KWB

Annual Report 2022

Welcome

Water is a wonderful substance – and a precious resource. This past summer's drought, the fourth in the last five years during these times of climate crisis, shows how precious it is. Crises – and debates about them – are omnipresent, and the associated vocabulary can seem inflationary, carrying an additional risk of desensitisation when awareness should be raised. However, there's no other way to put it: The water crisis is real and is getting worse.

Frank Bruckmann (left)
Nicolas Zimmer (right)

A gloomy prospect? Undoubtedly, but it's also an incentive to act for our future! So at K*W*B, we're taking action. In the 21st year of K*W*B's existence, we've established ourselves as an important player, not just in applied water research, but also in developing cross-sectoral solutions to climate change's key challenges and crises, in the realm of water and others far beyond.

Especially, but not solely for Berlin, this is a great gain. Through its expertise, development of ideas and acquisition of project funds at the national and EU levels, K*W*B is able to secure significant grants from ongoing projects and regional partners. These include Berliner Wasserbetriebe, Technologiestiftung Berlin (Berlin Technology Foundation) and the Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action. Above all, K*W*B was able to bring issues and pilot projects to Berlin which are highly relevant and significant far beyond the city's and state's borders. These run the gamut, from water supply and climate adaptation measures, to the circular economy and digitalisation, from trace substances in bodies of water and drinking water, to rainwater management, blue green infrastructure, and smart cities. K*W*B is also developing internally in a future-oriented way. An example of this is the establishment of a hydroinformatics group linking all of K*W*B's research topics – i.e. a group dedicated to using data science, artificial intelligence and geometric deep learning to solve urgent water problems.

All this is happening not only against the background of the climate and water crises but also in a Europe where war is raging, the consequences of which will be felt in many areas of society, including science. It's remarkable how safely K*W*B is navigating through increasingly turbulent times and how positive the economic medium-term views are. We're confident that K*W*B will maintain this positive course despite present challenges – such as the particularly high level of sick leave in 2022 due to the COVID-19 pandemic – and also in the face of upcoming challenges. This confidence is fed not only by the red-hot, socially relevant issues that K*W*B is pushing forward, which aren't subsiding and must continue to be promoted despite more difficult framework conditions. The expertise, wealth of ideas and, finally, motivation and passion of the staff at K*W*B also enable us to positively look to the future. We would like to thank all the employees and management for their important and effective work. Not only does it make us more hopeful about the future, it also creates the freedom and motivation to work even more closely together.

Frank Bruckmann
CFO Berliner Wasserbetriebe (BWB)
CEO Berliner Holding GmbH

Nicolas Zimmer
CEO Techologiestiftung Berlin (Technology Foundation Berlin)

Executive Summary

The relevance and significance of KWB's work along the water cycle can hardly be overestimated. In 2022, this is perhaps truer than ever before, and it will only increase in the future. No, it's not hubris that makes me begin this annual report in this way. More than anything else, it's climate change and the accompanying multifaceted water crises which are elevating the importance of KWB's work.

Managing Director
Jochen Rabe

Climate change hasn't been a future scenario for some time now. It's already manifesting itself in the here and now with extreme heavy rainfall events, increasingly frequent flooding, and, at the same time, increasingly prolonged droughts and heat waves, which, among other things, also impact groundwater levels and thus our drinking water supply. The COVID-19 pandemic and Russia's war of aggression on Ukraine add to the impression that the world is coming apart at the seams. At times, the number of crises appears to be overwhelming.

But at KWB, we're not burying our heads in the sand. We'd rather look to the future, because the many enormous challenges along the water cycle are actually the driving forces behind our inventiveness and zest for action, and we're doing our part to master them with equal amounts of thoughtfulness and determination. This annual report provides an insight into what this specifically means.

Our first article is about the role of polluted rainwater and how the transformation into a water-sensitive, resilient city with all its benefits for public services, the environment and quality of life can be achieved (see page 10). Discover how our research plays a decisive role in strengthening know-how about the sources, effects and possible mitigation of the material load of rainwater and links this to the demands of the water-sensitive city. The vision of green blue modern cities can become reality and, thanks to our contribution, is well on its way!

The research projects mentioned in the article exemplify the important contributions we've made in Berlin and how we've been able to develop and acquire many significant projects in recent years. With our research contracts, we bring in an important share of grants in Berlin for key stakeholders from politics, administration, state-owned companies and the private sector. At the same time, our work and its impact reach far beyond the city limits. The large scale European project NextGen, which focused on circular economy implementation and the results of which we present in the second article of this annual report starting on page 16, is a good example of this. Through our collaboration with many European partner institutions, we've been able to develop circular economy solutions to produce potable water for both irrigation and groundwater replenishment, and to produce high quality fertilisers for agriculture.

While NextGen nears completion, our major EU Green Deal projects IMPETUS and PROMISCES are in full swing. The former deals with, among other things, the effects of climate change on regional water management, and we're proud that we were able to win the Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action as an active local consortium partner. The latter examines the threat posed by per– and polyfluoroalkyl substances (PFAS) and other compounds to the circular economy. You can read more about these and other projects starting on page 28. Collectively, they demonstrate our understanding of how to successfully apply and scale research results and our ability to determine and optimise their economic, environmental and social impacts. This holistic view also benefits us when it comes to ways to address problems and research projects involving digitalisation and the smart city. An important aspect – in a way, the flip side of the opportunities of digitalisation – is highlighted in our article on cybersecurity starting on page 22. German water companies have reported that digital attack attempts have increased sharply in recent years. Cybersecurity will play a prominent role in the future in continuing to ensure the capability and security of supplies to critical infrastructures. We therefore present our recently published cybersecurity report, which, in addition to a comprehensive literature review and description of the problem, provides a series of actionable recommendations as a basis for discussion, intended to help plant operators create cyber-secure infrastructures. In doing so, we're creating a foundation for more resilient water infrastructures and thus for the resource resilience of our cities. The interplay of resilience and digitalisation is also the subject of an accompanying study within the framework of the Smart Cities Coordination and Transfer Office (KTS) of the Smart City Pilot Projects (MPSC) funding programme 'Resilience in the Smart City'. The study asks which concrete contributions can digitalisation make to increase the resilience of a municipality and what is needed to enable a sustainable transformation. Find out more on page 40. In addition to the accompanying scientific research, we're actively involved in two projects in Berlin within the MPSC funding programme: the green light was recently given for the model projects Data Governance and Smart Water, where we'll also benefit from my involvement in advising both the German Federal Ministry of Housing, Urban Development and Building and the Berlin Senate Chancellery on policy and strategy development.

In the second major section of the annual report, we dare to venture out and take a glimpse into the future. The prelude, which starts on page 50, is the basis for our future: groundwater. Groundwater, which is hidden deep underground, is essential to the drinking water supply. To raise awareness amongst the population about this valuable resource, we developed the augmented reality app 'Making groundwater visible' in the EU project digital-water.city, which interactively conveys knowledge about geology and groundwater in Berlin. The app expands from traditional visualisations into spatial, interactive views for a broad audience. At the same time, our work offers new approaches to representing complex information, which is crucial for the reproducibility of research results and adds a new quasi-physical dimension to complex numerical models.

Complex numerical models are also the appropriate keyword for the next article on Geometric Deep Learning and graph-based neural networks starting on page 54. In 2022, KWB established a new Hydroinformatics research group, an interdisciplinary group developing cross-departmental solutions against the backdrop of digitalisation to more effectively use existing systems and resources. In the group's article, the digitalisation potentials and how we'd like to achieve them are explained in detail. For example, our ageing prediction tool for sewers, SEMAplus, contributes to the goal of resilient, resource-saving urban development, through transferability, filling missing data or the development of new algorithms for the condition prediction of sewer reaches. There's also an in-depth report on SEMAplus on page 42, which, in addition to our cooperation with the city of Lausanne and the growing SEMAplus community, also takes a look at the application potential to our drinking water networks. While we're on the subject of digitalisation, I'd like to mention the online conference BLUE PLANET Berlin Water Dialogues, which we are organising for the first time this year and where I'm honoured to assist as an advisory board member. The conference, which focuses on artificial intelligence in the water sector this time, will bring together several hundred international representatives from governments, non-governmental organisations, research and academia, as well as international decision-makers from industry, energy and agriculture, and will provide opportunities for networking, developing new business models and potentially initiating new research and development collaborations.

Finally, the last article on the future of water reuse, which starts on page 58, rounds off the overview of our work. We can confidently call ourselves pioneers in the field of water reuse: after almost 10 years of work at the European level, we're now pleased to also be advancing reuse in various research projects in Germany. Here too, we've come full circle to my introduction: Against the backdrop of diminishing water resources due to a changing climate, water reuse makes a crucial contribution.

Despite the uncertain times, KWB is well positioned and we're looking toward the future with resourcefulness, courage and confidence. On one hand, this positive outlook is due to the successful economic development at KWB in 2022 – we've already been able to secure a healthy increase in project funding for the coming years. On the other hand, the optimism is due to our staff, all of whom are highly committed, competent and hungry for knowledge and who acquire and work on future facing national and international research projects for KWB.

By the way, who's behind KWB and what the world of applied science actually looks like behind the scenes can be seen thanks to the fantastic eye of our photographer Iryna Dazhura from Ukraine – check out our team on page 66 and see how we spent our latest company outing.

I hope you enjoy reading our annual report, and I hope it will inspire you in the face of the many challenges surrounding water and the city, climate change and digitalisation, to join our pragmatic optimism.

