, NbS can contribute substantially to solving some of the problems associated with heavy rainfall and stormwater.

Testing NbS 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 implementation. The product might be subject to a European Standard and required to adhere to certain specifications. Or the producer might need to document the water balance of a new NbS element or the permeability of a specific pavement. Denmark has more than 30 years of experience with 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 setup, using up to 30 l/s. Companies from other countries can also use the lab.

A tool for adapting to a changing climate
NbS, when strategically planned, represent a sustainable alternative of a storage/drainage facility compared to traditional rain and stormwater infrastructure. It is expected that more natural structures will drastically decrease the use of concrete structures and energy demanding technologies. Hence, integrating NbS into urban areas not only has the potential to solve climate change challenges, but also meet CO_2 emission reduction needs, mitigate heat islands, and increase biodiversity and public health via the creation of additional green areas in the city.



The 3-point approach
Pinpointing three main domains where decisions related to stormwater management take place.

Examples of typical NbS elements

Clima ponds
To increase biodiversity, ensuring a permanent water table, climaponds handling stormwater directly from the downspouts can be established. The trench in the inlet can be designed, so the inlet flow is smooth, even throughout cloudbursts.

Climate roads
Permeable asphalt is getting more common. The stormwater infiltrates through the surface and the bearing layers underneath, ensuring the water transport through all roadbox.

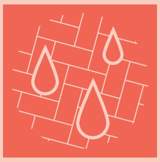
Ditches
A ditch is a narrow channel dug in the ground, typically used for drainage alongside a road or the edge of a field.

Green roof and walls
Green roofs/walls are roofs covered with a multi- layer system consisting of: growth medium, drainage layer and water-proof membrane that delay runoff. The degree of delay and volume reduction increases with the thickness of the growth medium. Green roofs/walls insulate structures from heat and can provide a habitat for certain insects and birds. Retained water evaporates.

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

Irish crossings
Using Irish crossings, the stormwater is able to cross a road, whenever this is needed. The trench is shaped as a pre-immersion in the asphalt itself.

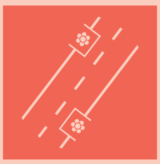
Linear drainage systems
Using linear drainage systems makes it possible to transport stormwater visibly just underneath the road. The linear drainage systems can carry heavy traffic. It can also be in the form of steel drain grates in a driveway or concrete drain grates alongside a motorway.



Permeable pavement
Permeable pavement provides a horizontal surface suitable for walking or driving with (heavy) traffic load but also allows rainwater to infiltrate. The infiltration capacity of the permeable pavement depends on the design and on the hydraulic capacity of the bearing layers underneath.

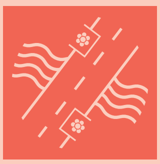
Rain gardens
A rain garden is a depression in the terrain designed to receive, store and filter runoff from roofs or surfaces and is also designed as a specially planted area with selected plants that can cope with dry and with wet conditions.

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.



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.

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.



Underdrains
An overlooked NbS is underdrains. Combined with all other NbS elements, underdrains contribute to distribute the stormwater into - or out from - the NbS, optimising infiltration rate from the NbS or securing a far bigger infiltration area.

Mix of NbS
All the above mentioned NbS can be combined in many different ways. Permeable pavements, linear drainage systems, raingardens, underdrains are all pieces of a larger puzzle, all contributing to the water infrastructure of climate adaptation.

Landscaping resilient courtyards of the future

'The Courtyard of the Future' includes a path crossing the traffic road into the courtyard, a 'garden zone', and a 'landscape zone'. Each have their own plant theme and handle rainwater in different ways.

The entire landscape zone is shaped like a ditch and can contain up to 300 m^3 water, which is enough to handle a 100-year rain event. It has a wilder appearance and invites children to play and follow the water through gutters and ditches. The garden zone is rich with orchards, rain beds, sheds for bicycling storage and a greenhouse for residential use. Here, rainwater is collected in underground water tanks, which allows the residents to reuse the rainwater later on. Additionally, the traffic road outside the courtyard is renovated with a permeable surface, parking spaces and specially developed fascines that allow for necessary tree root growth. Because of its many attractions and functions, the courtyard is popular among the residents and now doubles as a developed urban space and rainwater storage facility.

