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Groundwater-based water supply

How groundwater can aid in securing water supply amidst population increases and climate change

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the international water association

GROUNDWATER BASED WATER SUPPLY

How groundwater can aid in securing water supply amidst population increases and climate change

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FRONT PAGE PHOTO

VCS Denmark

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MINISTER FOREWORD

Ensuring tomorrow's drinking water supply by protecting groundwater supplies

The value of freshwater resources
Drinking water is a valuable resource and in many countries, the lack of access to a clean source poses severe challenges to human health and ecological nature as well overall development and growth. The UN estimates that almost 30 per cent of the world's population lack access to safely managed drinking water. With increasing populations and increasing climate change affecting surface water resources and replenishment, this is likely to increase. Understanding the geological aspects of the underground water resources may help to alleviate the water scarcity challenge. Using groundwater reservoirs as savings accounts to ensure a reliable water supply can be the way forward.

Groundwater based water supply
In Denmark, we get most of our drinking water directly from the ground. We carefully protect and manage the resource sustainably and have rules and laws put in place to protect and regulate the surface areas, where groundwater is created, and we have a strict regulation of pesticides. This ensures that our water only has to undergo minimal treatment before it comes out the tap ready to drink. Over past decades, our public entities and private businesses have together built some of the world's most extensive expertise within sustainable groundwater use and management. This expertise has been continuously developed from 1998, where we initiated an ambitious groundwater surveying programme to map the locations, distribution, and interconnectedness of the Danish groundwater resources. Doing so helped us identify the areas where our groundwater resources were vulnerable to land use and establish area-specific protection zones that are continuously monitored and adjusted. Our learnings have resulted in state-of-the-art surveying technologies and techniques that allow us to efficiently locate resources and help build necessary modelling and monitoring systems to ensure integrated water resource management and decision-making for sustainable groundwater management and use.

In short, we protect rather than purify, and pride ourselves on having some of the cleanest drinking water in the world. The groundwater belongs to everyone and the right to abstract and use it by utilities and private persons is granted by our local, municipal authorities. It enables better assurance that our groundwater is protected from pollution, overuse and making sure that access is available to everyone. Our utilities ensure the clean, safe, efficient, and sustainable abstraction and distribution by the smart usage of sensors and data that ensure effective responses to any deviation from the high quality provided.

Join us at the IWA World Water Congress & Exhibition in September 2022
Denmark will be hosting the IWA World Water Congress & Exhibition in September 2022. I invite you to join us for a week of interesting discussions on how we can shape our water future together. I am sure you will enjoy our clean and tasty drinking water, and perhaps even try a swim in one of our harbour baths.

Until then, I hope you will be inspired by this white paper.

"WATER IS ESSENTIAL FOR ALL LIFE. WHETHER WATER IS USED IN THE PRODUCTION OF FOOD OR AS DRINKING WATER, THE QUALITY IS OF GREAT IMPORTANCE TO ENSURE HUMAN HEALTH."

Lea Wermelin
Minister for the Environment, Denmark

IWA 2022 CONGRESS PRESIDENT FOREWORD

Groundwater: a fascinating element with enormous potential for further development

Groundwater flow is so slow that even specialists have difficulties in fully comprehending the timespan of the entire cycle. The slow flow has positive and negative effects. On the one hand, groundwater undergoes a very efficient purification process through natural filtration in the unsaturated zone and in the subsoil, from the time that it falls as rain, until it ends up in the aquifers. On the other hand, if groundwater is polluted, it takes years or even decades to remedy, as pollution usually originates in more or less distant "sins of the past". Effects of the implementation of today's groundwater protection measures will not be immediately assessable – perhaps not even in our lifetime. Nonetheless, the objective of securing clean groundwater for future generations demands action now. The recognition of this fact requires highly enthusiastic specialists and brave politicians.

Groundwater is "invisible". As a rule, groundwater investigations and mapping always struggle with a lack of data. However, in relation to the estimation of sustainable resources and assessment of the vulnerability of the aquifers, the rapid development and innovation in geophysical methods combined with more and more refined hydrogeological models have significantly reduced the level of interpretation required in the past.

Today, groundwater is a vital resource that provides almost 50 per cent of the world's drinking water and approximately 40 per cent of water for irrigation purposes. In rural areas, groundwater often presents the sole reliable resource for drinking water – both from a technical and hygienic perspective. However, the potential of groundwater resources as a means to ensure a more sustainable and resilient water supply in urban areas should not be underestimated.

In 2022, we have a dedicated focus on groundwater. On 22 March, World Water Day, the theme is "Groundwater: Making the Invisible Visible". Later in 2022, Denmark will host the International Water Association's biennial World Water Congress & Exhibition, where groundwater features prominently in the programme. The latter is no coincidence, as Denmark is one of the very few countries in the world with close to a 100 per cent groundwater-based water supply. In all areas of management, development and innovation relating to groundwater, Denmark offers some of the world's most specialised, tested and documented expertise, with knowhow that spans centuries.

In order to fulfil SDG 6 before 2030, leaving no one behind, we must direct significantly more attention to the enormous potential of groundwater.

Denmark is happy to share its groundwater expertise with you, and you can find inspiration in the following pages.

Anders Bækgaard
Congress President, IWA World Water Congress & Exhibition 2022, Copenhagen

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CHAPTER 1

Groundwater as a reliable source of high-quality drinking water

In a time where climate change, regional and local water scarcity and droughts are frequent and increasing, groundwater can be a sustainable source of high-quality drinking water. Whether relying on a groundwater supply entirely, or as a supplement to surface water, the potential is considerable.

The UN estimates that 1 billion people worldwide lack access to clean drinking water and have identified the need to ensure access to clean water and sanitation for all, as one of its Sustainable Development Goals (SDG6.1). Providing enough water for a growing population and increasing industrial production is a critical issue experienced in many countries and regions around the world. In addition, climate change is affecting global rainfall patterns and water distribution, in some cases resulting in population displacement due to water scarcity. Groundwater, a more protected subsurface water resource, can play a key role in ensuring stable access and meeting increasing demand.

Water supply from one or several sources

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 taken into account when planning for water supply. It is estimated that there is approximately 60 times more groundwater than fresh surface water from lakes and rivers on earth. Hence, there is undeniable value to be leveraged by managing this important source of drinking water. Whether it is the sole source of drinking water or a supplement to other sources, utilising groundwater creates many advantages. Whether it is ensuring water-related regional growth and development, restoring ecosystems or increasing life expectancy, groundwater can provide a stable and sustainable source of high-quality water when managed properly.

By incorporating groundwater into the water, supply mix or as the primary source, water utilities can benefit from long-term planning for water security and better meet the increasing demand for water. Whereas surface water is vulnerable to climate change and possible surface pollutants, groundwater can be a stable and high-quality source that generally requires less treatment before distribution.

At times, the production industry, food and beverage companies as well as the agricultural sector face conflicts over access to water with other sectors or the local population. If groundwater is added as a new water source, this may help alleviate these conflicts as well as contribute to economic growth and development. Groundwater mapping and sustainable management of the aquifer ensure improved knowledge of available water resources. When resources are monitored and managed, businesses and local communities can benefit from improved water efficiency, better water quality and security of supply

Sustainable groundwater management
A holistic understanding of various water supply sources as 'one source' enables better integrated and more sustainable management of the overall supply. Groundwater aquifers are naturally – although to some extent protected underground – influenced by the surface water above, such as rivers and wetlands, by specific land use and at times nearby coastal and marine environment. Over time, waste products from e.g., agricultural, or industrial land use, polluted streams or saline intrusion from marine environments can seep into an otherwise healthy aquifer. Equally, excessive abstraction, often common around agricultural or industrial land use, can further have a negative effect on quality. Adaptive measures to secure a balance between abstraction and recharge such as Managed Aquifer Recharge (MAR) are taking place across the globe, and the appropriate conditions for MAR can be mapped by geophysical equipment. Inadvisable land use can be alleviated through land banking and afforestation e.g., near wells.

Treatment of quality affected groundwater
Most groundwater needs little treatment e.g., aeration and filtration to remove iron and manganese. When resources are monitored and managed, businesses and local communities can benefit from improved water efficiency, better water quality and security of supply In some instances, the groundwater naturally contains minerals to an extent that makes it unsuitable for drinking water (for example high levels of fluoride or arsenic). Furthermore, an aquifer can deteriorate from excessive abstraction of groundwater permanently damaging the groundwater. Despite groundwater being better protected in comparison to other drinking water sources, groundwater pollution is a growing problem due to pesticides and/or industrial pollution that penetrate through the topsoil down to the aquifer. In some cases, the pollutant can be eliminated by dilution or removed using more advanced treatment methods, once again raising the water quality to drinking water standards. However, both alternatives challenge the economic benefits of a naturally clean groundwater-based water supply.

For an overview of the Danish water supply structure, see chapter 9 **"Regulation, pricing and benchmarking"**

Credit: Rambøll

CHAPTER 2

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, when planned as part of overall supply operations or, when prolonged droughts pose a threat to the surface water supply.

Collecting data and generating knowledge is key

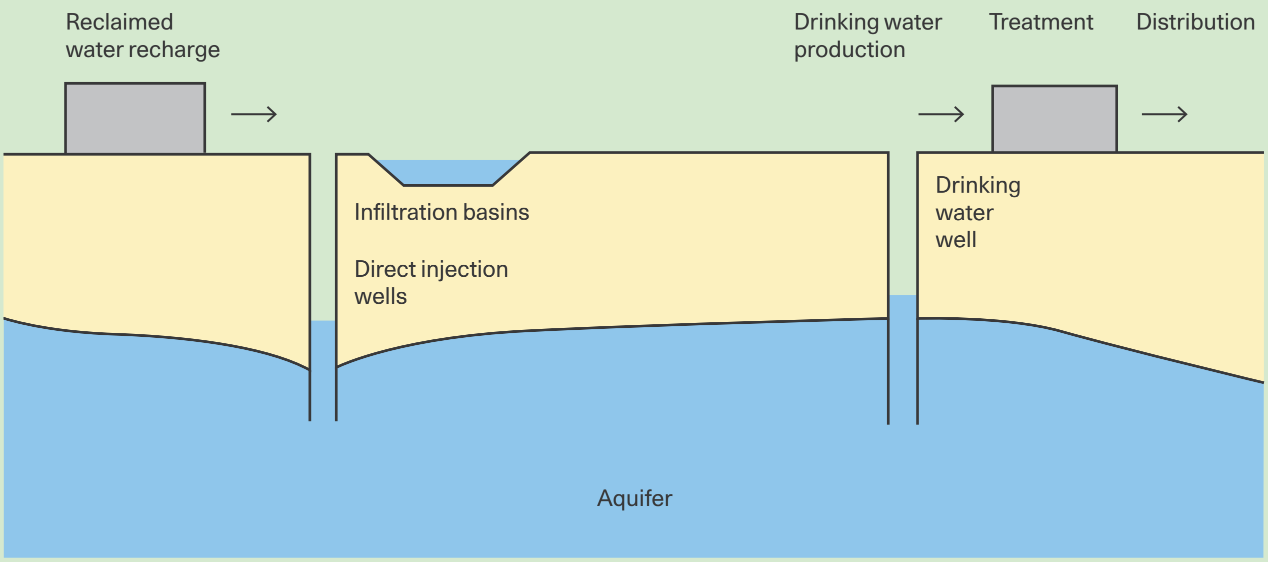
The first step towards sustainable groundwater management is to obtain enhanced knowledge and understanding of the aquifer system such as the extent of the aquifer, whether the conditions present in the aquifer naturally protect against pollution or leave the aquifer vulnerable to land activities on 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, thus 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 thus, more qualified knowledge. When decisions are to be made regarding sustainable groundwater management, this type of qualified knowledge forms 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.