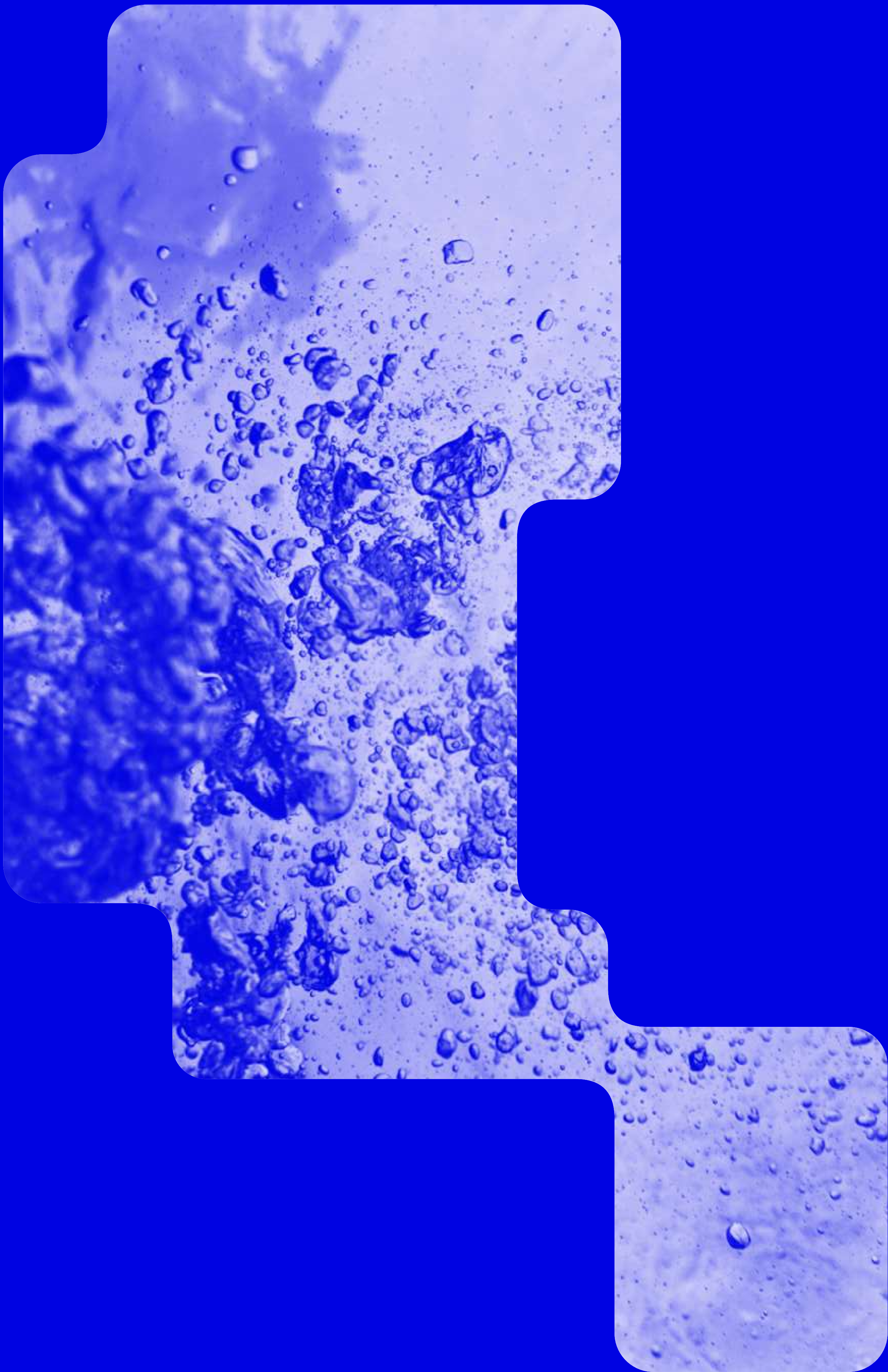
Jochen Rabe
Managing Director | October 2022

Immersion

Dive into the latest developments and research results at KWB with us. You'll find topics like rainwater in the water-sensitive city, innovative technologies for the circular economy, our report on cybersecurity, and a selection of current projects.

Find out what kept us busy in 2022 in the following articles:

- What does rainwater pollution mean for the water-sensitive city?
- How sustainable is the circular economy?
- New challenges: Cybersecurity in the water sector
- Selection of projects



What does rainwater pollution mean for the water-sensitive city?

Dr. Daniel Wicke

Dr. Andreas Matzinger

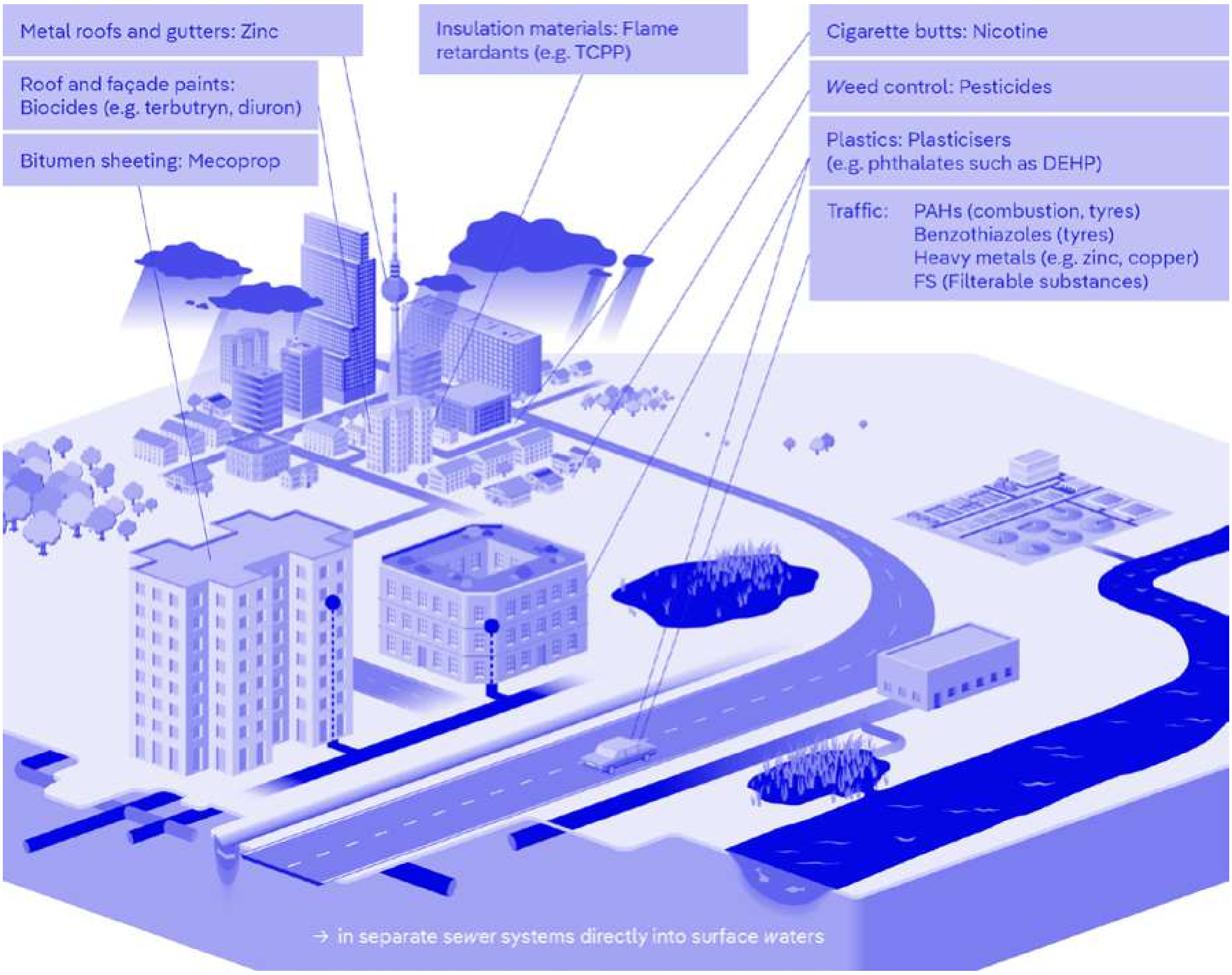


Fig. A: Sources of rainwater runoff pollution in the city

Thanks to the new blue green vision of a modern, water-sensitive city, the transformation of classic urban drainage is in full swing. This paradigm shift contributes to many goals, from water protection to livability, and to biodiversity. However, the often poor quality of rainwater is rarely considered, although it can reduce the positive potential of water-sensitive urban development, which include rainwater utilisation or supporting groundwater levels through infiltration. KWB's work in this field shows both a need for further research as well as an implementation gap.

"The transformation of urban drainage for water-sensitive cities undoubtedly brings many advantages for the environment and quality of life in urban areas and should definitely be promoted. It is critical that the benefits are not reduced or even reversed by polluted rainwater."

Rainwater runoff pollution

In the city, rain encounters a variety of different surfaces and materials, the components of which are washed out and away in the process (Fig. A). As shown in a number of studies in recent years (e.g. in the KWB projects OgRe and BaSaR), numerous substances end up in rainwater runoff: biocides from building materials, heavy metals like zinc and copper from metal roofing and traffic surfaces, polycyclic aromatic hydrocarbons (PAHs) from combustion residues (e.g. from traffic), nicotine from cigarette butts, and pesticides such as glyphosate from weed control, just to name a few. Plasticisers from plastic materials or flame retardants have also been found at significant concentrations in rainwater runoff.