CONTRIBUTORS

NIELS LÜTZEN Landskabsarkitekter, City of Copenhagen, Kuben Management, Envidan, Labland, Urgent Agency, Court-yard project: Møllerløkkegård, Askøgade project: Dalsgård

LOCATION

Copenhagen

From mangrove swamp to the Lakeside Garden restoring landscape heritage

Once a mangrove swamp, the Jurong region in the South-Western Singapore is being developed into a new business and leisure destination called the Jurong Lake District. The Lakeside Garden is the first phase of the Jurong Lake Gardens, which is the recreational area of the new district. One of the most visible features of the garden is the 'Rasau Walk', which is a winding, barrier-free, waterfront boardwalk along the Jurong Lake shoreline. Other features include grasslands for bird hides, islands for herons and a stream forest, which is a suitable habitat for dragonflies. All fallen trees have been repurposed into site furnishing and landscape features such as bird platforms, habitat logs, pathway curbs or nature trail features - all in order to support and improve biodiversity. There is a nature-inspired play area, which is the largest of its kind in the country. It offers a variety of experiences for children, such as the opportunity to crawl through a 'squirrel's nest' and glide through a tree canopy. Jurong Lake Gardens is a park where people, animals and plants can co-exist and mutually benefit.

CONTRIBUTORS

Ramboll

LOCATION

Singapore

The circular water economy

In contrast to the linear "take-make-consume-dispose" economy, the circular economy aims to decouple economic growth from resource use and associated environmental impacts. The notion of decoupling is that economic output shall continue to increase at the same time as rates of increasing resource use and environmental impact are slowed and, in time, brought into decline. For example, Denmark has significantly reduced its energy and water consumption while the economy has grown by roughly two-thirds since 1990.

In the context of water resources management, the circular water economy aims to design out externalities and keep resources in use, all the while regenerating natural capital. Specifically, the circular water economy optimises the amount of energy, minerals, and chemicals used in the operation of water systems in concert with other systems, optimises consumptive use of water, and uses measures or solutions which deliver the same outcome without using water. Regarding keeping resources in use, the circular water economy aims to optimise resource yields (water use and reuse, energy, minerals, and chemicals) within water systems, optimise energy or resource extraction from the water system and maximise their reuse, and optimise value generated in the interfaces of water systems with other systems. Finally, the circular water economy aims to maximise environmental flows by reducing consumptive and non-consumptive uses of water, preserve and enhance natural capital (e.g., pollution prevention, quality of effluent, etc.), and ensure minimal disruption to natural water systems from human interaction and use. To action the circular economy, water resources managers can implement the circular economy 5R approach of reduce (water conservation and water efficiency), reuse (rainwater harvesting, etc.), recycle (recycling of wastewater for various uses), recover (recover nutrients and energy from wastewater), and restore (use of nature-based solutions to restore environmental flows).

Collaboration is vital to unleashing a global circular water economy's potential. As such, Denmark in 2019 established 14 Climate Partnerships to forge financially viable paths where corporations and governments work in tandem toward energy efficiency, greenhouse gas reduction, and greener industries. Amongst more than 400 tangible recommendations, the Danish Climate Partnership for Waste, Water and Circular Economy suggested in 2020 to strive for an energy and climate-neutral water sector in Denmark by 2030. Denmark is moving quickly towards its target with an emphasis on digitalisation, energy savings, reduction of water loss, efficient collection, and treatment of wastewater.

CHAPTER 7

Urban wastewater treatment and its potential for the city

Globally, 80% of all wastewater is neither collected nor treated adequately. This poses a significant negative impact on both environment and human health. Combined with new challenges from a changing climate, urban wastewater management must move from wastewater treatment to resource and energy recovery.

Urban population growth means wastewater treatment plants (WWTPs) must treat an increasing volume of wastewater in order to secure the health of the local population and water environment. It is important that both large centralised and small decentralised plants can discharge the treated wastewater without harming the recipient, whether it is the sea or a small stream.

Danish WWTPs operate under strict requirements for improved treatment of wastewater. The wastewater sector has spent many years refining and developing technologies that treat wastewater to a high level (through primary, secondary and tertiary treatment) to ensure that it does not contaminate the recipients. Combined with a taxation system which incentivises WWTPs to treat the wastewater beyond the legal requirements, this has resulted in outlet concentrations which contain far less discharged material (only 20-70 % compared to the legal limits), according to a study from the Danish Water and Wastewater Association (DANVA).