Managed aquifer recharge can be performed through direct injection wells or through an infiltration basin

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.

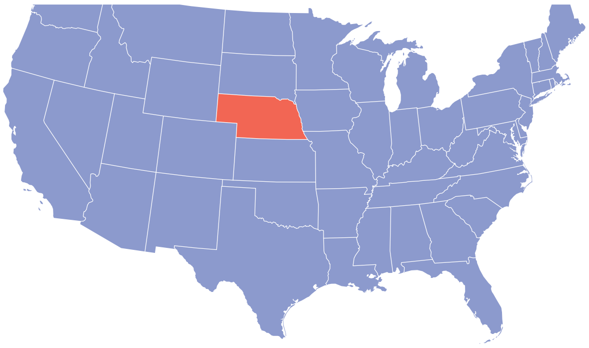
CONTRIBUTORS

Saldanha Bay Municipality
SkyTEM
Institute for Water Studies - University of the Western Cape

LOCATION

Saldanha Bay, South Africa

Visualising digital data to aid groundwater and management



Due to a growing amount of groundwater data such as drill logs, AEM- and GIS-data, The University of Nebraska-Lincoln's Conservation and Survey Division needed an easily accessible, web-based data management platform for storing, sharing, and visualising data.

The Nebraska GeoCloud (NGC) allows several institutions to archive, access and consolidate the data. It includes databases, webservers and web interfaces, which have been developed to meet the storage and distribution needs of model builders and models users. The NGC includes key guidelines and standards for quality assurance, usability and uniformity of data to ensure reliability. The web-based platform enables the Nebraskan geoscientists to build models with direct, importable access to the large amount of relevant data, when building models in GeoScene3D or GIS-applications. The NGC was custom developed, based upon decades of Danish groundwater data management experience.

This state-wide web-based platform is an important part of the water resource assessment and management. The modelled and visualised data are an essential tool for decision-makers, allowing them to make informed decisions for their water resource management, securing water for food and future generations.

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Conservation and Survey Division

LOCATION

Lincoln, Nebraska

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.

CONTRIBUTORS

Rambøll

Orange County Water District (OCWD)

LOCATION

Orange County, California

CHAPTER 3

Sustainable utilisation of groundwater

Minimising stress on water resources and the energy consumption used to provide drinking water must be addressed at all steps throughout the drinking water production cycle. This involves abstracting the necessary quantity of water only, without abundant consumption or losses.

Proper groundwater protection requires knowledge on the formation of groundwater. An important tool to estimate the catchment areas of the wells is groundwater modelling. Modelling can be used to provide information for optimised groundwater protection and can be used in the planning of groundwater abstraction. Furthermore, modelling can help estimate the quantities that can be abstracted sustainably from an aquifer, hereby eliminating the risk of over-abstraction with possible lasting, detrimental effects. When addressing the establishment of an actual well field however, more processes are involved.

Optimised abstraction and well field management

The production of groundwater is – from a hydraulic point of view – the most complicated part of managing groundwater supply. Natural processes such as groundwater flow in the aquifers must interact with technical installations such as wells, pumps, pipes, and valves. The interaction between all these elements and how they influence each other can be rather complicated when dealing with larger wells. Many Danish utilities use the Danish developed Well Field Model, which takes all these aspects in consideration, and use the model to plan the abstraction from the reservoir with considerations of groundwater reservoir preservation, acceptable water quality and optimisation of energy consumption. Furthermore, the Well Field Model is an excellent tool for planning a reconstruction or design of a new well field.

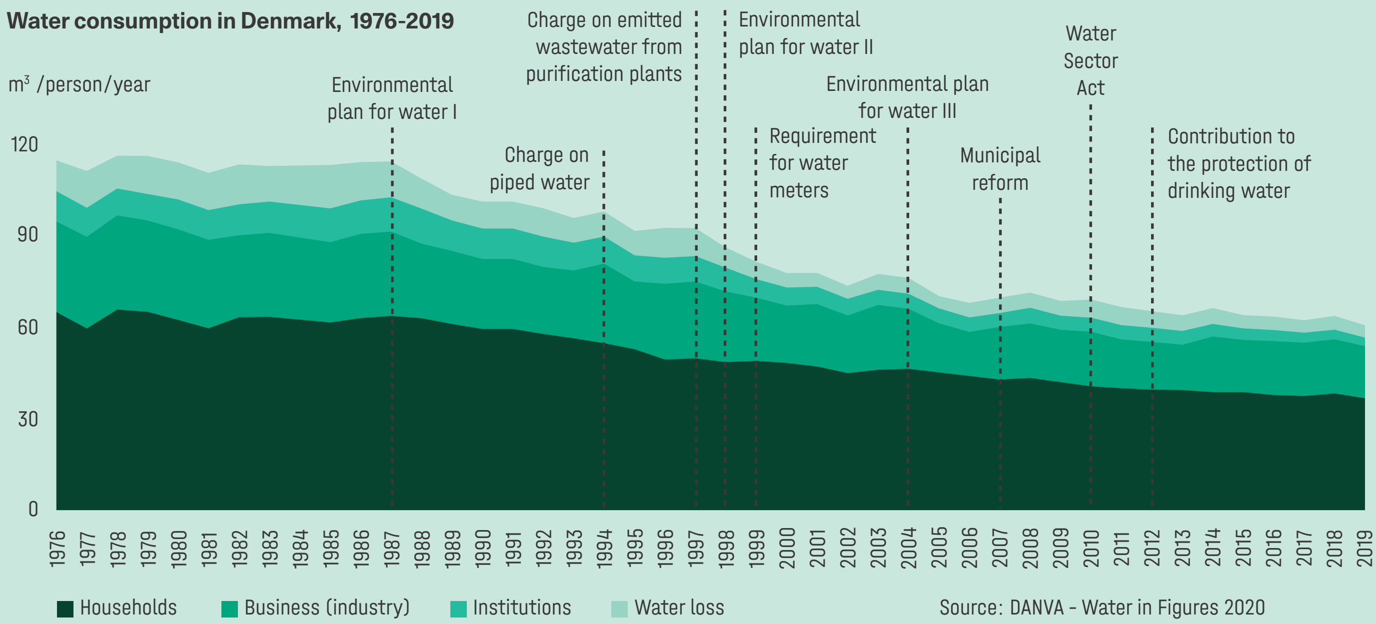
The operation of a well field is controlled by a SCADA system, for which the model provides the necessary analysis for determining the set points. Abstraction of groundwater is customarily based on speed regulated pumps, operated by SCADA supervision and control. The control includes monitoring online data from borehole water level sensors and flow meters. The SCADA monitoring and data collection is further used in reporting compliance in regard to abstraction permits to the authorities.

Groundwater supply conservation measures

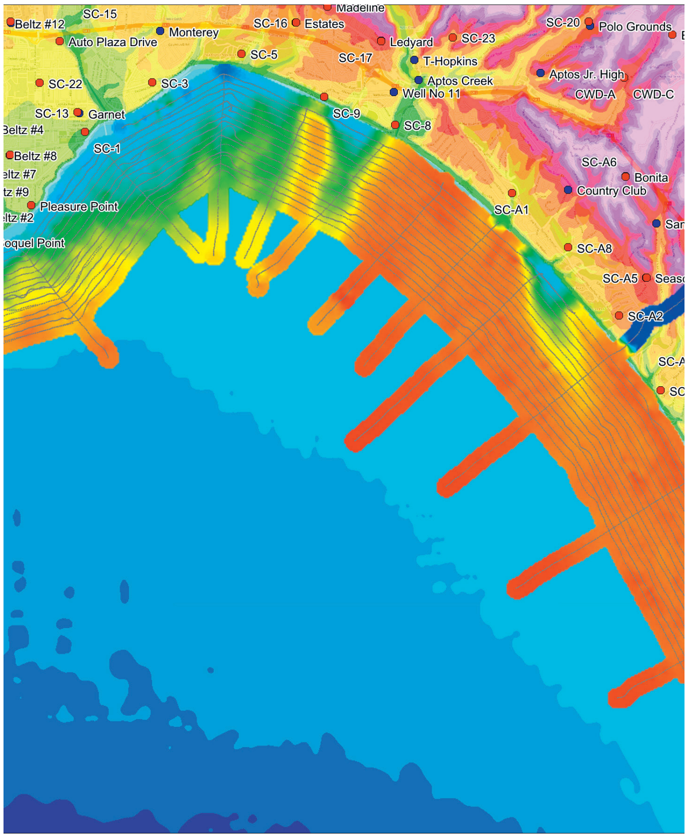
In Denmark, conservation strategies have been put in place to reduce the demand for water. Benchmarking measures performed based on major water utilities in Denmark show that domestic consumption is as low as 101 litres per person per day. A combination of education on conservation and increased environmental awareness as well as an increase in water prices have been highly efficient tools, paving the way for a reduction in water consumption. Household metering is mandatory, and now more than half of the meters installed are 'smart meters', enabling remote meter reading whilst also contributing to the utilities' supervision of potential water loss in the distribution network.

Equally, another closely related aspect of sustainable groundwater abstraction is the minimisation of water loss in the distribution network supplying water to the consumer. In Denmark, the national Non-Revenue Water is as low as 6.5 per cent. This has been achieved by efficient asset management of the distribution network, planned rehabilitation has been conducted and District Metered Areas widely introduced. This has also enabled advanced pressure management of the network, hereby avoiding pressure-introduced leakages as well as resulting in energy savings.

A sustainable use of groundwater requires a number of coordinated activities within the fields of hydrogeology, well field implementation, abstraction methodology, monitoring good utility management and continued emphasis on minimising water loss.


Water consumption in Denmark, 1976-2019
m³ /person/year
120
90
60
30
0
Environmental plan for water I
Charge on piped water
Charge on emitted wastewater from purification plants
Environmental plan for water II
Requirement for water meters
Environmental plan for water III
Municipal reform
Water Sector Act
Contribution to the protection of drinking water
1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019
Households
Business (industry)
Institutions
Water loss
Source: DANVA - Water in Figures 2020


Credit: VCS Denmark



Managing risk of saltwater intrusion in coastal water-scarce basins

The Soquel Creek Water District (SCWD) in Monterey Bay, CA is experiencing a shortage of freshwater resources. Surrounded by mountains and the Pacific Ocean, saltwater intrusion has become a primary concern. This has become a widely recognised issue in growing cities along the coast and highlights the importance of aquifer management. For SCWD, understanding the saltwater-freshwater interface in the aquifer is crucial and can be done using the geophysical airborne electromagnetic method (AEM).