In separate sewer systems, where rainwater runoff is discharged separately from wastewater, all these substances enter surface waters directly and are therefore mostly untreated. In Berlin, about 70 % of the total rainwater runoff volume is discharged directly into rivers and lakes. In surface water bodies, permissible maximum values (environmental quality standards – EQS) exist for several pollutants, which, at least in rainwater runoff, can be significantly exceeded. Whether these EQS are also exceeded in the surface waters depends on the dilution in the water bodies. As seen in Figure B, dilutions by a factor of 5-10 or higher are necessary avoid exceeding the EQS for some substances, e.g. for the dissolved heavy metals zinc and copper or the PAH benzo[b]fluoranthene. This shows the relevance of pollution in rainwater runoff, especially for smaller urban water bodies, which may receive rainwater runoff shares of more than 50 % and have a correspondingly low dilution. Reducing pollution inputs is therefore necessary from the perspective of water protection. ▶

Focus on the *w*ater-sensitive city

Water-sensitive urban development generally leads to decoupling rainwater runoff from sealed surfaces from the sewer, thereby directly protecting urban waterways from such pollution. In Berlin, this type of development is strongly promoted by the current state government's coalition agreement. The Berlin Rainwater Agency, which promotes water-sensitive urban development via information, consultations, events, and networking, was already established during the last legislative period. A similar development can also be observed nationally and internationally: nature based solutions (NBS) (EU), low impact development (LID) (USA), sustainable urban development (SUD) (GBR), sponge city (PR China), water-sensitive urban design (WSUD) (Australia) and decentralised rainwater management (DE) are terms used in international water-sensitive urban development. KWB supports this development via modelling and systematic evaluation of measures' effects as well as the development and application of planning methods and planning aids, such as measure cards (BMBF projects KURAS and netWORKS4).

Although measures and goals vary between cities and countries, the general focus is on the idea of managing rainwater runoff in situ. Depending on the objective, the aim is not just to protect water, but also to irrigate urban greenery, improve the quality of life and urban climate, supply groundwater/small bodies of water, or for other uses (e.g. sanitation, swimming pools, etc.).

Ho*w* sensitive is the *w*ater-sensitive city to pollution of rain*w*ater?

The contamination of rainwater runoff does not disappear simply by disconnecting the sealed surfaces from the sewer system. This just relocates the pollutants. The significance of this relocation is still unknown for the entire range of substances, but there are already findings for various substances.

"The good ne*w*s is that a variety of effective measures already exist to reduce pollutant inputs to rain*w*ater runoff and surface *w*aters."

When rainwater runoff is infiltrated, there is a fundamental risk of displacement into soil or groundwater. For dissolved heavy metals from metal roofs and for biocides from building materials, various research groups have shown that these substances are not sufficiently retained in the soil and may enter groundwater. However, information on the fate of these substances in groundwater is still scarce. As a precautionary measure, Berlin has, for example, made infiltration of rainwater from building surfaces containing biocides subject to approval (see Berlin's Precipitation Water Exemption Ordinance).

If collected rainwater should be used for fountains/water features or toilet flushing, the hygienic load is currently being evaluated, e.g. in the case of

Rainwater-fed pond at the Berlin malt factory

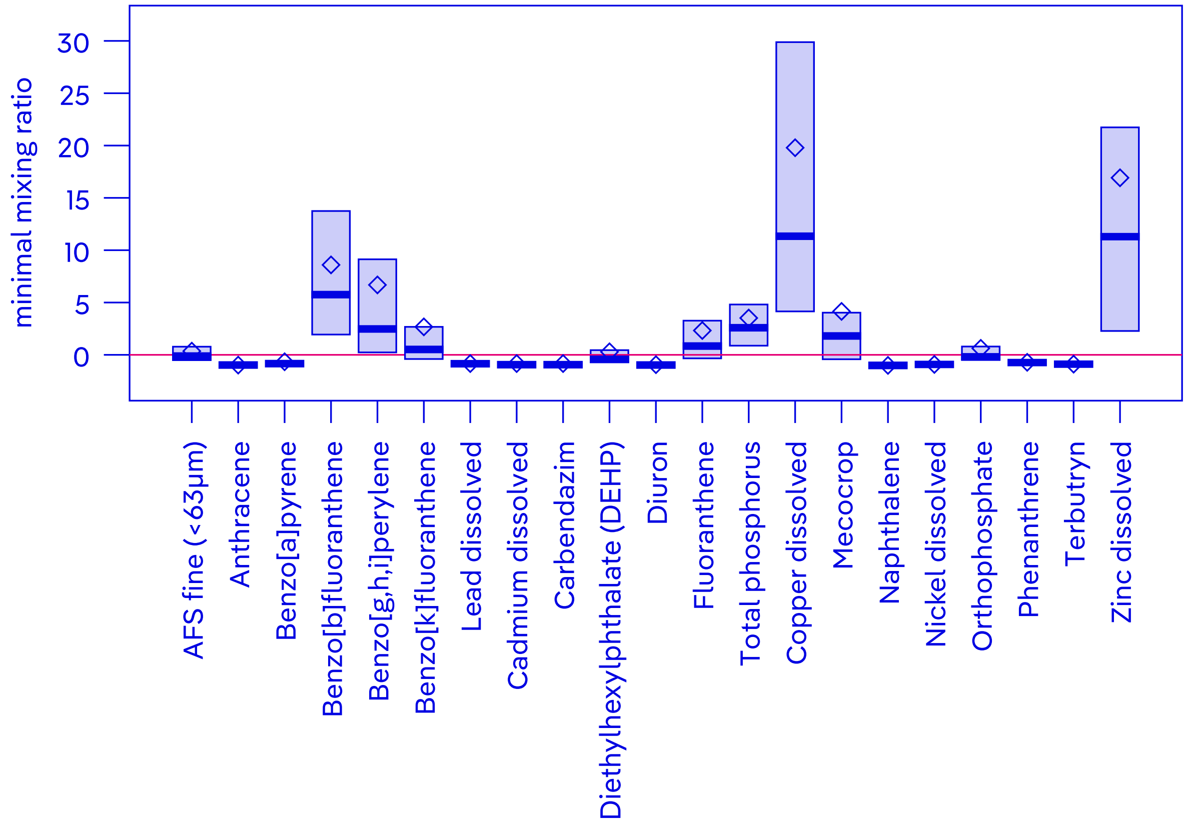


Fig. B: Minimum mixing ratio between uncontaminated river water and contaminated rainwater required to meet environmental quality standards. The boxes show the middle 50 % of the measured values from the OgRe project, the diamonds are mean values, and the black lines are median values.

rainwater runoff from pavements (e.g. due to animal excrement). In the case of irrigation with rainwater, biocides (from building materials) and dissolved copper (e.g. from gutters or roof fittings) are particularly problematic, as they negatively affect plant growth. Additionally, other pollutants, such as road salt, can also have negative effects.

For many substances and measures, on the other hand, no knowledge exists at all. However, with the exception of street and pavement runoff, pollution often occurs on the same properties where water will be managed.

The solution is so close

The good news is that a variety of effective measures already exist to reduce pollutant inputs to rainwater runoff and surface waters. In the BaSaR project, for example, we have developed three fact sheets which contain a series of concrete measures to reduce emissions from façades, roofs and properties. These can be used for new buildings or major renovations. For example, green roofs can be implemented using waterproofing without chemical root protection agents. Construction related weather protection, such as a sufficient roof overhang, can prevent rain from reaching the façade. The choice of building materials for façades also has a major influence. In this context, measures to avoid pollutant inputs (like choosing building products with no or low emissions) are preferable to end-of-pipe measures (e.g. treatment of polluted rainwater with filters).

The fact sheets have been published by the German Federal Environment Agency (UBA), which commissioned the study. The measures are estimated to reduce emissions from buildings by more than 90 % if considered at an early stage in the planning process. If rainwater is to be managed on site, considering potential pollution is particularly useful so as to not restrict the uses of rainwater.

New commercial product development can also contribute to the reduction of emissions. In the SpuR project, we successfully demonstrated two innovative solutions together with our partner companies: a façade paint with active substances which quickly degrade in the environment, and a rain filter with a newly developed substrate which removes more than 90 % of organic trace substances such as biocides. ▶

What happens next

The aim is to allow as few pollutants as possible to enter the environment from urban surfaces so that water-sensitive cities can thrive with clean water. This can only succeed with teamwork. There are also gaps in knowledge that need to be filled – for example, research on the relevance of polluted rainwater runoff for soil, groundwater and municipal use is still needed. Additionally, the behaviour and the interaction of the substances in the measures themselves have not been widely studied.

From a practical point of view, it is important to link planning aids together. KWB has created planning aids for reducing biocides in building related measures (BaSaR fact sheets on behalf of UBA) as well as for rainwater management measures (KURAS fact sheets and netWORKS4 measure cards). We also offer consulting services based on our extensive experience. On the other hand, it is important to educate investors and construction companies (as well as producers of building materials) about how increased, sensible and local management of rainwater and potentially other water sources also leads to higher demands on the environmental compatibility of building materials.

Particularly for small urban lakes, the water-sensitive potential of rainwater runoff as a water source is directly related to the risk of pollution. On one hand, small urban lakes need sufficient inflow to continue to fulfil their ecosystem services. Rainwater runoff from the surrounding urban areas is a suitable inflow for this. On the other hand, untreated rainwater runoff from sometimes heavily polluted areas leads to problematic lake pollution, for example with nutrients or (accumulating) priority trace substances. Since September 2022, KWB has been addressing this dilemma in the EU project AD4GD (All Data for Green Deal), aimed at proposing data-driven, lake specific solutions.