Liveable cities depend on successful wastewater management
Sewage collection and treatment systems play a key role in creating liveable cities where recreational activities are possible along the city's harbours, lakes, or rivers. In Denmark, blue-green cities, harbour baths and other recreational facilities would not have been possible without well-managed wastewater infrastructure. Climate change is putting increasing pressure on wastewater infrastructure in cities around the world. A common challenge is to ensure sufficient capacity in the sewer systems to prevent overflows, especially in times of heavy rain. When redesigning the wastewater infrastructure, focus should also be on separating and treating stormwater from roads and other contaminated surfaces to prevent pollution.

Powering the city through energy recovery
In alignment with the country's overall green transition strategy, the Danish water sector aims to become energy and climate neutral by 2030. To fulfil this ambition, a green conversion of the wastewater sector is currently taking place in Denmark. The starting point has been to focus on energy efficiency and energy recovery. Today, several plants are now net producers of energy, where the sludge is used to produce biogas and electricity and excess heat is used in the district heating system. Recovery of energy by using heat pumps is also a new area for innovation and development.

From wastewater treatment to resource recovery
In the future, wastewater treatment needs to be designed in a way which allows for not only energy but also other resources (e.g., phosphorous) to be extracted and included in the circular economy while also ensuring that harmful substances do not reach the recipient. Considering wastewater as a resource is a relatively new perspective and new knowledge and technology is still needed to recover valuable resources in the wastewater on a commercial scale. Research and development in Denmark is dedicated to this field. Advanced membrane technology is already undergoing rapid development, but new specialised technologies are still needed. Sorption technology that enables collection of low concentrations of valuable substances or pollutants will also have a prominent place in the future WWTP. For instance, new bacterial cultures need to be developed to produce base chemicals etc. WWTPs can be seen as production lines, where usable substances e.g., phosphorus and ammonium are removed along the way and other products are removed and further processed e.g., organic matter to produce biogas or base chemicals which can be used for high priced products in the pharmaceutical industry etc. Furthermore, wastewater from industries must be carefully reviewed to ensure that valuable components are separated. Of course, not all substances in the wastewater can be recovered as some will still need to be removed and degraded for the sake of the purity of the products and the discharged wastewater.

WWTP contributes to circular economy in the urban water cycle

Wastewater treatment can contribute significantly to the implementation of circular economy principles in the urban water cycle of Greater Copenhagen. A new project - VARGA – aims to transform the traditional treatment plant Avedøre WWTP (350,000 PE) into a Water Resource Recovery Facility, by implementing several innovative technologies within wastewater treatment, nutrient recovery, and greenhouse gas reduction. Major elements in the project include prefiltration in full scale, P recovery in pilot scale and active reduction of N2O. As part of the project, a Life Cycle Assessment and an eco-efficiency analysis has been conducted. Initial results show that the Total Added Value is higher after implementing the VARGA concept compared to business as usual – without compromising the treatment efficiency. Circular economy is central for the project and the experiences gained further contribute to the Danish national goal of an energy and climate neutral water sector in 2030 as well as the UN agenda on sustainable development.

CONTRIBUTORS

BIOFOS, EnviDan, Unisense Environment, ARC and DTU Environment with financial support from the Danish Eco-Innovation Programme

LOCATION

Copenhagen, Denmark

Solrødgård – a fully covered WWTP designed in harmony with nature

The old WWTP in Hillerød was challenged by a growing city and complaints about bad smell and noise. Building a new traditional plant outside the city would simply cause the problem to reoccur in 30 years. Instead, a 100 % covered WWTP was built in a 52-ha area 4 km from the city centre. The new 'Solrødgård Climate and Environment Park' is home to all of the utility's activities; district heating, waste, water and wastewater. All processes are encapsulated and equipped with advanced DIMS control systems, which provides maximum control of odour and nitrous oxide emissions. Surplus energy goes to the district heating grid and helps displace fossil fuels. The vision was to draw inspiration from nature's integrated systems where everything is produced from renewable energy sources. The plant's exit strategy is to leave a well-functioning wetland in 40-60 years' time, where the biological and recreational aspects are strengthened compared to today. The master plan is designed with respect for the surrounding nature with the functional areas as 'pockets' in this contiguous landscape. A new neighbouring district is under development with a hospital, railway station and 5000 homes and businesses. Real estate prices are up to 30 % higher than if the plant had been a traditional WWTP.