To better understand this saltwater-freshwater interface, SCWD used an AEM survey to produce 3D subsurface imagery. Flown by a helicopter towing the sensor as a sling load, an AEM survey measures variation in conductivity in the subsurface, which translates to salinity. Due to safety and possible data disturbance by power lines and other man-made structures, the survey was flown along the coast and 1.5 km offshore.

In certain areas, the results showed freshwater pushing the saline water out into the bay. In other areas, saline water was close to extraction wells. To substantiate the AEM results, SCWD measured salinity in screened intervals at different depths. The correlation of these two data sets ensured SCWD had an accurate snapshot of the saltwater-freshwater interface. The district plans to conduct a second survey after a period of five years to see if changes in recharge or extraction rates have changed the location of the saltwater-freshwater interface.

CONTRIBUTORS

Rambøll
SkyTEM

LOCATION

Santa Cruz, California

Abstraction optimisation using a wellfield model

The water utility, VCS Denmark, has an annual production of 9.6 million m^3 of groundwater. Since 2004, they have used wellfield models to optimise the abstraction of groundwater from their seven wellfields, which are treated at five waterworks. The first-generation wellfield models were used to redesign all wellfields, both in regards to the raw water network, submersible pumps and determining the optimal production modes from an energy saving prospective. This has resulted in substantial energy savings (an average of 50 per cent) - primarily as a result of various production components now matching actual production requirements.

Since 2016, a second, more advanced version of the wellfield model, uGraph, has been used on all wellfield related activities. When decommissioning a waterwork, groundwater from the wellfield was transferred to another waterwork, where project design was performed using the advanced wellfield model. At another wellfield, the water quality is complex due to elevated levels of natural minerals and the occurrence of pesticides. The abstraction was planned by using the model, securing optimal water quality and avoiding spreading the occurrence of pesticides. At the oldest waterworks, the raw water network from two wellfields were redesigned for optimal wellfield operation.

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WSP
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LOCATION
Odense, Denmark

CHAPTER 4

Smart use of data in water utilities

The continued and increasing availability of data unlocks new opportunities and solutions to achieving high-quality water production with data- based control systems. The production and distribution of drinking water from source to consumer is automatically monitored and optimised for planning operations and maintenance.

The amount of data generated by water utilities has increased dramatically during recent years and the rate of data being collected seems to accelerate even further. This is, to a large extent, caused by an increased use of online sensors, which consequently necessitates advanced data management and interpretation. The amount of data being generated by a modern utility surpasses the capabilities of manual interpretation, hence manual interpretation is, in some cases, no longer a satisfactory and realistic option. Danish water utilities have electronic sensors, which report to the SCADA system installed throughout their system. The most common sensors are those for physical parameters as flow, pressure, and water level but also several water quality sensors measuring pH levels, oxygen, conductivity, and UV transmissivity. Other more specialised sensors are occasionally included, a trend which will most likely continue as sensor technology improves.

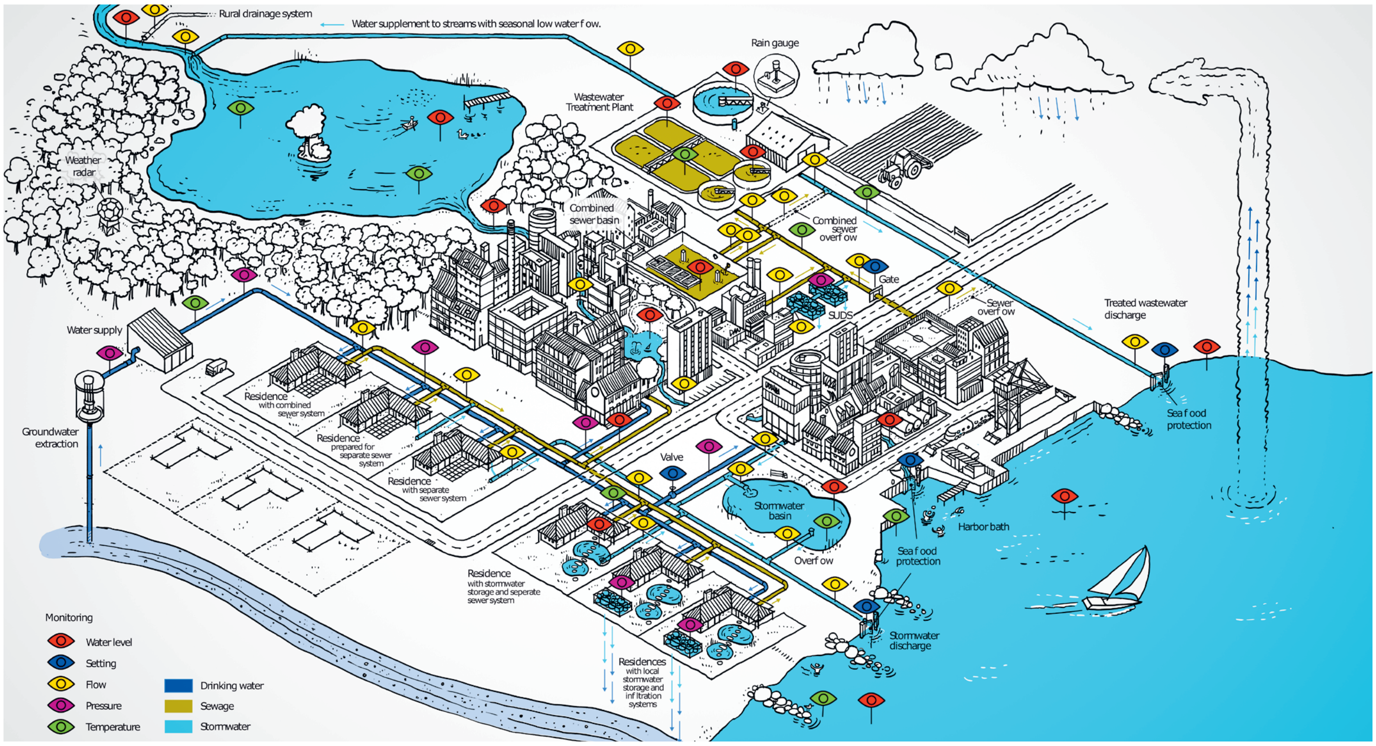
Transition to automated control systems

Performance improvements in the Danish water sector have been driven by demands from regulation regarding economic efficiency as well as a focus on an energy efficient and climate neutral production. Equally, increased requirements from consumers in regard to the quality of the water service delivered have also driven utility improvements. The diversity in these demands has caused a shift from manual supervision to automated control systems and an operational water utility, where all production facilities are unmanned. The relatively high number of sensors placed throughout the utility provides input to the SCADA systems, where measurements are held up against set points. Data collected from the systems is used for operations and maintenance planning, detecting alarms and supervising service quality. Just as in any industrialised production, the SCADA system ensures that the production is automatically adjusted when measured data deviates from expected results.

With more severe abnormalities, an alarm is given to the operationally responsible staff member on duty. In general, all staff have instant access to relevant data on laptops or smartphones, which enable a fast response to any abnormalities. The staff access the date through laptops or smartphones, which also eliminates the need for the utility to have operational staff on-site 24 hours a day. Such unmanned facilities have also prompted the introduction of systems, such as Reliability Centred Maintenance, use of Maintenance Scheduling Software and a broad introduction of the principles of Pressure and Asset Management, throughout the utilities. Instant registration of pipe bursts secures instant reactions and fast repairs, resulting in a national Non-Revenue Water (NRW) level of 6.5 per cent in Denmark, according to benchmarking measures performed based on major water utilities in Denmark. Considering the current infrastructure in Denmark, a 6.5 per cent NRW level is considered an economical optimum, where the cost of maintaining the low level does not supersede the economic benefits of minimised water loss.

The digital future

The water utilities of today are becoming ever more digital with the help of sensors for data collection and software for operational real-time analysis as well as predictive capabilities, offering fast reaction times to abnormalities and the possibility to avoid abnormalities before they potentially occur. What is even more interesting for the future is the possibility of using data in a new way. There is a huge amount of data from all over the system and collecting, storing, and analysing data enables new possibilities for using it to operate water production and distribution intelligently. These data can be related to meteorological data, energy prices and consumer behaviour to further ensure high-quality drinking water production and distribution.



Example of distributed monitoring of the urban water cycle with approx. 60 measurement units. A distributed monitoring network could consist of hundreds or even thousands of measurement units in a single city. (Credit: Aarhus Vand.)

DONUT - distributed online monitoring of the urban water cycle

Water managers often lack coherent and updated information that clarifies the complex water system interactions to a degree where vital correlations and dependencies are known and understood. As large investments are made every year in maintenance, replacement, and expansion of the water infrastructure to better deal with the challenges faced, it is a necessity to ensure effective decision making for government officials and water utilities managers.

To help tackle this, the DONUT-project partners have worked together to develop a unified solution, which enables cost-efficient distributed monitoring of the hydrological and hydraulic states of the entire urban water cycle and provides data and knowledge about the system correlations. The project partners have taken a novel approach, utilising a network of simple, low-cost and low-energy sensors, combined with software sensors and machine learning to obtain a holistic overview of the water cycle, which can then be used across administrative boundaries to ensure a consistent basis for decisions on e.g., future investment.

More than 200 monitoring sensors were installed throughout the urban water system, from pressure monitoring in groundwater abstraction and distribution, to monitoring of water levels at a local stormwater management solution and in sewer systems. The results reveal that the total cost of ownership (TCO) can be lowered up to 90 per cent compared to traditional monitoring approaches. Further value creation has been obtained, by releasing resources from data collection and analysis to problem solving and decision making for water utilities and municipalities.