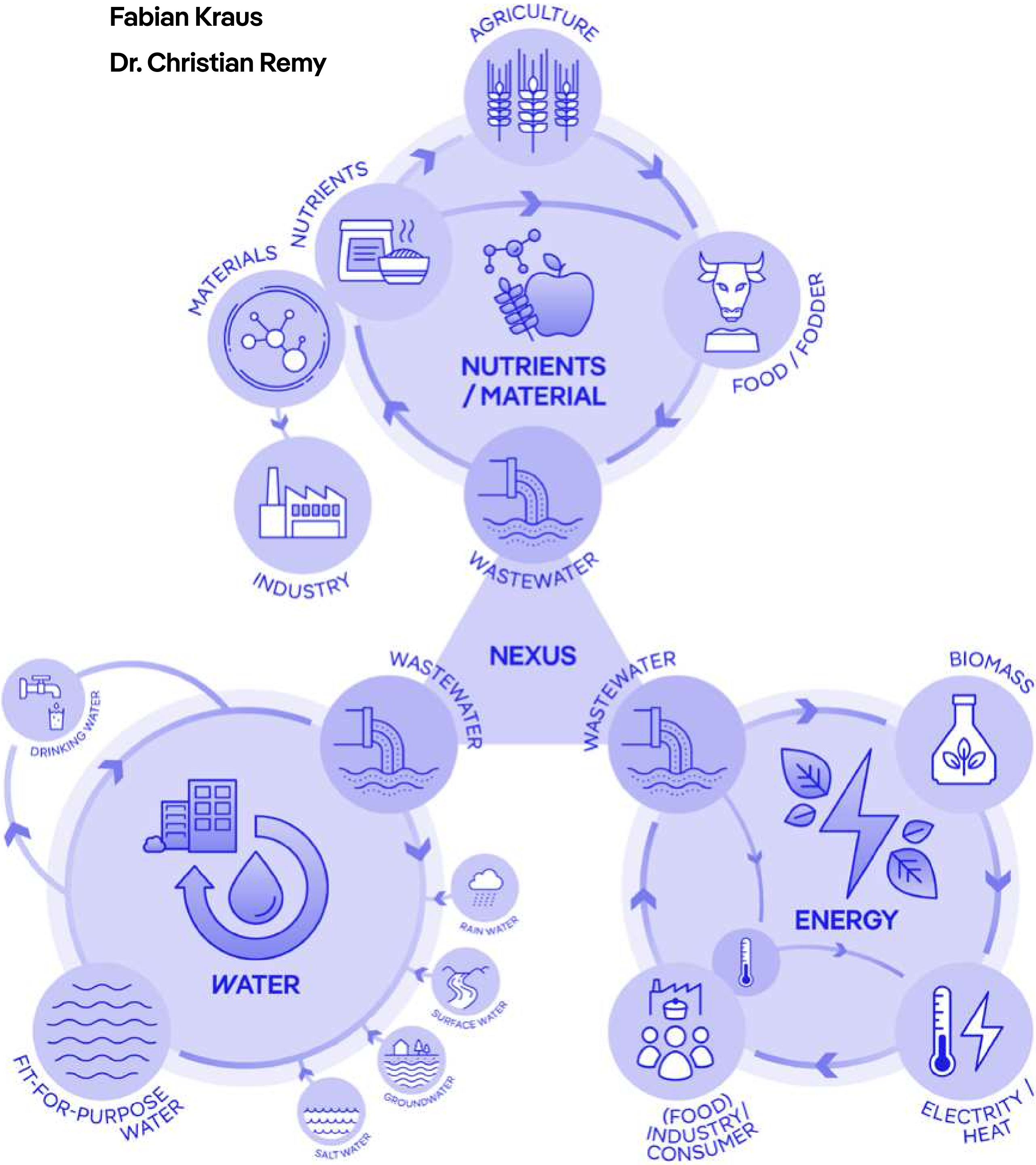
"Knowledge of sources, effects and possible reduction of rainwater pollution, as well as their connection to the demands of the water-sensitive city are an important basis for implementing blue green modern cities."

The transformation of urban drainage for water-sensitive cities undoubtedly brings many advantages for the environment and quality of life in urban areas and should definitely be promoted. It is critical that the benefits are not reduced or even reversed by polluted rainwater. Measures to avoid or treat the pollution of rainwater runoff should be considered accordingly when implementing water-sensitive city solutions. Knowledge of sources, effects and possible reduction of rainwater pollution, as well as their connection to the demands of the water-sensitive city are therefore an important basis for implementing blue green modern cities. ●

How sustainable is the circular economy?

Innovative technologies from our project NextGen

Dr. Anne Kleyböcker
Fabian Kraus
Dr. Christian Remy



Synergies in circular economy: wastewater is a resource for producing fit-for-purpose water and also contains materials (e.g. nutrients) and energy which can be recovered.

The year 2022 will, once again, be one of the hottest, driest and sunniest in Germany and Europe since the start of weather records. Due to advancing climate change, higher temperatures and changing rainfall distributions are expected to become the new normal. How do we deal with this situation in Germany, where until just a few years ago, most regions were barely affected by water scarcity?

"In the circular economy, *w*aste*w*ater is considered a valuable resource for the recovery of *w*ater, nutrients and energy. Synergies can often be exploited in the technical treatment of *w*aste*w*ater to produce reusable *w*ater."

In the recently completed EU Horizon 2020 project NextGen, KWB, along with 30 European partner institutions, considered, implemented, and evaluated various approaches to closing water, material and energy loops in ten case studies. In addition to countries like Spain and Greece, which have been struggling with water shortages for years, Romania, Sweden, the Netherlands, Switzerland and Great Britain were also involved.

In the circular economy, wastewater is considered a valuable resource for the recovery of water, nutrients and energy. Synergies can often be exploited in the technical treatment of wastewater to produce reusable water, so that certain resources contained in the wastewater, such as nutrients and/or energy in the form of heat or biomass, can be simultaneously recovered.

For four years, we scientifically cooperated with the case study in Germany (Braunschweig), evaluated different approaches to the circular economy in terms of their sustainability for the environment, and investigated whether closing loops can create risks for people and the environment.

*W*ater reuse versus *w*ater scarcity

The case studies from Spain (Costa Brava) and Greece (Athens) examined how treated wastewater can be reused for irrigation or to replenish natural groundwater resources. In Costa Brava, Spanish partner institutions were able to show that the relatively high costs of membrane processes can be significantly reduced by reusing used modules. The quality of the purified water nevertheless meets the high standards for groundwater recharge in Spain. In terms of energy, water reuse is significantly more economical than desalination of seawater and therefore also emits fewer greenhouse gases, making it an overall sustainable solution.

In Athens a decentralised approach was tested, in which wastewater was 'mined' directly from the sewer and treated on site in a membrane bioreactor. The treated water can be used to cover the freshwater needs of a nursery, but with higher energy consumption compared to the central freshwater supply. So that the carbon footprint is not further affected by this approach, renewable energy, such as wind or solar power, should be used. The consistently high quality of the purified water is important in water reuse: possible pathogens must be reliably removed or killed so that no sanitary risks arise during use. This level of safety can be achieved using membrane processes, which were also combined with UV disinfection in Athens. Sound scientific assessment of the potential risks of reusing reclaimed water is very important. With the help of an in-house risk assessment tool, KWB was able to show that the requirements for safe use of this water can be met in both cases. ▶

Decentralised solution for water reuse in Athens: membrane bioreactor producing water for irrigation at the tree nursery

Nutrient recycling versus raw material consumption

Since 2019, nitrogen and phosphorus have been recovered from highly concentrated liquors originating from digestate dewatering at the Braunschweig wastewater treatment plant. The nutrients are recovered as fertilisers in a two-stage process. Liquors from both the dewatered excess sludge digestate and from the mixed sludge digestate are treated year-round in the final stage. This amounts to about 20 m^3 of sludge water per hour.

Firstly, carbon dioxide stripping raises the pH of the liquors, which promotes the precipitation of the fertiliser struvite (ammonium magnesium phosphate). Magnesium chloride is dosed to control precipitation. The precipitate is separated in a sedimentation reactor. The pH is then raised by adding caustic soda and the liquor is heated to 55 °C, which converts the remaining ammonium into ammonia. This is stripped out of the sludge water with air and collected in a scrubber with sulphuric acid. Finally, the fertiliser diammonium sulphate is formed.

Depending on the mode of operation, about 150 to 300 tonnes of struvite and about 2,000 tonnes of diammonium sulphate solution can be produced annually. This corresponds to a total annual load of 18 to 37 tonnes of phosphorus and 190 tonnes of nitrogen. In relation to the wastewater treatment plant influent load, this results in recovery rates of 8-16 % for phosphorus and 13 % for nitrogen. Both fertilisers are very low in heavy metals and can be used in agriculture.

The growth of struvite crystals was technically difficult. They require a certain size (and mass) for sedimentation in the crystallisation reactor. The dosing line for magnesium chloride was adapted and analyses were carried out to find out which compounds were hindering crystal growth.

From an ecological point of view, the wastewater treatment plant's reduced nitrogen load due to the targeted runoff of nitrogen is particularly noteworthy. This leads to lower emissions of climate-damaging nitrous oxides, as well as better treated wastewater effluent with less nitrogen. In terms of energy and climate, nutrient recovery is roughly neutral, as additional chemicals and energy are required to obtain the savings in mineral fertiliser and emissions.