CONTRIBUTORS

Hillerød Forsyning, Krüger, Stjernholm, DHI, WSP, Gottlieb Paludan Architects and Henning Larsen Architects

LOCATION

Hillerød

CHAPTER 8

Wastewater as a source of clean energy

Reducing the costs for collection and treatment of wastewater is an important issue for water utilities around the world. To achieve reductions, focus must be on cost efficiency, improvement of the wastewater treatment plants' energy self-sufficiency and possible sale of surplus energy to the grid. In Denmark, this means heading for energy producing wastewater treatment plants and an energy neutral water cycle.

On a global level, the International Energy Agency (IEA) estimates that the water sector accounts for approximately 4% of the world's total electricity consumption and wastewater treatment alone accounts for a quarter of this. Meeting the UN's target of halving the proportion of untreated wastewater by 2030 could therefore put significant upward pressure on energy demands, unless energy efficiency and recovery technology is applied at the treatment facilities. In Denmark, the water sector's share of the country's total electricity consumption has fallen to 1.9% as more and more utilities have realised the great potential for energy savings and energy recovery in wastewater treatment. Most wastewater treatment plants (WWTP) in Denmark have invested in an assessment of different ways to reduce their energy consumption. These include implementation of online monitoring and energy management systems, replacement of surface aeration by more energy efficient bottom aerators and different operational approaches.

New focus towards energy self-sufficiency
In the recent years, Danish water utilities have moved beyond simply focusing on reducing energy consumption to also focusing on energy production. The first goal is typically to become energy neutral, and the second goal is being able to sell excess electricity and heat to the local electricity and heating companies. Some of the largest water utilities are already well on their way. In Denmark's second largest city, Aarhus, the Marselisborg WWTP produced 30% more electricity than the amount consumed by the plant itself on average between 2015-2019. At the same time the treatment plant produced 75% more heat than it consumed, resulting in a total net energy production of 150%. In Odense the Ejby Mølle WWTP achieved similar levels of total net energy production. As a next step, the water utilities in both cities are now looking into recovering the heat from the wastewater before it is discharged with the additional benefit of reducing the temperature impact on the receiving waters.

"Danish water utilities will contribute to Denmark's goal of 70 % CO_2 reduction in 2030 through energy recovery and a significant reduction of energy consumption from wastewater treatment. At Aarhus Vand, we have reduced our GHG emissions by nearly 80 % since 2008. This shows that there are great benefits to be gained by working systematically with energy optimisation." Lars Schrøder, CEO, Aarhus Vand and Vice Chairman of the Danish government's Climate Partnership on Waste, Water and Circular Economy.

Solutions depend on plant design and context
More and more WWTPs in Denmark are upgraded with anaerobic digestion of sludge and/or co-digestion with organic waste products and they utilise the produced biogas to generate electricity and heat. The optimal solutions depend on the individual plant design and the possibilities for either internal use or external sale of the produced electricity or heat. The tipping point for which the implementation of anaerobic digestion is financially viable depends on the development of new technologies and changes in the price structure for purchase and sale of electricity and heat. In Copenhagen, a technology is currently under implementation which allows for upgrading biogas to a quality which is similar to natural gas or vehicle fuel.

Heading for an energy and climate neutral water cycle
By introducing new technologies to reduce energy consumption and improve energy production, it is the goal that the utility companies can provide an energy neutral water cycle. In this scenario, the energy production from the utility's treatment plants is able to cover the energy consumption related to its groundwater extraction, water treatment, water- and wastewater transport as well as wastewater treatment. In 2019, VCS Denmark demonstrated a 100% net energy production for the water cycle in the entire service area for the utility, covering all 8 WWTPs and the production and distribution of water in the City of Odense, Denmark's third largest city with a population of 200,000. The Danish water sector has set a common goal of becoming energy and climate neutral by 2030. In 2020, this goal was implemented in the government's national climate plans.