CONTRIBUTORS

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LOCATION

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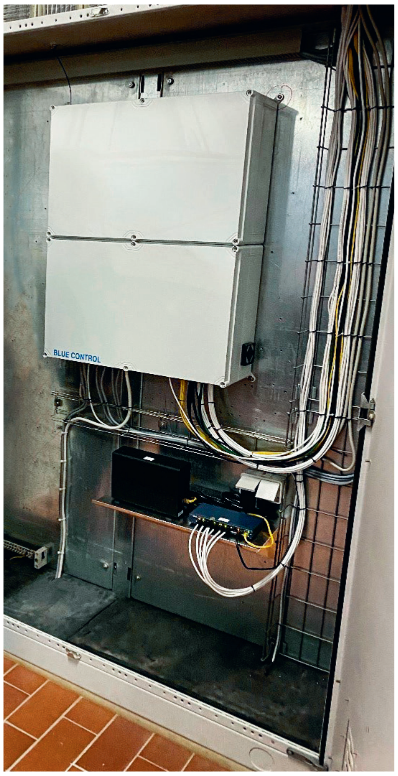
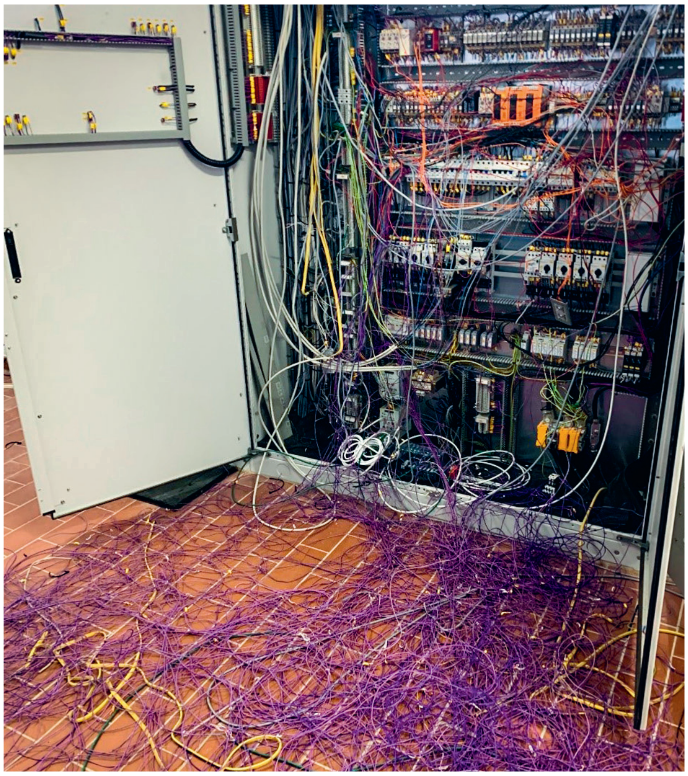


New system based on distributed network



Old system being decommissioned while still in operation

Data-driven automation technology enabling immediate response rate

The Ullerød Water Utility had reached a point where the water treatment process management system was outdated and expensive to maintain. Traditional SCADA systems for control, regulation and monitoring of a waterworks require countless wires and components. The previous system was therefore replaced with a system based on industrial grade automation technology and standards. One single data cable connects all the components, e.g., pumps, filters etc. in a distributed network, eliminating the need for hardwiring between components and the control panel. This also makes repairs and maintenance easier, reduces the risk of malfunctions, and minimises the complexity of the initial installation.

For Ullerød Water Utility this has taken useability to a simpler and more intuitive level. All phases of the process are monitored constantly, and any anomaly is alarmed immediately to those in charge, who can decide on the appropriate action. The utility now has a data-driven management and decision support system that allows safe access from anywhere. This can be done via a browser, a table or a smartphone at home and enables control over filters and pumps, without the need to be at the specific waterworks or well location.

CONTRIBUTORS

BlueControl
Ullerød Water Utility

LOCATION

Ullerød, Denmark

Reducing water loss and energy use with intelligent pressure solution

Pressure Management is in general considered the most cost-effective way to reduce water losses. In the Chilean city of Talca, the Essbio-Nuevosur waterworks company has improved a neighbourhood's water supply and cut water losses by approximately 15 per cent. At the same time, energy consumption has been reduced by 32 per cent. The gains have come through the implementation of an intelligent pressure management solution, which is stabilising and adjusting pressure to meet demand, and, at the same time, reducing excess pressure condition in the network. Real-time data from pressure sensors is relayed back to a control unit in the pump station, where pumps and frequency converters adjust to meet the needed pressure and flow.

This technology can be applied on local pump controllers and is recently also developed for data cloud platforms. This simplifies implementation and enables the use of enhanced control strategies, where elements such as leak detection and water quality management can be included. Cloud-based control systems allow for the introduction of new business models e.g., performance-based contracts, where savings generated by the pressure management solution finance the entire project.

CONTRIBUTORS

Grundfos

Essbio-Nuevosur Waterworks Company

LOCATION

Talca, Chile

CHAPTER 5

Protecting tomorrow's water resource

A groundwater resource is often an older resource, containing the accounts of previous years and decades of land use, hence taking proactive action today, to protect the water resource of tomorrow, is key.

In most cases, high-quality groundwater resources are found to be of a significant age – from several years to several generations – and the recharge of the resource is a slow moving and delicate process. In this perspective, present contamination may seem limited in space and time, but can potentially have severe and long-lasting impacts on the resource in the future. In order to maintain a groundwater resource of high quality, understanding and protecting the recharge system is of the utmost importance.

Contamination of groundwater can originate from various sources, commonly classified as either a point, line or surface source. Point sources are generally understood as contamination from a specific point such as a chemical deposit, landfill, industrial site etc., while line sources are seen along infrastructure such as roads, railways, and pipelines. A surface source is a more diffuse source of contamination, often understood as contaminating substance release on a larger area over a period, e.g., nitrate and pesticides. In Denmark, where groundwater is the primary water resource, maintaining pure groundwater of high quality is paramount. As such, a key plank in the country's groundwater policy has been to focus on the prevention of pollution, rather than treatment options. It places a clear emphasis on spending resources on protecting the groundwater, rather than spending resources purifying contaminated water for drinking purposes.

Areas of special groundwater interests
An effective measure to take in the prevention rather than treatment of the groundwater, is the proactive detection and removal of contaminated sites that pose a risk to the specific aquifers. This requires locating and monitoring e.g., landfills, chemical storage or other potential point sources of contamination. This can be performed on a regional basis, where the regional authorities are entrusted with the task of mapping activities which may pose a risk to the groundwater resource. In the event of contaminants posing an imminent risk to an aquifer, a remediation process is prioritised and initiated by the regional authority. In Denmark, major areas are appointed as 'areas of special groundwater interests. Originally, these areas were meant as a reserve for future groundwater abstraction, and areas where the removal of contamination risk from point sources were prioritised and the land use of that area could be regulated.

Protection zones with different focus
Over the last decades, focus has intensified on the risk of surface source contamination, such as nitrates and pesticides from agricultural activities. These types of activities generally take place in more rural areas, where the majority of the natural recharge occurs, and where Managed Aquifer Recharge practices often are performed. As all groundwater resources have their origin from infiltration in some way or form, detailed knowledge and understanding of the entire water flow from surface to well intake is required to protect the groundwater resource from surface source contamination.

Inside the 'areas of special groundwater interests', the catchment area, as well as layers of infiltration and of protecting clay, should be mapped and understood, and major areas of groundwater recharge identified. Obviously, protection efforts yield the most value for money when performed where most volumes of groundwater infiltrate and where it is identified as most vulnerable. These areas are recognised as 'focus areas', where regulation and limitation on use of e.g., nitrates and pesticides are necessary to protect the groundwater. A national approval scheme for pesticides, alongside other permits and approval schemes for permitting possible polluting industries, as well as the spread of sewage sludge are also included in the Danish groundwater protection strategy.

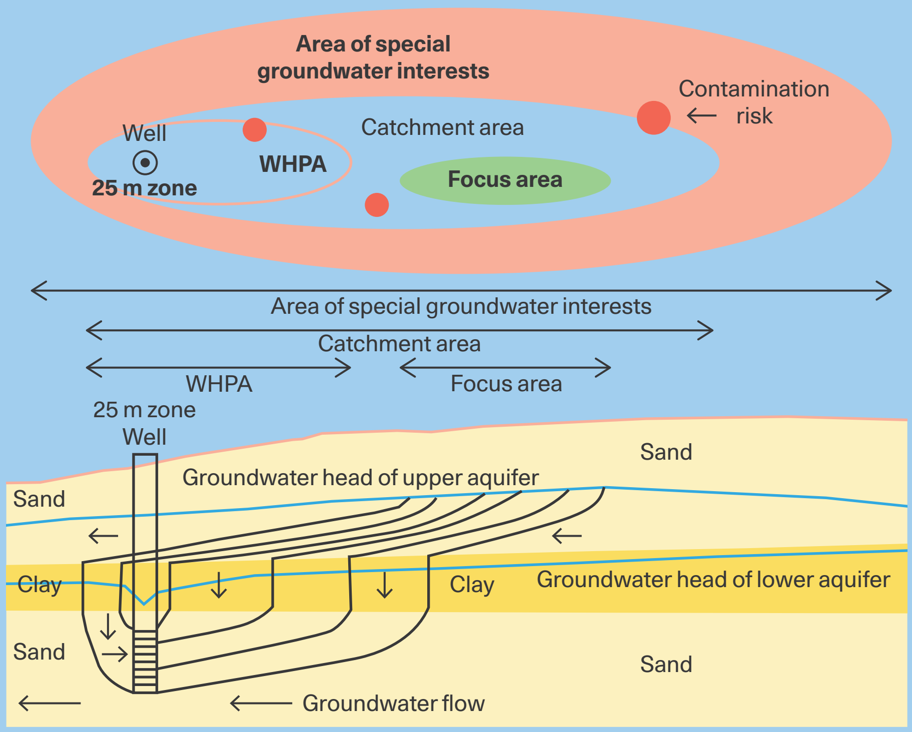
Wellhead Protection Areas

An increased focus on assessing and protecting the areas closer to the well area has been implemented over the last years. This is known as 'wellhead protection areas' (WHPA). A WHPA is a surface area above the aquifer, where water and any polluting substances that may be present, can reach the well within one year. In such areas, the authorities can put restrictions on the application of pesticides. Additionally, urban planning will disallow any polluting industries in the surrounding area. In an area identified as vulnerable and where water – and any pollution that may be present – can reach the well within 200 years, the authorities can enforce restrictions on the application of fertilisers and pesticides. These instruments provide sound possibilities for effective groundwater protection efforts.

Partnerships and the way forward

Recent experience from Denmark reveals that collaborations and partnerships between the waterworks, the local (municipal) authority and the state or regional authority have proved successful in detecting pollution and implementing advanced measures to counteract the imminent consequences for the abstraction. The driver in all these situations has been to apply strong local knowledge along with state-of-the-art investigation techniques in order to map and eliminate threats to valuable water resources. Following this, a partnership between waterworks and landowners as a balanced agreement e.g., lease or continued operation under certain conditions, can ensure groundwater protection while also ensuring the landowner continued earnings from the area.

Prioritised areas and efforts to protect and secure the future drinking water resource



- **'Area of special groundwater interests'**, monitoring and/or removal of sources of contamination e.g., former landfills, chemical storage or other potential sources of contamination, and general regulation for area use.
- **'Focus areas'** with protection of the vulnerable parts of the groundwater aquifers e.g., where protective clay layers are thin and restrictions on the use of nitrates and pesticides are necessary.
- **'Well head protection areas (WHPA)'** in the vicinity of production boreholes with 25 m protection zones or protection of the well field area, where the use of fertilisers and pesticides are prohibited.
- **A 10m physical protection zone** around each borehole to protect against physical damage to the well.

The Elmelund Forest

To protect a vulnerable groundwater catchment area outside the City of Odense, the local water utility VCS Denmark collaborated with the local municipality and the Danish Nature Agency on a solution. The aim was to find a multi-beneficial solution for groundwater protection. The Elmelund Forest was established and is a publicly owned 4km^2 forest located in a vulnerable groundwater catchment area. The area, which is located to the west of the city, delivers around one-third of the drinking water demand of VCS Denmark's 175,000 customers.