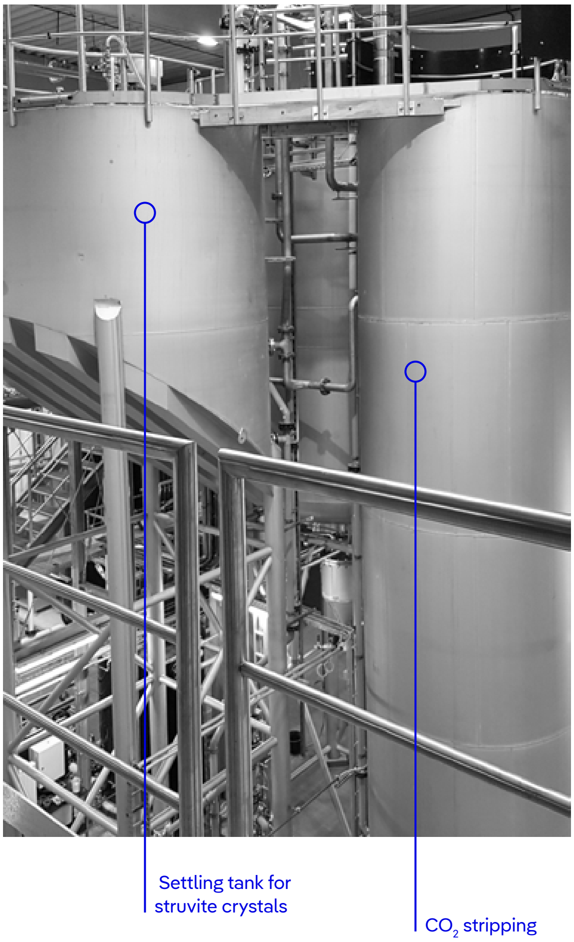
The farmers in the Wastewater Association Braunschweig will directly use fertilisers from the wastewater treatment plant. Especially with currently high fertiliser prices, the pathway of nutrient recycling from wastewater is becoming attractive. However, before application, further processing of the recovered nutrients is still required to make them suitable for use in agriculture.

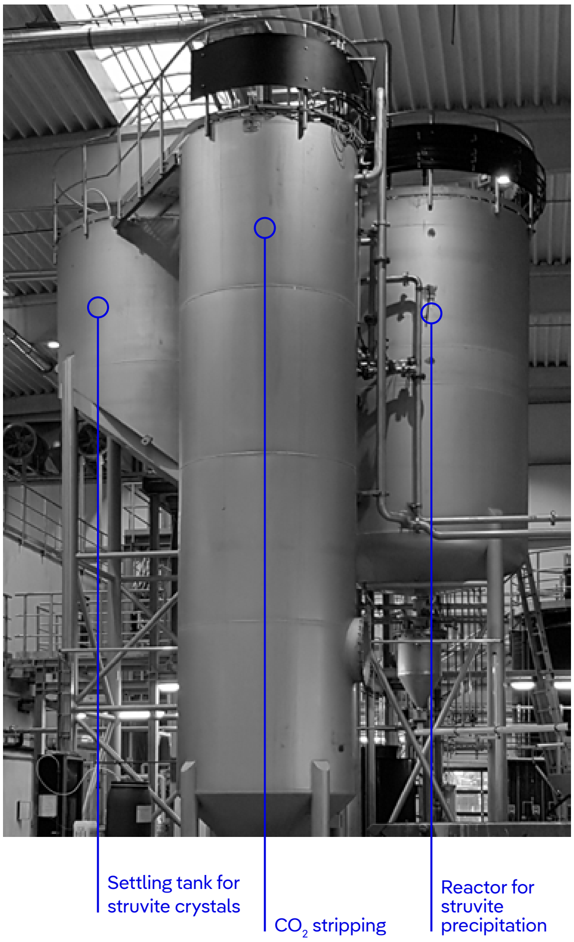
Energy recovery for climate protection

The recovery of energy from wastewater and sewage sludge was the focus of the case studies in Braunschweig, in Athens, and in Spernal, England. One way to use energy is to convert organic material into biogas, like the anaerobic (oxygen free) process in a biogas plant. In Braunschweig, the existing digestion of sewage sludge was improved by pretreating and hydrolysing the sludge at a high temperature. After steam injection, temperatures of over 150 °C prevail, so treated sludge can subsequently be better converted into biogas. This means more energy from the local combined heat and power plant and some extra effort for the steam and further treatment steps. The overall balance showed that good integration of the system can reduce the climate footprint by up to 650 t CO2e per year. Moreover, synergies for nutrient recovery exist, as more nutrients can be released and recovered through improved sewage sludge degradation.

In Spernal, England, a completely new concept for wastewater treatment was demonstrated: instead of purifying wastewater with an abundant input of oxygen, an anaerobic (oxygen free) process was used. During the process, a large portion of the organic matter is converted directly to methane, which can then be separated and used. However, separating the methane still dissolving in the water proved to be a challenge: the membrane process used consumed more energy than was gained from the additional biogas. It is better to use only biogas independently outgassed from wastewater. This configuration can save significantly energy and has a more than 50 % reduced CO2e footprint compared to a normal wastewater treatment plant operation. Again, there are synergies with nutrient recovery: nitrogen and phosphorus can be removed and recovered via physical processes after the membrane stage. This also avoids climate damaging nitrous oxide emissions from sewage treatment, which can arise in the previous concept of biological nitrogen removal. It's another success on the road to climate neutrality.

In Athens, an attempt was made to use the waste heat contained in wastewater at small scale on site. A heat pump can extract up to 5 K of heat from purified water, which is then available for various purposes such as heating or hot water. Using green electricity from renewable sources for the heat pump is important here. That way, CO2 emissions are also saved in the overall balance if natural gas for heating can be replaced by heat from wastewater. ▶



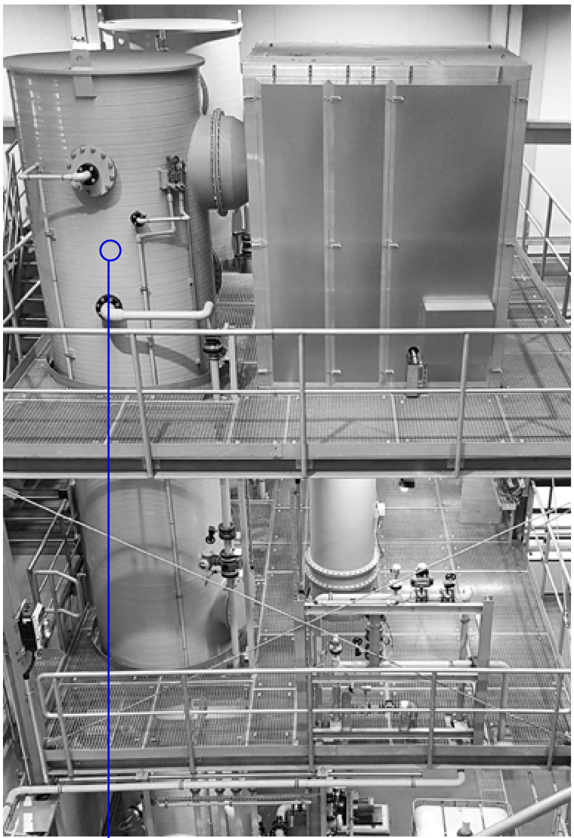


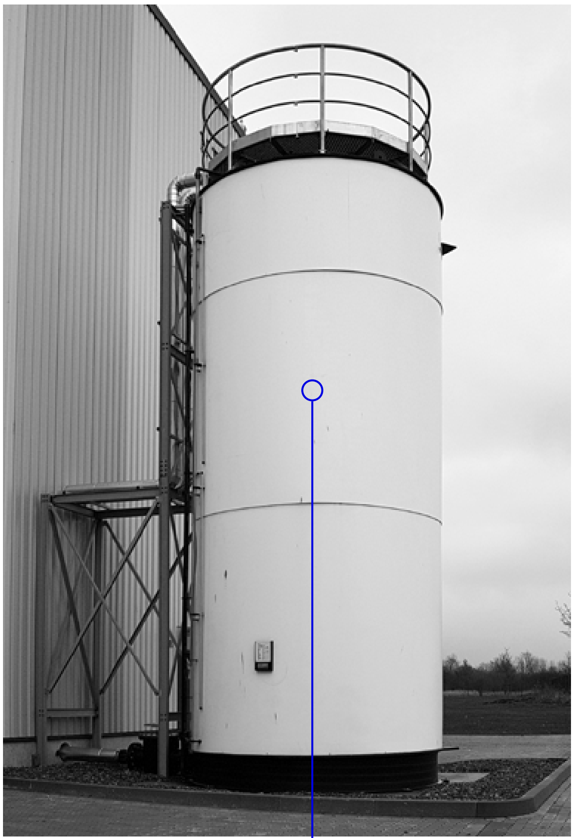
Phosphorus recovery plant for struvite production in Braunschweig

*W*hat did *we* learn from NextGen?

Our risk assessments showed that the circular economy approaches are suitable for producing water safe for human health, water for irrigation and groundwater recharge, and high quality fertilisers. NextGen technologies also enable the increasingly efficient recovery of renewable energy. Nevertheless, the sustainability assessment indicates that circular economy concepts are not automatically better for the climate and environmental balance. Efficient operation of technologies and good integration into an overall concept are important for this. When water is scarce, the reuse of treated wastewater is a very good solution, but this can often only be achieved with higher energy consumption. Thus, green energy with a low CO2e footprint should be used for operation to avoid possible increases in the carbon footprint. Furthermore, nitrogen recovery can contribute to preventing nitrous oxide emissions. As a powerful greenhouse gas (265 times as harmful as CO2), nitrous oxide can be produced during the biological conversion of nitrogen in wastewater treatment plants. The circular economy has an answer to this, too.