Benchmarking and innovation lead to lower costs
The innovation of new wastewater treatment optimisation and cost-efficient solutions for both the construction and operation of infrastructure is largely driven by the fact that Danish water utilities are subjected to mandatory benchmarking on operational parameters and cost efficiency across the water sector. Innovation projects are often based on collaboration across governmental bodies, water utilities, consulting companies, technology suppliers, universities and research institutions. The Danish Water and Wastewater Association (DANVA) also carries out its own voluntary benchmarking each year.

Energy positive operations at Downers Grove WWTP

The Downers Grove Sanitary District in Illinois has dedicated significant resources to reduce its energy footprint. Improvements in process efficiency including plant automation, aeration system improvements, upgrades to HVAC and building management systems, and variable frequency drives have resulted in a 30% reduction in electricity usage at its wastewater treatment plant. The remaining electricity used by the facility is produced on-site using a biogas driven combined heat and power system. Biogas is produced by co-digesting hauled food waste and sewage sludge generated on-site. The biogas is used as fuel to drive an engine-driven electric generator. Furthermore, heat recovery in the form of circulating hot water is used for plant process heat. The CHP plant was installed in 2017 with a payback time of 3.5 years. Total Infrastructure investments of roughly USD 5 million are expected to have a 10-year payback period. In 2021, the plant produced enough energy to supply its own operations, and feed energy back to the grid.

CONTRIBUTORS

NISSEN energy Inc., Landia and Downers Grove Sanitary District Wastewater Treatment Center

LOCATION

Illinois, USA

Achieving 150% energy self-sufficiency

Over the past five years, the water utility Aarhus Vand has put great focus on energy savings and energy production. At its Marselisborg WWTP, the utility has implemented energy-saving technologies such as an advanced SCADA control system, a new turbo compressor, sludge liquor treatment based on the anammox process, as well as optimised the fine bubble aeration system. This has resulted in a reduction in power consumption of approximately 1gwh/year which corresponds to about 25% in total savings. During the same time period, the energy production has been improved through implementation of new energy efficient biogas engines (CHP), resulting in an increase in electricity production of approximately 1 gwh/year. Furthermore, a new heat exchanger has been installed with the aim of selling surplus heat to the district heating grid, which represents approx. 2 gwh/year. Between 2015 and 2019, Marselisborg WWTP had an average total energy production of 9.6 mwh/year and an energy consumption of 6.4 mwh/year, equivalent to a net energy production of 150%. Most of the installed technologies have a payback time of less than 5 years.

CONTRIBUTORS

Aarhus Vand

LOCATION

Aarhus

CHAPTER 9

Resource recovery from wastewater

Traditionally, wastewater has been considered a liability, meeting increasingly stricter standards for wastewater discharge with increases to the costs of treatment. Utilising the resources in the wastewater can prove an important step in the opposite direction, considering wastewater treatment plants as resource recovery facilities.

Considering wastewater as a resource is a relatively new perspective. However, today it is widely recognised that the organic content in the wastewater can be a resource for energy production, the nutrients - especially the phosphate – can be used for fertiliser production, and the water itself can be cleaned to such high standards that it can be reused in a number of ways – e.g. for flushing toilets or laundry machines.

Utilising organic content
As described in the previous chapter, organic material in wastewater can be separated and utilised for biogas. This has been standard procedure in larger wastewater treatment plants for a while, and new water treatment technologies and more efficient equipment for combined power and heat production have increased the potential. Organic content can be saved for energy use in biogas production if new carbon saving processes for nutrient removal are introduced. Denmark has vast experience in optimising the use of carbon and is now also gaining know-how in nutrient recovery.

Phosphorus recovery from wastewater sludge
Phosphorus is a scarce resource with great value for the agricultural sector. Phosphorus is accumulated in the wastewater sludge and in internal side streams and if treated properly, it is possible to change this into a controlled harvesting of a pure fertiliser. The recovery of phosphate for fertiliser enables a multitude of possibilities for sludge handling, not wasting the valuable phosphorus to end up in low quality form as ashes or mixed with heavy metals and micro pollutants from wastewater in the sludge. The phosphorus product struvite has been approved in Denmark as a fertiliser product. Two full-scale plants in Aarhus currently forms the background to increase the current P-recycling from approximately 15% to 25%. Once these are completed, the total phosphorus recovery throughout the catchment area is expected to be increased to approximately 22 tonnes P/year or approx. 0.5 tonnes of struvite fertiliser per day.