Elmelund Forest provides recreational value to the local citizens, with its 15km walking tracks supporting a healthy lifestyle. The forest naturally absorbs CO_2, thereby contributing to mitigation of greenhouse gas emissions and supports biodiversity in a landscape otherwise characterised by agricultural use. The forest is an example of a multifunctional, sustainable solution for protecting the groundwater quality of tomorrow and aiding in the city of Odense's target of climate neutrality by 2030. In early 2021, a decision was made to initiate a similar afforestation and groundwater protection project on the other side of the city.

CONTRIBUTORS

The Danish Nature Agency
Odense Municipality
VCS Denmark

LOCATION

Odense, Denmark

Conserving drinking water by making use of technical water

Until around the year 2000, water abstraction in the northern part of Esbjerg contributed a large portion of the city's drinking water supply. A part of the abstraction area had been polluted by pesticides and chlorinated hydrocarbons though to have originated from a garage in function during the second world war. The groundwater in the area was no longer of drinking water quality. To ensure pollution would not spread to the southern wells, abstraction from the contaminated wells has continued in the form of remedial pumping. However, water from the contaminated wells are used for technical water today.

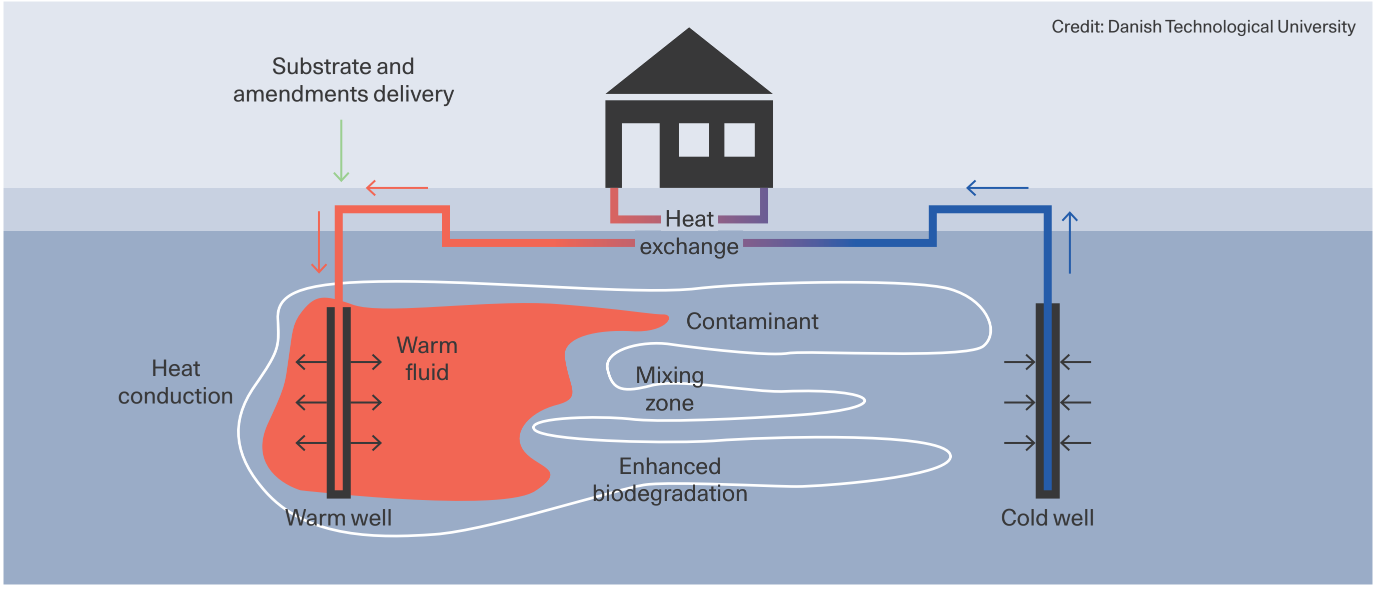
The local water utility now supplies local businesses with technical water for cooling and industrial purposes, where water of drinking water quality is not required. It is possible to collect technical water from the polluted wells and use it for sludge tankers and the like, at a self-service station in the area. The continuous abstraction aids in ensuring that groundwater pollution does not spread towards the clean southern wells. At the same time, the available drinking water resource is conserved when local businesses use technical water for industrial purposes instead. It is part of the utility's strategy to expand the supply of technical water to businesses in the future, reducing possible future demand for finding new clean drinking water resources.

CONTRIBUTORS

DIN Forsyning (Water Utility Esbjerg)

LOCATION

Esbjerg, Denmark



Treating polluted groundwater whilst heating and cooling buildings

Groundwater aquifers in peri-urban areas are often polluted with e.g., chlorinated solvents from previous industrial activities or petrol stations. Biodegradation of pollutants in the groundwater is an option for treating the water and is more effective when it occurs at high temperatures. This creates the possibility for cleaning the polluted groundwater on site and eliminates the groundwater threat using biodegradation technology and combining it with groundwater energy storage.

The concept was first demonstrated with good results in 2019 at a contaminated site in the Capital Region of Denmark, where groundwater was abstracted from the cold well (approximately 10°C), heated to 20 °C in the heat exchanger, reinjected into the warm well and recirculated through the contaminated zone in the subsurface. Soluble electron donors (lactic acid and sodium acetate) and bacteria were added to the system to stimulate microbial degradation of the contaminants.

When performing this remedial measure of cleaning polluted groundwater, the aquifer can simultaneously be used to store energy to sustainably heat buildings later. Up to 80 per cent of the stored energy can be used to heat buildings in colder months. Next steps include understanding water flows and heat transport further, so that the use of biodegradation technology and energy storage may be used to eliminate these types of groundwater threats in the future.

CONTRIBUTORS

Capital Region of Denmark - Department of Environment
Rambøll
Technical University of Denmark - DTU

LOCATION

Capital Region of Denmark

CHAPTER 6

Ensuring high quality

Supplying good quality drinking water starts with water source protection and lasts throughout the distribution system. Therefore, protecting groundwater from contamination is of principal importance, and primary cornerstone in being able to ensure high-quality drinking water. At times, allowing for chlorine-free drinking water.

Groundwater, if protected accordingly, requires little to no treatment in comparison to surface water. Examples across the world exist where groundwater is being supplied chlorine-free and with virtually no treatment. However, ensuring drinking water of high quality also requires high standards for hygiene during the treatment section at the waterworks and throughout the distribution system to the customer's tap. In addition, the requirements can vary from one waterwork to another, depending on whether the supply is based entirely on groundwater or if it is mixed with other sources. Equally, the natural quality and amount of water also affect the hygiene standards required in the waterworks.

Hygiene standards and the necessary barriers

Until recently, groundwater in Denmark has only required simple treatment, such as aeration and sand filtration, but additional treatment is becoming more widespread. As an extra hygienic barrier, UV disinfection is commonly installed and the calcareous groundwater causing lime scale build-ups in bathrooms and household appliances has led to growing customer demand for softening the drinking water. The less attractive advanced treatment is borne out of necessity, due to the increased occurrence of pesticides in the groundwater. So far, boreholes have mainly been taken out of operation as a consequence of discovering pesticides in the groundwater – even when it concerns very low concentrations. However, the situation has developed into a reluctant acceptance of active coal filtration or other advanced filtration techniques for at least some decades until pesticides or their metabolites are no longer found in the groundwater. In countries where the water source is a mix of groundwater and surface water, it will in most cases be the quality of the surface water which will determine which hygienic barriers need to be installed.

Management systems for quality control

All major water utilities in Denmark apply the management support system 'Documented Drinking Water Safety' (DDS) and all major utilities have obtained an ISO 22000 certification, which is the international standard concerning food safety. The principles of the Hazard Analysis and Critical Control Point (HACCP) in the ISO 22000 are operationalised in the water utility practice by Documented Drinking water Safety (DDS). The system supports utilities in analysing possible water quality risks within abstraction, treatment, distribution, and installation at the custome; enabling identification of specific control points in the distribution network based upon quality targets set by the individual water utility. A monitoring plan is drawn up, which summarises the most important threats to the quality targets and how to avoid them. The monitoring is mainly performed through continuous hygiene, sampling and maintenance routines. If there are critical areas posing a threat to the quality targets, a specific risk management procedure is commenced.

Hygiene at the waterwork

Due to the use of groundwater as a protected sole source, it has been possible for Danish waterworks to maintain a non-chlorinated water supply. When lacking the hygienic barrier in the form of chlorination at the distribution side, the Danish waterworks adhere to high standards for hygiene. Because of this, waterworks are divided into hygiene classes, with gradually more strict behavioural requirements for areas with open access to the drinking water. The utility employees, as well as any utility subcontracted employee from private companies, must participate in a skilled worker's course and obtain a hygiene certificate.

A safe distribution system

When operating a system without chlorination, it is paramount that the system is continuously pressurised to avoid the intrusion of pollutants through pipe failures. Adjusting the water distribution to ensure water quality and optimising the amount of time the water is in the pipes is a task made possible by advanced technology e.g., SCADA systems and hydraulic models of the network. Hydraulic models help calculate the age of the water in the network, based upon data on pipe locations and dimensions as well as estimates on customer demands throughout the network.

Best practice is to break down the distribution network into smaller sections – so-called District Metered Areas (DMAs). Detailed information on consumption and time-dependent demand variations by each District Metered Area support the creation of a more advanced hydraulic simulation model of the distribution network. By combining hydraulic model data with data from the SCADA system, leaks, possible low flow sections and dead ends can be detected. Additionally, it can help ensure that optimised pressure is maintained, thereby minimising risks to the water quality. The water quality is monitored at selected points throughout the distribution system. To further ensure the quality of the water, tests can be performed at the tap in customers' private homes.

Active leakage and asset management for pipe rehabilitation enable a quick response to – or even prevention of – potential water quality dangers, which can occur with unidentified and unattended pipe corrosion, leaks and possible pressure drops caused by valve or pump failures. Hence, effectively managing non-revenue water- related issues not only saves water and energy for pumping; it also addresses the question of high-quality water assurance.

Credit: VCS Denmark

Supplying groundwater for dairy facilities and the local village

BIAGR dairy in Ukraine expanded their business and therefore needed a new water supply. This meant a complete water treatment solution based on groundwater. Six wells were equipped with high quality pumps operated by frequency converters. The speed regulated pumps eliminate the need for intermediate holding tanks, reducing any microbiological risks caused by standing water. As the groundwater content of iron (Fe) and manganese (Mn) are above the drinking water limits, two pressure filters were installed with an aeration system controlling proper oxidation. This process is followed by two membrane filtration units, producing a total of 50m^3 of demineralised water per hour. The treated water is collected in separate storage tanks. One tank is for filtered drinking water for domestic purposes and the second is for demineralised water that is used for a wider range of processes, such as CIP (clean-in-place), rinsing as well as cooling to produce butter, cottage cheese, powder milk, whey, and processed cheese. Distribution of the water is executed to the various points of use with energy efficient pumps that ensure the appropriate flow and pressure. Besides meeting the dairy's daily water demand of 300 m^3 of drinking water and demineralised water of 850 m^3, clean drinking water is supplied to the local kindergarten and village centre - all the while exhibiting a lower OPEX than the previous system.