"Our risk assessments showed that the circular economy approaches are suitable for producing water safe for human health, water for irrigation and groundwater recharge, and high quality fertilisers."





Nitrogen recovery plant for ammonia stripping and diammonium sulphate production (left); storage tank for diammonium sulphate (right)

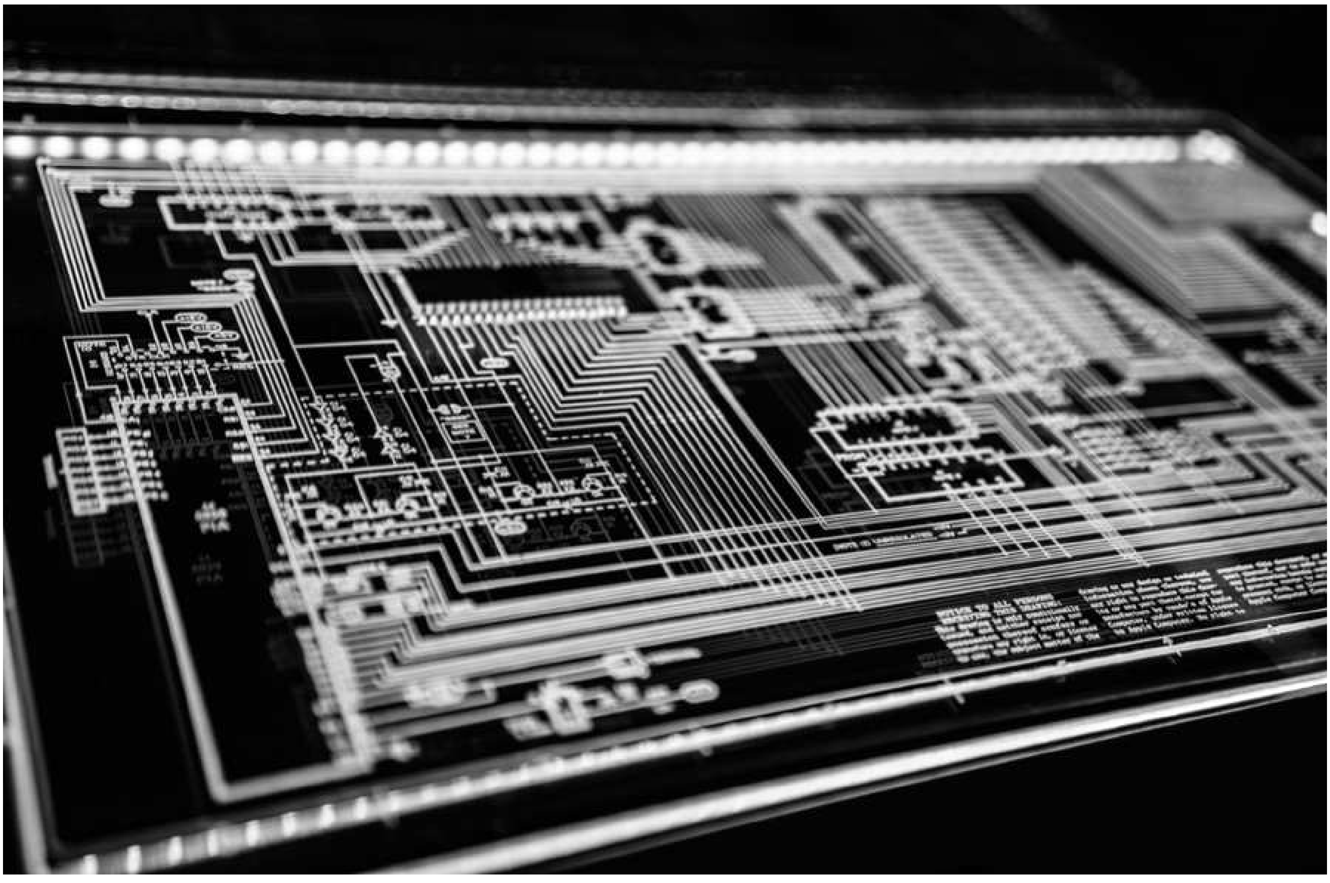
However, it should be noted that the priority of wastewater treatment plant operators is the quality of the purified water, and not how to market fertilisers for agriculture. With mostly decentralised solutions and comparatively small product volumes, wastewater treatment plant operators are facing major competition from the fertiliser industry. In contrast to that industry, though, operators lack the logistical opportunities and the legal know-how to market their fertilisers. To close the gap between producers and end consumers, a middleman who could upgrade their fertiliser products with environmentally friendly products from the circular economy and successfully market them is needed.

Detailed results of these technical solutions and case studies, as well as their life cycle and risk assessments, can be found in the following KWB publications: Kleyböcker et al. (2022a), Remy et al. (2022) and Kleyböcker et al. (2022b). 'Technology Evidence Base' (TEB) (Kleyböcker et al., 2022b) is a kind of Wikipedia for technologies from the circular economy, where all the NextGen technologies are explained in detail and linked to the case studies' results. Additionally, two other projects called Ultimate (Horizon 2020) and B-WaterSmart (Horizon 2020) will also include their solutions in the TEB. ●

New challenges

Cybersecurity in the water sector

Nikolaus de Macedo Schäfer



Climate change, a growing and increasingly urbanised world population, as well as ageing infrastructures and the transformation of the labour market, call for urgent modernisation in the water and sanitation sector. Among other measures, this can be achieved by connecting and automating components and processes in urban water management.

However, the introduction of networked and integrated digital solutions provides new vulnerabilities for malicious cyber activities. In recent years, the number of cyberattacks has increased dramatically – a prominent example being Oldsmar, Florida in the USA, where hackers managed to remotely increase the levels of lye in the drinking water, which is otherwise used in small quantities for deacidification, thus endangering the health of the population. In Germany, water companies have reported that in recent years, and especially since the pandemic-related rise of working from home, digital attacks have sharply increased. To continue providing the necessary performance and supply security of critical infrastructures, corporate management will have to place much greater importance on cybersecurity in future.

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Due to this, KWB carried out a comprehensive literature review on behalf of the Berliner Wasserbetriebe, and conducted interviews with experts in five key development areas of modernisation and digitalisation in urban water management, its infrastructures, and its associated risks. The five development priorities were:

1. Internet of Things (IoT) and smart sensors
2. Artificial intelligence (AI) for the water industry
3. Cloud migration
4. Transformation of the infrastructure
5. Smart Cities

Water 4.0: Opportunities and risks

The digital transformation of the water sector, also called Water 4.0 (analogous to Industry 4.0), leads to a clear increase in efficiency and sustainability compared to conventional water infrastructure. This is accomplished via process innovations, such as advances in data collection and processing, as well as through new applications, such as plant monitoring, or even by taking advantage of synergy effects from blue green infrastructures, for example. However, to ensure optimal and functional urban water management, a drastic expansion of cybersecurity is required, both in terms of technology and personnel.

Advances in IoT make it possible to secure water supplies, improve water quality and reduce water and energy consumption through automated system monitoring (Koo et al., 2015). IoT systems can also be scaled up relatively easily due to both the low cost and low complexity of their components, and they require little configuration thanks to widely used communication protocols (Singh & Ahmed, 2021). The first examples of such advances are automated water quality measuring stations which collect, evaluate, and communicate data in real time (Chowdury et al., 2019) or in smart irrigation systems that can save up to 70% of the water consumption of conventional systems (Ismail et al., 2019). Flood monitoring and warning systems or remotely controlled drinking water networks (smart water grids) are also possible through IoT advances. However, new vulnerabilities are simultaneously emerging due to the enormous number of endpoints (which are the sensors themselves) and the increased links to the internet. Due to the sensors' low computing power, the implementation of safety and security measures is more difficult. This increases the vulnerability of central data protection platforms and means that all personal and operational data, and subsequently also the maintenance of the higher level network, are at risk of attack (Koo et al., 2015). ▶

Report on cybersecurity in the water sector published in 2022 (available on the KWB website).

The use of AI in the water sector particularly supports the areas of forecasting and simulation, for example in predicting water demand and consumption, infrastructure maintenance or the occurrence and impact of disruptive events such as attacks or natural disasters. AI is also considered one of the underlying core technologies for digital twins, which are modelling systems linked to real-time data streams that can provide a continuously updated picture of the physical infrastructure as well as control it. AI can also be used in cybersecurity: on the one hand in attack prevention, where threats can be detected earlier and pursued more effectively (Tufan et al., 2021), and on the other hand in the reaction to attacks, so they can be fended off independently and defence strategies can be adapted automatically. However, newer forms of cyberattacks target not only the cyber-physical assets, but also the AI itself to gain control of the system and change its behaviour. Due to the core functionality of AI, decision making processes take place in a black box and are therefore hardly or completely untraceable, which means that cyberattacks on AI are (currently) very difficult to detect.

Cloud solutions and the integration of information (IT) and operational technologies (OT) are seen as key technologies to manage the storage and transfer of rapidly growing amounts of data. The data collected and processed in IoT networks can be forwarded and used for automatic plant control. This not only increases the efficiency, but also the speed and, above all, safety of operations, as the system can immediately react in the event of a malfunction and human actors can access the system remotely. However, a particular challenge in the development of cloud applications is that cloud systems are particularly vulnerable to security breaches, thereby exposing risks regarding the protection of data confidentiality, integrity, and availability. Additionally, merging with IT networks creates new attack vectors for OT infrastructure, so even internet applications in daily use in an office environment create opportunities for hackers to gain control over water and wastewater infrastructure (Rasekh et al., 2016).