Benefits of using struvite fertiliser compared to sewage sludge
The solution of recovery of struvite as a pure mineral phosphorus fertiliser offers several advantages in comparison to the application of sewage sludge on agricultural land:

- **Environmental benefits: Struvite is significantly cleaner than the sewage sludge in terms of heavy metals. The content of the typical problematic metals such as lead, cadmium, nickel, chromium copper and zinc is a factor of 20-100 times lower in relation to the content of phosphorus.**

- **Reduced risks of groundwater contamination: Phosphorus from wastewater can be utilised for agriculture without risking a contamination of soil and groundwater with the accumulation of heavy metals and other harmful substances to the environment, which makes it possible to carry out subsequent groundwater exploitation in the same area.**

- **Greater flexibility in terms of usage and storage: Struvite is much more flexible as a fertiliser as the material is concentrated, comes in a dry form and is possible to store for longer periods of time.**

- **Economic benefits: Struvite can be sold at a high price (up to EUR 335 per tonne)**

- **Ready-to-use as fertiliser: There is no need for further processing as the material is ready to use and can be mixed with other mineral fertilisers if there is a need for changing the level of potassium or nitrogen.**

- **Better suited as dedicated fertiliser: Struvite has shown excellent properties for fertilising specific plants and crops with need for extra phosphorus and magnesium. Golf courses and plant nurseries are good examples of this.**

- **Low solubility: Struvite has a low solubility, making it suitable for depot fertiliser where the phosphorus content is released slowly in line with the needs of the plants. This is an advantage for fertiliser spreading without danger of dissolution into groundwater or surface water.**

- **Lower cost: Sludge from P-recovering plants, which is low on phosphorus, can be used as a bio-fuel without it resulting in a loss of phosphorus to ashes. The cost of regaining phosphorus from ash is much higher than extraction as struvite from wastewater.**

Struvite based P-recovery is the state-of-the-art for phosphorus recovery from wastewater. The technology is still under development and Danish wastewater utilities and companies are working on developing even more efficient process solutions.

Phosphorus recovery from wastewater

In 2015, the water utility Herning Vand Ltd. Opened the second P-recovery plant in Denmark, which recovers phosphorus from a concentrated side stream in the wastewater treatment plant. For several years, the WWTP suffered from struvite scale build-up in its sludge and wastewater pipes, causing problems for the dewatering process of sludge and biogas production. In addition to solving the problem, Herning Water wanted to exploit the potential of recycling the struvite into agricultural fertiliser. A solution based on controlled precipitation of struvite was therefore designed, and a full-scale recovery plant of the phosphorus compound struvite was built based on previous test results from Aarhus Vand at its plant Aaby WWTP. At both plants, the struvite is precipitated as a 'ready-to-use fertiliser' and sold to a fertiliser company. An official approval of the product as commercial fertiliser has been obtained for the struvite produced at both the Herning and Aarhus plants under the name Phosphorcare™. The operational savings at the treatment plants and the expected revenue from sale of struvite is expected to result in a payback time of 10-12 years.