CONTRIBUTORS
Silhorko-Eurowater
Grundfos
BIAGR

LOCATION
Poltava, Ukraine

Implementing groundwater remediation technology

Naturally occurring arsenic (As), a potent carcinogen in drinking water, threatens the lives of hundreds of millions of people worldwide. A majority of affected people live in more rural areas and lack the means for conventional arsenic treatment.

Researchers from India, the US and Denmark have developed and implemented a low-cost electrochemical As treatment method in a rural part of South Asia. It is iron electrocoagulation (Fe EC), where a minor electric current is applied to steel that is in contact with pumped groundwater. This oxidises the metal to produce reactive iron oxide precipitates (i.e. rust particles) that effectively bind the As and prepares it for removal by gravitational settling or filtering the As loaded iron oxides. The Fe EC-method can be powered by a local solar cell setup.

The FE EC serves the local school of 2,500 children with 1L of arsenic-free water, per child per day and has a maximum capacity of 10,000 L/d. The simplicity of Fe EC has enabled technology transfer to the local village. Village residents are operating the plant and selling excess water to the village at an affordable price. It has improved trust in the technology and created jobs for local residents.

Measurement performed at a 10,000 L/d Fe EC plant. Bird's eye view of the electrolysis tank and rust particles that adsorb arsenic.

CONTRIBUTORS
Geological Survey of Denmark and Greenland GEUS (DK)
University of California, Berkeley(US)
Jadavpur University (India)

LOCATION
Kolkata, India

Resource efficient ceramic membranes ensure drinking water quality

In Mayskiy Pavlodar, a region in the northern part of Kazakhstan, they needed to increase their water supply by 4150 m^3/day. The available water source was a 75 meter deep groundwater well containing high amounts of Iron (Fe) and Manganese (Mn) exceeding 12 mg/l. It was decided to use ultra-filtration (UF) membranes to ensure an absolute barrier against bacteria and turbidity. To make conventional UF membranes function with such high amounts of Fe and Mn in the water, extensive membrane cleaning and backwashing would be required; resulting in 5 per cent water losses, which would require installation of a recovery system to comply with local regulations. For that reason, the local system integrator investigated alternative solutions and came across a unique ceramic membrane module. A total of 288 m^2 ceramic membranes in 48 modules were installed in the membrane area of the treatment process chain. These can operate with high solids loading, with no pre-treatment whilst providing less than 1 per cent water losses, essentially treating the water in one step with no need for a recovery system. This also saved the customer more than 80 per cent of the energy consumption, when compared to conventional UF membrane systems.

CONTRIBUTORS
Cembrane

LOCATION
Mayskiy Pavlodar, Kazakhstan

Parameter	Unit	Raw water	Filtrate
pH	-	6.8	7.9
Turbidity	NTU	9.5	<0.1
Color	Pt-Co	44	5
Iron	mg/l	12	<0.1
Manganese	mg/l	2.18	<0.01
Temperature	°C	7.5	7.5

CHAPTER 7

Good governance for sustainable groundwater management

Integrated groundwater management is key to preserving a sustainable and pollution-free resource, therefore Danish authorities and water utilities have, and have had for over three decades a, dedicated and focused approach towards protection of the natural groundwater resources. However, more and more groundwater abstraction wells are being closed due to pollution.

The water supply in Denmark is regulated by the Ministry of Environment, who delegate the enforcement responsibility to the country's 98 municipalities. As an essential commodity, the water sector is governed by long-term planning. This is especially important when using a limited natural resource such as unpolluted groundwater. The groundwater belongs to the public and a landowner does not own the groundwater beneath his/her property. The right to abstract and utilise the groundwater is granted by the local authorities where the well field is located. Abstraction permits given to water utilities can have a duration of up to 30 years. This gives the water utilities a decent time horizon to plan the water supply structure and investments in wells, pipes and waterworks. Farmers using water for irrigation purposes also need a permit and are normally granted this for a period of 15 years. The aim for continued the use of groundwater has led to an extensive investigation, mapping and protection of groundwater resources that is partly financed by a fee paid by consumers, which is connected to the deliverance of water, and partly by taxes.

Knowledge is the necessary basis for all decisions

Denmark is divided into three different zones: i.e., 'areas with special drinking water interests', areas with drinking water interests and areas without drinking water interest, which are typically situated along the coast. During the last 25 years, our knowledge about the subsurface in 'areas with special drinking water interest' have increased enormously through intensified mapping campaigns and the introduction of digital geological and numerical hydrological models. This knowledge is used to assess the impact from groundwater abstraction on water dependent nature, the state of groundwater and surface water and water quality, following the principles of the EU Water Framework directive.

Public awareness saves water
Campaigns on various platforms (social media, newspapers, TV) arranged by water utilities and authorities at different levels increase public awareness about water usage and the protection of water resources. Furthermore, school classes in Denmark learn about water issues and often visit waterworks to learn about the water cycle. Combined with the tax policy on water consumption, the use of tap water has decreased by more than 40 per cent over the last two decades.

Owned by the consumers
The Danish water utilities are subject to solid democratic control, as they are owned by the consumers, either directly or via the municipality. The economy of the water utilities is legally based on a break-even principle; hence water utilities are not allowed to make a profit from supplying water or collecting and treating wastewater, and subsequently, commercial investment in water utilities is limited. The accounts as well as the water quality has to be publicly available, with all information and data accessible for all. This transparency is also reflected in the water price, as it reflects the actual cost of production and distribution. The Danish water price is unsubsidised and includes taxes and VAT, covering both water supply and wastewater treatment. Consequently, it is one of the highest water prices in the world, despite relying on a relatively cheap and climate insensitive resource. The price incentivises water efficiency and water loss prevention, whilst acting as a source of funding for efficient, well-developed and well-maintained infrastructure as well as the national groundwater mapping programme.


Credit: Unsplash

Citizens pumping groundwater from a public water post in a village in the uThukela municipality, Kwa-Zulu Natal province. (Credit: Danish Environmental Protection Agency)

Demonstration projects for groundwater governance, South Africa

South Africa relies heavily on surface water for its water supply, and with the prolonged droughts in south Africa, water shortage is becoming a more frequent problem. One solution is the utilisation of groundwater resources. With more demonstration projects initiated by the Danish Environmental Protection Agency, Danish groundwater experts assist their South African counterparts in developing techniques, good governance, funding models and guidelines for the mapping and utilisation of groundwater resources. In the projects, focus is on the sustainable use of groundwater, which will contribute to a more secure water supply.

In Cape Town there was a feasibility study regarding augmenting the water supply with private boreholes, mapping for new well fields and enhancing the groundwater resource with artificial recharge (MAR). Based on site visits, the quality of the boreholes was found to be very varying and often the boreholes were too shallow for long-term groundwater development. In parallel to the technical approach, there has been an investigation into the legislation regarding the possibility for the public water supply to gain access to boreholes on private lands. These investigations have shown that several options are available, but with the current legislation, it is crucial that the private landowner gives consent. In another project, a detailed geological and hydrological model has been developed in the uThukela municipality in the Kwa-Zulu Natal province using the Danish groundwater mapping approach. The model was used to identify potential locations and dimensioning new wellfields, without violating the design criteria on groundwater drawdown.

CONTRIBUTORS

Danish Environmental Protection Agency

Rambøll

Danish Ministry of Foreign Affairs

LOCATION

uThukela, Sotuh Africa

Credit: VCS Denmark

CHAPTER 8

The Danish groundwater example

A national water supply entirely based on groundwater has required development of standardised data collection and public databases, enabling national hydrogeological groundwater models aid in the sustainable abstraction and protection of groundwater.

As a relatively densely populated country with intensive farming activities covering approx. 60 per cent of the country, posing a range of contaminations threats in terms of nitrates and pesticides, the protection and sustainable use of the water resource are the two primary focuses of groundwater governance in Denmark. This is mainly due to the fact that nearly 100 per cent of Danish water supply is groundwater based. Only one small island in Denmark with less than 100 inhabitants relies on other sources for its drinking water. This has led to the implementation of some of the most comprehensive groundwater mapping, monitoring and protection programmes in the world, not least regarding pesticides.

Enabling sustainable groundwater management

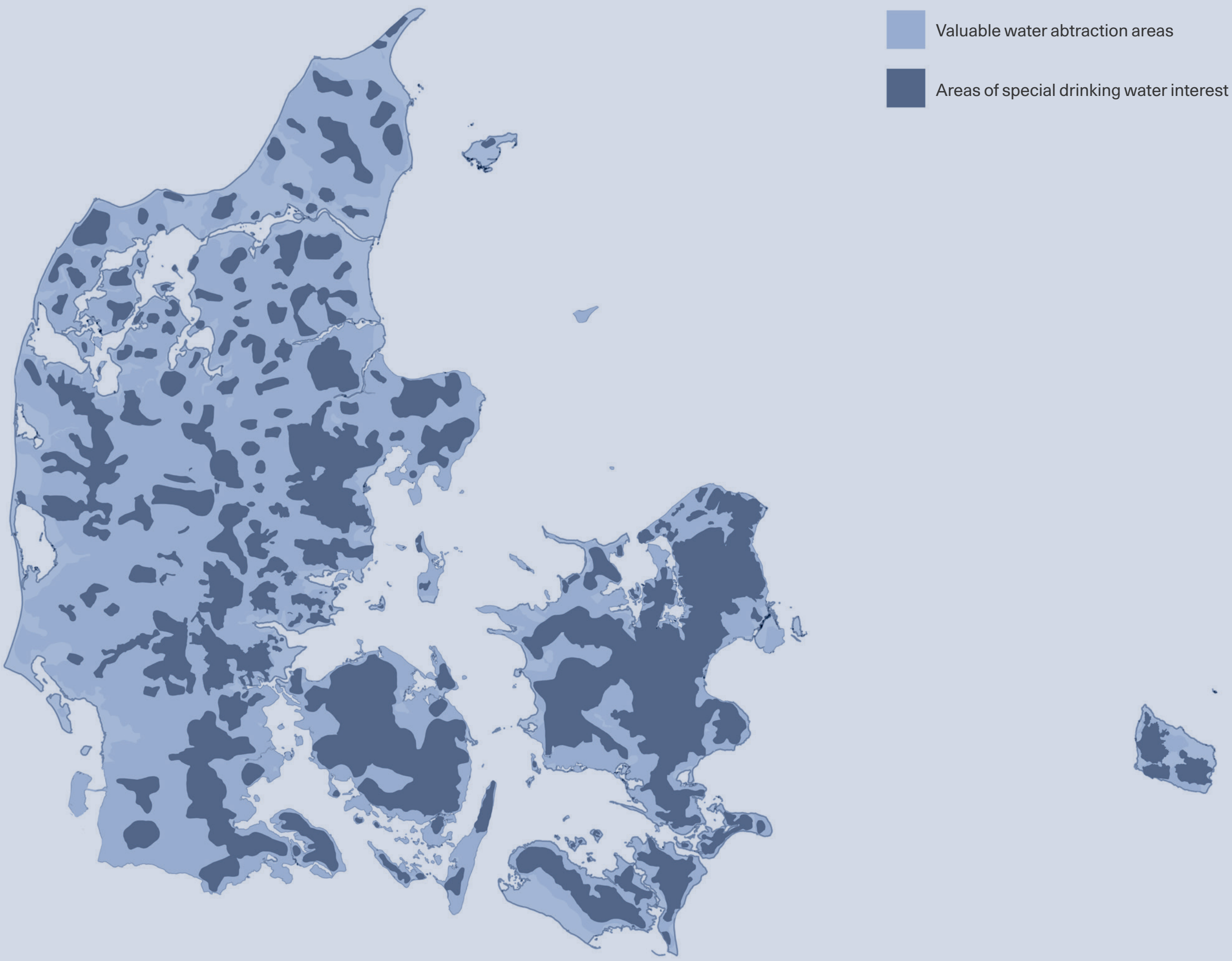
Sustainable management and consumption of groundwater are obtained by having the right knowledge. Therefore, the Danish government adopted a plan for hydrogeological investigation in Denmark. An ambitious groundwater-mapping programme was initiated in 1998 with the aim to map the location of the Danish aquifers, the extent of their distribution and interconnection, as well as to identify particularly vulnerable areas. Area-specific protection zones were established to ensure accurate protection from contaminating land usage, i.e., urban development or agricultural practices. These protection zones are continuously monitored and adjusted. The programme has laid the foundation for Danish expertise within groundwater management, where registration and databases, surveying technologies, software tools for integrated water resource modelling and decision-making systems remain essential to sustainable management.