Analogue infrastructures are also changing. Technological progress is promoting the emergence of new hybrid (e.g. blue green) and decentralised systems, such as sustainable rainwater management, water reuse, source separation and decentralised water treatment (Rabaey et al., 2020). Innovations in this area enable considerable reductions in land and resource consumption (partly through the reuse and recovery of resources) and in the environmental impact of infrastructures for drinking water treatment, wastewater disposal and even flood protection. However, there are still uncertainties about the appropriate levels of integration and about optimal planning, design, and maintenance of decentralised and hybrid infrastructures. Moreover, the need to control such infrastructures leads to new cyber risks, not only due to their great heterogeneity in terms of type and function.

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Through the vertical and horizontal integration of urban systems, i.e. networking of different levels within a sector and cross-sector networking, the Smart City offers a framework for optimally implementing the Water 4.0 concept. As water utilities are connected to a variety of other infrastructures, operators can exploit synergies to improve their own operational capabilities. Such intersectoral cooperation is already displayed in the energy sector, which can improve the sustainability of water services, for example by enabling a reduction in energy consumption or measures for energy production or heat storage. However, the increased exchange of information within Smart Cities inevitably leads to increased risks and concerns about data security and privacy. In particular, the enormous size, complexity, heterogeneity and dynamics of Smart Cities' data ecosystems make conducting risk assessments and developing comprehensive cybersecurity strategies extremely difficult.

The next steps

To continue to support the security of the urban water sector’s digital transformation and its vital societal functions in the future, our cybersecurity report provides a series of actionable recommendations to assist plant operators in the shift to secure and resilient cyber-physical infrastructures. The focus lies on developing technical facilities and cybersecurity protocols as well as on the education and cooperation of actors in the sector. ▶

The former includes issues related to the protection of networked components, which requires the development of all-encompassing security frameworks (such as SDN, FRESCO, OrchSec, IOT@Work) that can handle heterogeneity. At the same time, however, AI solutions need to be further refined, not only to realize their potential for intrusion detection, but especially to strengthen their responsiveness and adaptability. This can be achieved by capturing the behaviour of cybersecurity analysts in designing training data sets.

Further development is needed to explore new requirements created by decentralised and networked infrastructures, such as uniform data standards that can promote the interoperability and the security of urban data. In addition to such preventive measures, the development of tools to simulate cascading effects and their propagation through the entire plant (already demonstrated in the SWaT testbed, the WADI testbed or the DHALSIM digital twin open source platform) is also particularly promising for planning redundant and resilient systems.

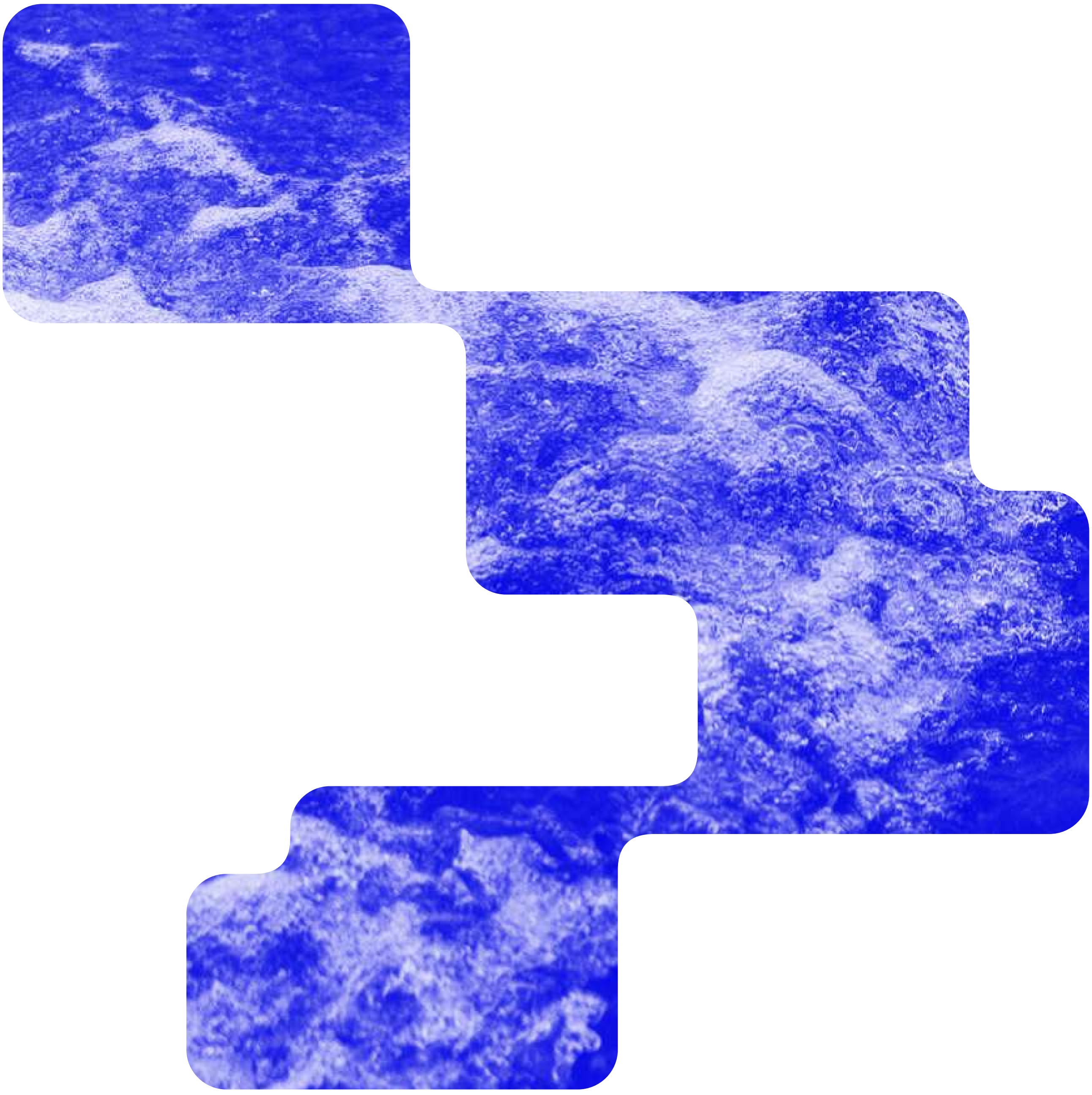
Since human error plays a key role in most cybersecurity incidents, it is considered one of the most important factors in systems' vulnerability. Therefore, establishing new educational opportunities must be given special priority. Practical and interactive education and training programmes that are integrated into daily routines have proven to be most effective in improving cybersecurity literacy. However, as most of the related research has been carried out in the energy sector, there is a significant need to tailor such measures to the water and wastewater sector. In the context of cybersecurity skills development, a growing skilled labour shortage is also a challenge, which needs to be addressed by revising outdated training formats and contents and updating comparatively low salaries.

One of the fundamental problems of Water 4.0 is the uncertainty of the convergence of IT and OT. This requires a complete risk-benefit analysis, for which new research, ideally carried out by an overarching working group, is needed. Such working groups can also develop concrete recommendations based on existing standards (e.g. ISO, BSI) and sector-specific needs. Expanding cooperation models for inter- and intrasectoral strengthening of cybersecurity is essential for the organisational and educational development of urban water management. By pooling expertise into a central institution which can formulate best practices and provide guidance to all, especially small and medium-sized operators, the overall goal of reducing human error can be achieved more quickly.

Addressing numerous and heterogeneous challenges in urban water management, both in climatic and safety issues, is difficult due to a lack of infrastructure and resources, and in particular, a lack of skills and expertise. The solution requires a drastic expansion of cybersecurity protection measures, in terms of both technology and personnel. This is the only way to ensure optimally functioning urban water management in the future. In its cybersecurity report, KWB formulated initial actionable recommendations to support water companies in fulfilling their critical tasks. Thus, we are making an important contribution to a safe and innovative future water industry landscape. ●

Selection of projects

- ▶ PROMISCES
- ▶ AMAREX
- ▶ CIRCULAR AGRONOMICS
- ▶ IMPETUS
- ▶ KTS
- ▶ SEMAPLUS
- ▶ DIGITAL-WATER.CITY



PROMISCES

Project volume
€ 11,995,413.75, financed by the European Commission

Partners
Bureau de Recherches Géologiques et Minières (coordination), Institut national de l'Environnement et des Risques, Institut de Physique du Globe de Paris, QSAR Lab, Umweltbundesamt, Berliner Wasserbetriebe, BioDetection Systems b.v., Fundacio EURECAT, COLAS Environnement, Gesellschaft für Chemische Technik und Biotechnologie e.V., Rijksinstitut voor Volksgezondheid en Milieu, Agencia Estatal Consejo Superior de Investigaciones Científicas, Stichting Deltares, Technische Universität Wien, Bundesanstalt für Gewässerkunde, Università Politecnica delle Marche, Consorci Besòs Tordera, Hoogheemraadschap van Delfland, Esolve Consultoria e Ingenieria Medioambiental SL, ACEA SPA, Sofia University St. Kliment Ohridski, Simam SPA, MicroLife Solutions b.v., ISB Water, Fovarosi Vizmuvek Zartkoruen Mukodoreszvenytarsasag, In Extenso Innovation Croissance

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▶ (1) Other groups of iPM(T)s include chemicals such as industrial additives, corrosion inhibitors, chlorinated solvents, and others. Software solutions include models operating at various temporal and spatial scales.

▶ (2) Here, environmental compartments include urban runoff, bank filtration, groundwater, sediments, soil in simulations, in urban areas and in large scale catchment areas.