CONTRIBUTORS

Herning Vand, Aarhus Vand, Stjernholm, Grundfos, Norconsult, Suez and SEGES

LOCATION

Herning and Aarhus, Denmark

Resource recovery for the future

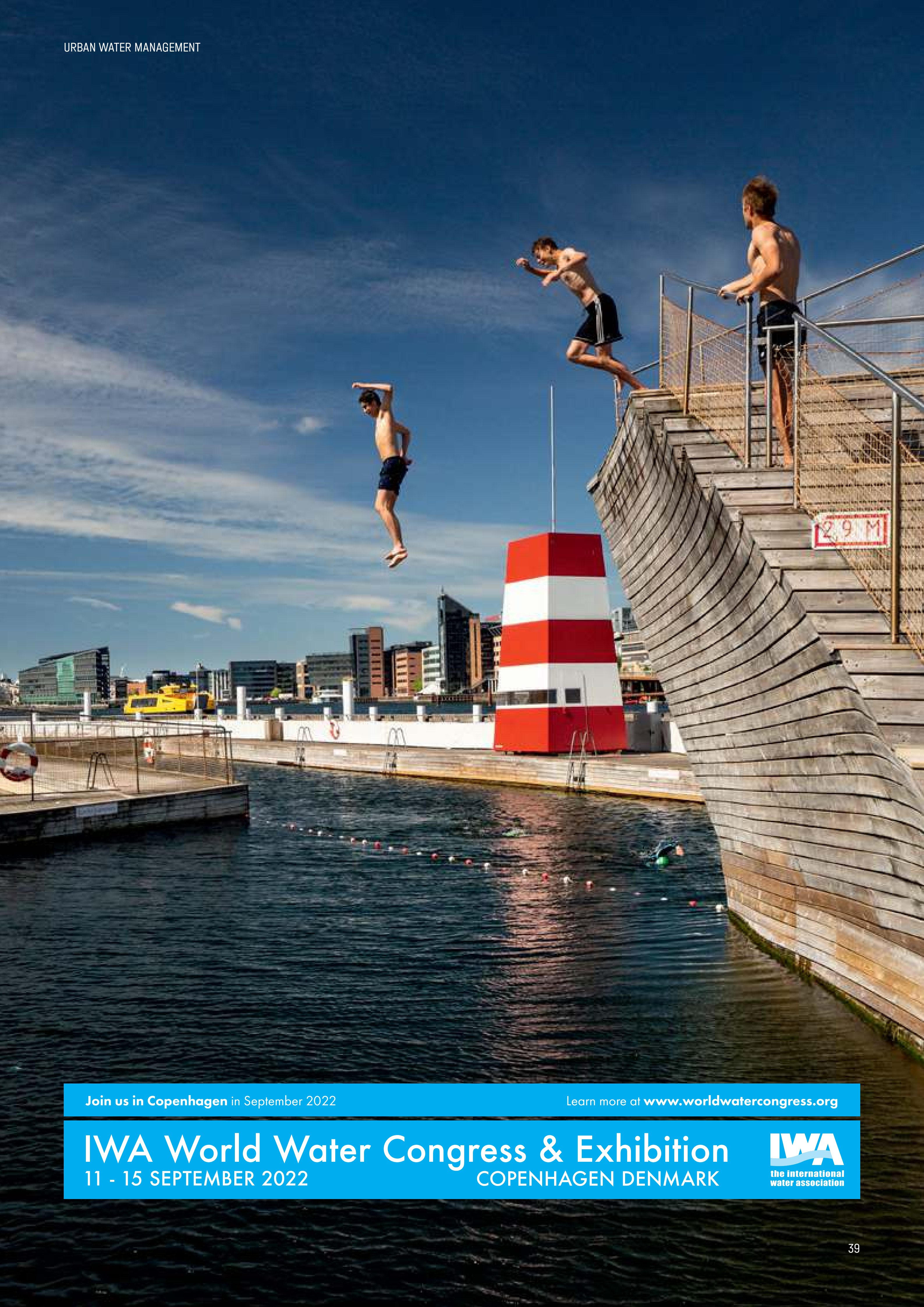
Billund Biorefinery (BBR) is a resource recovery plant that integrates waste management and wastewater treatment. BBR produces clean water, energy for the local public district heating and power grids, as well as high quality natural fertiliser for the surrounding agricultural areas. The wastewater catchment areas consist of combined and separate sewer systems and the waste comprises of sorted organic waste from households and local industries. BBR integrates wastewater treatment with anaerobic digestion and other innovative processes like Exelys™ (thermal hydrolysis) and Anitamox™ (Anammox process). These, along with STAR™ advanced online monitoring and control system, minimises energy usage and maximises energy production and effluent quality. As a result, effluent nutrient concentrations (N, P and COD) have been reduced to a quarter of the level required by Danish legislation and the plant operates with a 200% energy surplus relative to the plant's own consumption. BBR is a public private partnership and was financially supported by the Danish Eco-Innovation Programme (MUDP) and the Danish Water Sector Foundation (VTUF).

CONTRIBUTORS

Billund Vand og Energi A/S and Krüger Veolia A/S

LOCATION

Billund, Denmark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