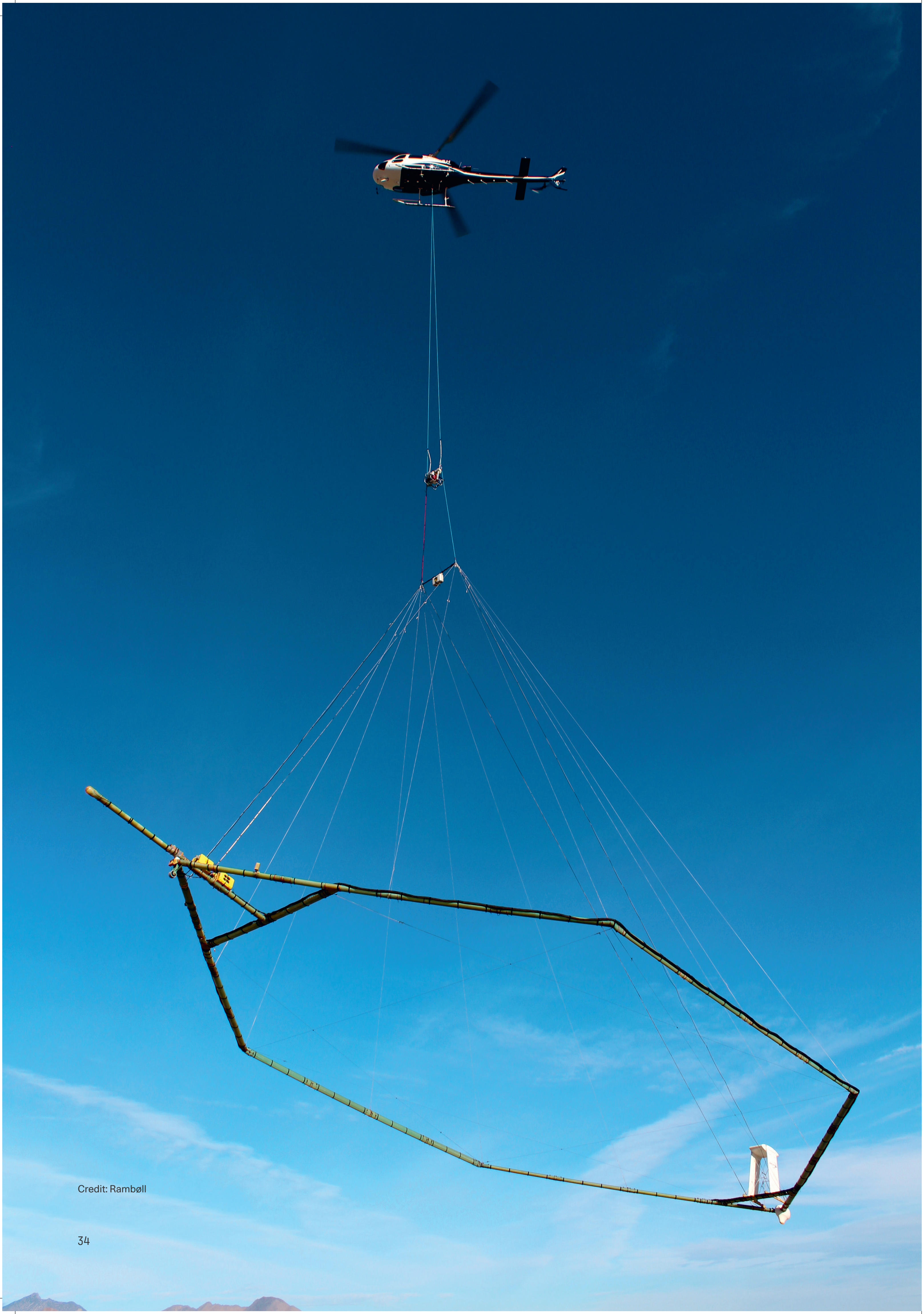
Land banking for groundwater protection

Another method to ensure establishment of sustainable management and protection zones in catchment areas include, land banking and consolidation. Where funds are not available from the purchasing side, or lack of interest in selling from the landowner's side, the option of land exchange can be explored. Both options are of course performed in partnershipwith the current landowner and the utility aiming to acquire the land for groundwater protection purposes. In some of the best examples of this practice from Denmark, a third-party consultant has been hired to conduct property pre-studies among the private owners of the agricultural land. This aids in uncovering motivations and possibilities for the landowners, who can indicate interest in selling or in exchanging their land, for land elsewhere to continue current practices, be it for agricultural use or otherwise. In one afforestation project for groundwater protection purposes, it was made possible to acquire a total of 316 hectares of land. A total of 120 hectares of was made available through land exchange arrangements.

Right knowledge based on accurate and accessible data
A crucial precondition for knowledge-based groundwater management is that all data is stored in easily accessible national databases. For that purpose, Denmark has developed two such databases; Jupiter and GERDA, which today are web-based with open access to all, including many options for free downloads of data for private and professional use. The Jupiter database contains all data related to boreholes such as geological descriptions, groundwater heads, water quality samples and pumping, whilst the GERDA database contains all geophysical data. These databases have been developed over several decades and in close collaboration with private and public stakeholders. Private and public stakeholders populate the databases with standardised data, whereas it is the Geological Survey of Denmark and Greenland (GEUS) that host and maintain the databases as well as develop any functionalities needed for the use of database. The database development has been enabled by appropriate national legislation and stakeholder agreements, commencing with the Danish Water Act of 1926, where it became officially mandatory to send geological data from all water supply boreholes to the national database.

Expanding the models for improved knowledge
Another key element of the national infrastructure is a national hydrological model (the DK model), which provides a digital virtual reality description of the hydrological processes, including precipitation, evapotranspiration, infiltration, soil moisture, groundwater recharge, groundwater heads, overland flow and streamflow for the last three decades with daily time steps. The model covers the entire country in a 100m grid with up to 20 vertical geological layers. The DK model extracts data directly from the Jupiter and GERDA databases and uses other national databases on topography, soils, vegetation, rivers, streamflow and climate. It has been developed and continuously updated and improved since 1996. Model input, geological interpretations and model simulation results are made available online to authorities, private companies and stakeholders. The model output is used for providing advice to the government on national water management issues and used by consultants as a benchmark and a basis for further refinement in regional and local water management projects.





Credit: Rambøll

Undertaking state-of-the-art groundwater exploration

Ranhill SAJ is supplying water to a population of around 3.9 million. Supply is based almost 100 per cent on surface water resources. The reserve capacity is decreasing with the increasing population, and water supply shortages occur in the dry seasons. Compared to surface water, groundwater resources are less sensitive to seasonal variations and may provide important additional resources. Therefore, the Johor Groundwater Project was launched in 2017.

Phase 1 included a desk study to prioritise areas for investigation. Phase 2 included an airborne geophysical survey, which covered an area of around 3,655 km². Phase 3 included infills in the airborne survey with closer line spacing in selected target areas, followed by 2D resistivity surveys, test drilling and pumping, water quality analyses and an estimation of maximum sustainable groundwater abstraction, using groundwater modelling. Test drilling is ongoing in the first half of 2021. On the basis of the results from the various phases, groundwater may very well become a future supplement to the current supply of Ranhill SAJ, ensuring a more reliable supply to local residents.

CONTRIBUTORS

Ranhill SAJ Sdn. Bhd., Malaysia
NIRAS Denmark
Aarhus Geophysics
OCNED Water Technology Sdn. Bhd., Malaysia
SkyTEM Surveys

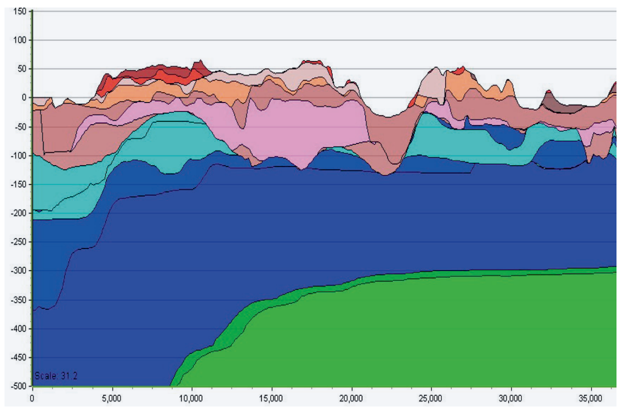
LOCATION

Johor, Malaysia

Digital geological model of Denmark

A 3D geological raster data model has been constructed of the Jutland peninsula, Denmark, covering about 30,000 km². The model displays geological units for the upper 2-300m in 3D in an internally consistent manner. The units are based on a lithostratigraphic classification developed during the model interpretation. This classification was used to interpret more than 20,000 boreholes from the national subsurface database, in about 300 separate regional digital geological models that afterwards were digitally joined together, providing one consistent model.

Point information from boreholes is then used to interpolate the basal surfaces of each unit on raster cells. The combination of all interpolated basal surfaces results in a 3D Digital Geological Model (DGM) of the entire Danish subsurface. Access is available for end users through the Danish Ministry of Environment. This development is a major step forward for local, regional and state authorities, as well as water utilities, consultants and private stakeholders as a platform and tool for common decision-making support.



CONTRIBUTORS

COWI
Geo
NIRAS
Rambøll
IGIS
Ministry of Environment
GEUS

LOCATION

Denmark

CHAPTER 9

Regulation, pricing and benchmarking

Successful governance in the water sector has meant going from public water utilities to private entities, meeting efficiency demands through benchmarking and water price regulation.

In some countries, regulation of the water sector can be fragmented and short-sighted. In Denmark, two ministries are primarily responsible for regulating the water sector: The Ministry of Environment is responsible for the environmental regulation and The Ministry of Climate, Energy and Utilities is responsible for the economic regulation.

Traditionally, the Danish drinking water sector has been highly decentralised with a large number of small consumer-owned waterworks covering approximately a third of the consumption and the rest supplied through the municipalities. Since a reform of the water sector in 2007, all water and wastewater utilities have been economically independent entities, however still fully owned by the municipalities.
60 per cent of the total supply is delivered through utilities owned by 98 local municipalities either as single communal company or a joint company with ownership shared between several municipalities and thus under public control. 2,500 small consumer-owned waterworks, which are also economically independent, deliver the remaining 40 per cent.

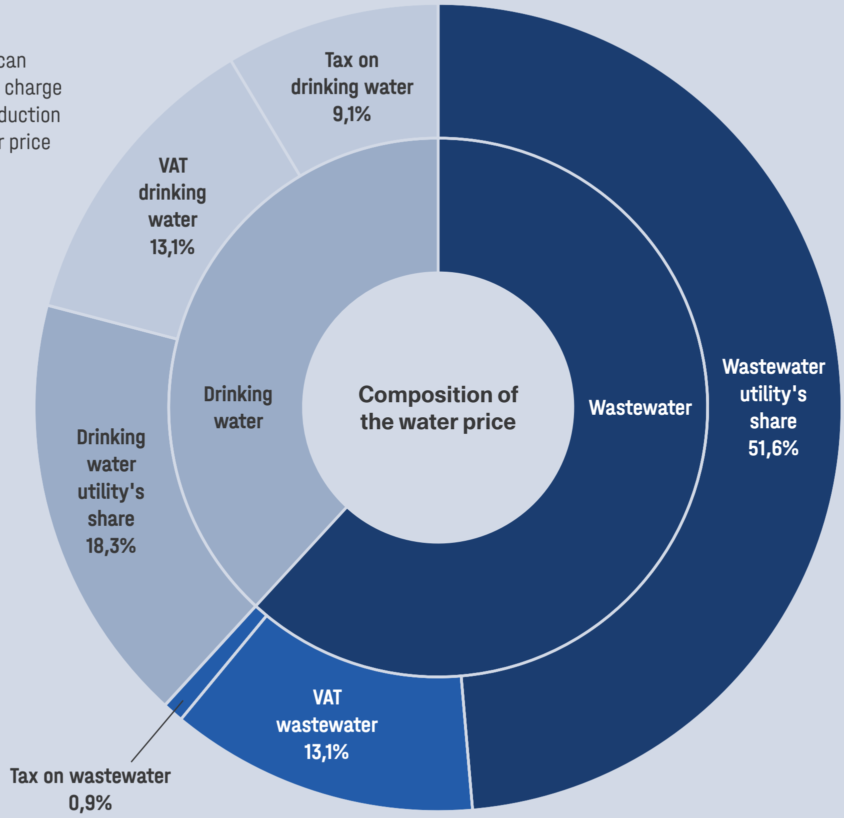
The municipalities serve as water authorities responsible for local water plans and compliance with legislation, issuing permits to utilities. The municipality also appoints the board to the publicly owned companies. Within this framework, utilities are not for-profit and operate under a break-even principle based on full cost recovery and within a price cap, that is set by the national regulator. All costs for running the utility must be covered by water and wastewater consumer charges. Utilities are not subsidised and similarly, the utility's funds cannot be used for purposes other than daily operations, investments, innovation, and contributions to the overall development of the utilities and the water sector.

Water consumption is closely related to the price
The average water price in Denmark is approx. EUR 9 per m^3. Two-thirds of this covers handling and treatment of wastewater and one-third covers the drinking water supply. This price covers the drinking water companies' costs for groundwater protection, pumping and delivery of drinking water and quality control.

Benchmarking measures performed, by DANVA, based on major water utilities in Denmark show that domestic consumption is as low as 101 litres per person per day. This has decreased by 40 percent since 1980 due to a combination of rising prices and general environmental awareness campaigns. Although the Danish water price might seem high, the average household spent only 1.4 per cent of their household budget on water and wastewater in 2018, well below a UN recommendation on affordable water, which sets a limit of 3 percent. While water prices may have increased, household expenditure on water and wastewater has been stable in recent years in line with lower consumption levels.

Danish water prices

The price of water charged is decided by each utility, and can include a fixed fee + charged per consumed m³ or simply a charge per consumption only. It will reflect the actual cost of production and maanegement, a full cost recovery. The Average water price in Denmark is approx. EUR 9 per m³.

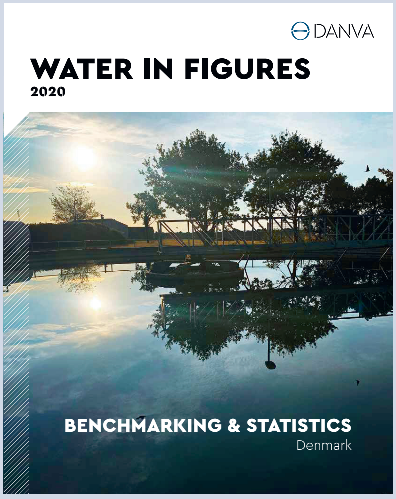


Water statistics from 1918 to modern benchmarking
To secure and supply the population with safe and sufficient drinking water, comprehensive knowledge is an advantage. In Denmark, water statistics have been collected since 1918 and includes data such as:

- Number of houses with running water
- Abstracted groundwater
- Average daily consumption – litres/person
- Number of toilets

By 2020, this had evolved into an advanced benchmark system, where information about drinking water and wastewater from 162 water and wastewater utilities is collected and published by the Danish Water and Wastewater Association (DANVA) in their annual publication, 'Water in Figures'. This benchmarking is a voluntary tool for the water sector to share knowledge on their performance and identify areas for possible efficiency gains. The data covers many areas, such as number of plants, length of distribution pipes and company operating costs. The participating utilities deliver drinking water to 60 per cent and handle wastewater from 80 per cent of the Danish population.

In many cases, innovation in new water and 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 also subject to mandatory benchmarking. The benchmarking is based on operational parameters and cost efficiency across the water sector. Here, the voluntary benchmarking provided by DANVA can aid the water utilities with knowledge sharing in between, helping to ensure they meet the operational and cost-efficiency demands required of them by legislation. Innovation projects are often based on collaboration across governmental bodies, water utilities, consulting companies, technology suppliers, universities, and research institutions.



Download their latest report here: www.danva.dk/waterinfigures

CHAPTER 10

The true value of water

A Danish perspective on how we can shape our water future. In Denmark, we value our water. We care for how we extract it, use it and release it back to nature. We consider water a valuable resource in the circular economy and a contribution to reaching our sustainable energy and climate goals. Above all, we value water for its potential to improve lives.

Let's protect our drinking water
Everyone deserves water that is clean and safe to drink. In Denmark, our drinking water is sourced entirely from groundwater. Our strategy is to protect our groundwater resources and in return, our drinking water only receives minimal treatment. Most waterworks simply pump, filtrate, and distribute it to the consumers. We monitor it carefully and work to secure clean groundwater for future generations.

Let's care for every drop
Water is a scarce resource – and every drop counts. We must make the most of the water we have. In Denmark, we have low levels of water consumption. Benchmarking measures performed, by DANVA, based on major water utilities in Denmark show that the average Dane consumes just over 101 litres a day, our water loss is less than 8 per cent and our industries are increasingly focusing on water efficiency and reuse in their production. The price is based on full cost recovery, which ensures a reliable and efficient water supply 24 hours a day. Now let's fight to make every drop count worldwide.

Let's use our wastewater as a resource
Wastewater should no longer be thought of as a problem. Instead, let's turn our wastewater treatment plants into energy and resource recovery facilities, where we can extract phosphorous and produce organic fertiliser and biogas. In Denmark, we also aim to utilise wastewater even further up the value chain to produce products such as biofuels and bioplastics.

Let's move towards an energy and climate-neutral water cycle
Water plays a key role in creating a sustainable world. It is important to make sure our water management is sustainable as well. In Denmark, we use a minimum of energy to pump and treat water. We work continuously to be energy efficient, and we contribute to a greener and more flexible energy system by producing energy from wastewater. In fact, some facilities are now producing more electricity than they consume. By 2030, the Danish water sector aims to be energy and climate-neutral across the entire water cycle.

Let's use rainwater to create resilient and liveable cities
Rainwater can improve urban life if it is managed wisely. In Denmark, we store and delay rainwater and stormwater in parks, streets and football fields to create both resilient and liveable cities for a growing population. By doing so, we adapt to the changing climate and weather patterns as well as increase our biodiversity. So, while we may not be fans of rainy days, we appreciate what rainwater can do for us.

Let's swim in our city harbours
Water can be used actively in urban development. Waterfront areas and blue-green infrastructure can transform neighbourhoods and create economic growth. By treating our wastewater and managing our stormwater in underground basins, we have transformed polluted inner-city harbours into urban oases. So that when the weather permits, you can go fishing or swimming in the harbour in Danish cities.

Let's collaborate and solve the global water challenges
We want to connect, inspire, and learn from each other in global partnerships – and work together to contribute to a more sustainable world. Water is one of our most valuable resources and it plays into many other agendas such as adapting to and mitigating climate change and increasing biodiversity. Through national and global partnerships across sectors, we can deliver on the UN Sustainable Development Goals on water and sanitation, affordable and clean energy, sustainable cities and communities and life on land and under water.

Water is life. And with the right care for water, we can make better lives.

The partners behind Water Vision Denmark aim to further innovation in the Danish water sector, increase Danish water technology exports to the world and contribute to job creation across the water sector.

WATER VISION DENMARK
INNOVATION | EXPORT | REGULATION

Ministry of Environment
of Denmark

DANVA

Danish Environmental Technology Association
Association for Danish Environmental Technology Companies

DI | Water

Learn more about Danish water solutions, find more cases from around the world and connect with Danish water experts at

www.stateofgreen.com

Join us in Copenhagen for the IWA World Water Congress & Exhibition, 11-15 September 2022

www.worldwatercongress.org

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

Confederation of Danish Industry

DANISH ENERGY

Danish Agriculture & Food Council

wind denmark

MINISTRY OF INDUSTRY, BUSINESS AND FINANCIAL AFFAIRS

Danish Ministry of Climate, Energy and Utilities

Ministry of Environment of Denmark

MINISTRY OF FOREIGN AFFAIRS OF DENMARK