▶ (3) Probabilistic risk assessments will be conducted for 4 of the 5 CE routes investigated in PROMISCES using a Bayesian approach to improve the transparency of the assessment.

▶ (4) Here, environmental compartments include soil, water, wastewater, sediment, landfill leachate, and sewage sludge.

Combatting industrial pollution to enable a circular economy

In case you haven't yet heard about forever chemicals, it's time to familiarise yourself with the topic. From your kitchen cookware to your outdoor clothing to your takeout boxes, per- and polyfluoroalkyl substances (PFAS) are nearly ubiquitous in 21st century life. Not only are they everywhere, but they've managed to get into everything – soil, sediment, and water – and removing them is no simple task.

That's precisely the goal of PROMISCES, which stands for Preventing Recalcitrant Organic Mobile Industrial chemicalS for Circular Economy in the Soil-sediment-water system. The project began in November 2021 and draws on the expertise of 12 KWB employees. PROMISCES aims to increase the circularity of resources by overcoming barriers associated with the presence of very persistent, very mobile (vPvM) and potentially toxic substances (PM(T)) in the soil-sediment-water system. In that way, PROMISCES will facilitate improved human health protection, contribute to the European Union's zero pollution ambition, and increase the acceptance and sustainability of the circular economy.

The project will investigate the removal of industrial PM(T) (iPM(T)) compounds in the following 5 circular economy (CE) routes in 7 case studies located in Spain, France, Italy, Bulgaria, Germany, and the Danube river basin above Budapest:

- Soil remediation for safe reuse in urban areas (e.g. construction, recreation)
- Semi-closed water systems providing drinking water supply
- Municipal wastewater reuse for crop irrigation
- Nutrient and energy recovery from sewage sludge and its valorisation as soil amendment in agriculture
- Materials recovery from dredged sediments and their valorisation for eco-materials or civil engineering.

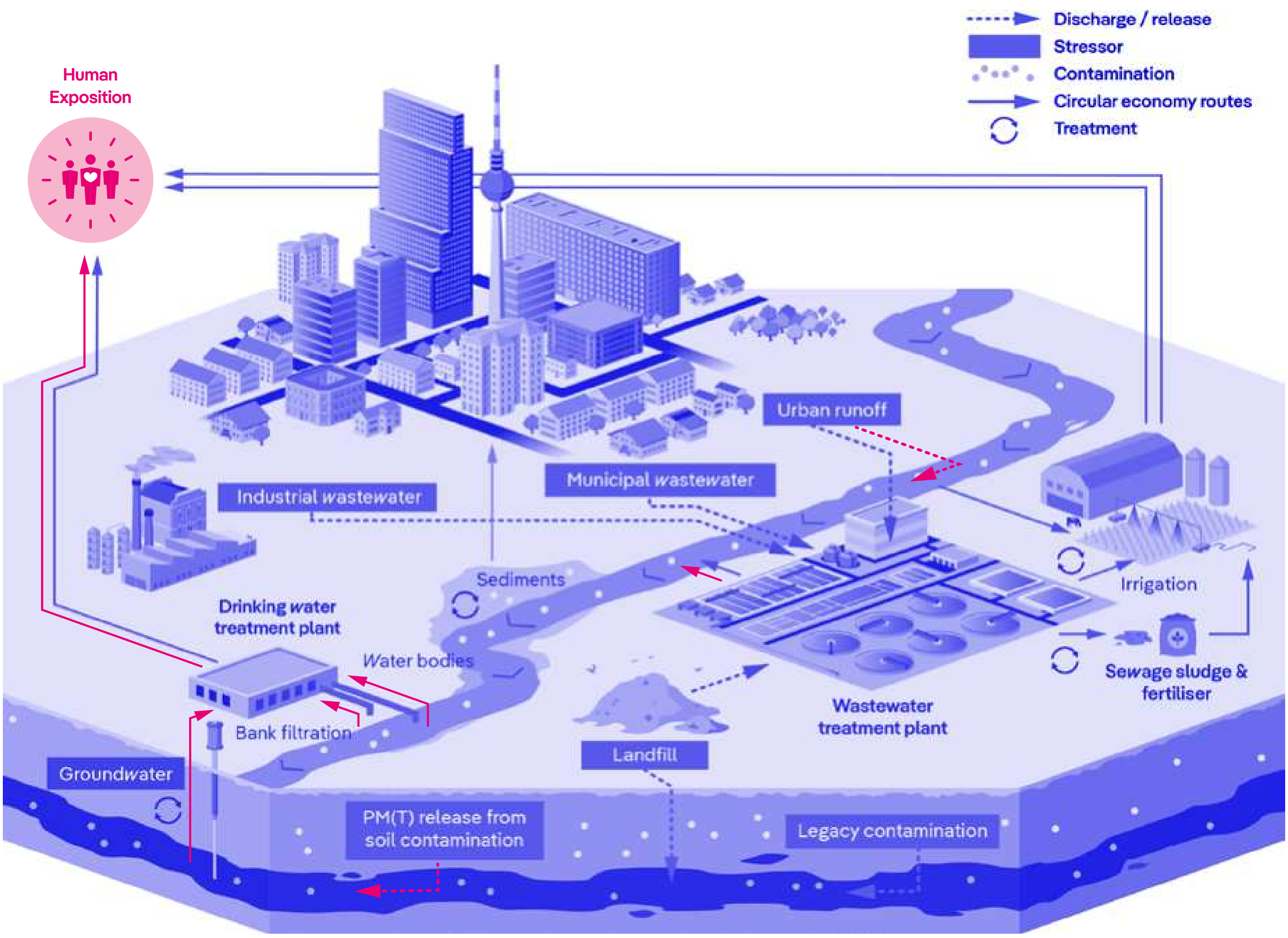
Within these case studies, PROMISCES will deliver extensive analytical and modelling results. The project will develop reliable quantitative analyses for different chemical groups including PFAS and their transformation products and for other iPM(T)s. ▶ (1) Fate and transport modelling will enable tracking of PFAS and iPM(T)s across several environmental compartments ▶ (2) to ensure interoperability of software solutions. By integrating measured or predicted chemical and toxicological data into risk assessment models, the uncertainty related to human health risk assessment in regards to the investigated CE routes will be reduced. ▶ (3) To provide more cost-effective, sustainable and ecological treatment technologies for environmental compartments ▶ (4), (bio)remediation technologies for PFAS/iPM(T) removal will be developed and assessed. Finally, a decision support framework (DSF) will enable stakehol-

▶ (5) The DSF will considering multiple types of data (e.g. the NORMAN database system (NDS), IPCHEM, the SPIN database, the REACH portal, data generated in PROMISCES, and literature data) for the its three components – diagnosis, solutions, and strategies – to provide the most comprehensive assessment of specific PM-use combinations.

ders to select solutions which can solve both short- and long-term PM pollution concerns, and evaluate strategies towards a non-toxic environment and safe reuse of resources. ▶ (5)

Within PROMISCES, KWB will monitor and model the fate and transport of PFAS and iPM(T)s in surface water and groundwater, focusing on quantifying chemicals in urban runoff and locating indirect discharges (i.e. non-point source pollution) of the contaminants. KWB will also conduct human health risk assessments for drinking water and groundwater to evaluate impacts of corrective measures and address decision making and risk management under uncertainty.

In regards to sludge valorisation, KWB will assist in creating a database of coefficients of PFAS transfer and conversion during sewage sludge treatment/valorisation using current and upcoming wastewater treatment plant (WWTP) technologies. Based on PFAS fate during different sewage sludge treatments which produce (in)organic fertilisers, a list of recommendations for delivering PFAS-free fertilisers, in line with the Sewage Sludge Directive and EU Circular Economy Fertilising Products Regulation, will be compiled.



Circular economy routes and chemical emissions pathways which are relevant and investigated in PROMISCES (Berlin's semi-closed water cycle route depicted in pink)

KWB will also lead the work package demonstrating solutions for zero pollution water cycles, including secondary effluent from municipal and industrial WWTPs, sewage sludge, landfill leachate, and drinking water. The Berlin case study features a tightly knit expert group including KWB, the Berliner Wasserbetriebe (BWB), the German Environment Agency (UBA) and the German Federal Institute of Hydrology (BfG). These partners will analyse the presence of PFAS and iPM(T)s in Berlin's semi-closed urban water cycle. Additionally, the PFAS and iPM(T) removal performance of ozonation and activated carbon treatment will be studied at full-scale wastewater treatment plants, the results of which will be written into a design and operation guideline for operators and engineering consultants.

Finally, KWB will put the DSF through rigorous testing by project partners as well as end-users (i.e., utilities and chemical companies) to ensure that the connections, pathways and solutions identified in the framework provide meaningful options for facilitating a circular economy. As the Innovation Manager of the project, KWB is also responsible for the technical follow-up of the work and will support the coordinator in monitoring the partners' progress.

AMAREX

Project volume
€2.4 million, sponsored by Federal Ministry of Education and Research, WaX Wasser-Extremereignisse, FONA Research for Sustainability

Partners
University of Kaiserslautern, Department of Urban Water Management (coordination); Universität Stuttgart, Institut für Siedlungswasserbau, Wassergüte- und Abfallwirtschaft; Berliner Wasserbetriebe; Ecologic Institut; Technologiestiftung Berlin; HELIX Pflanzensysteme GmbH; Stadtentwässerungsbetriebe Köln

Associated partners
Berlin Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action; Senate Department for Urban Development, Building and Housing, Geoatlas; Stadt Köln, Amt für Landschaftspflege und Grünflächen

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▶ (1) Water balance modelling

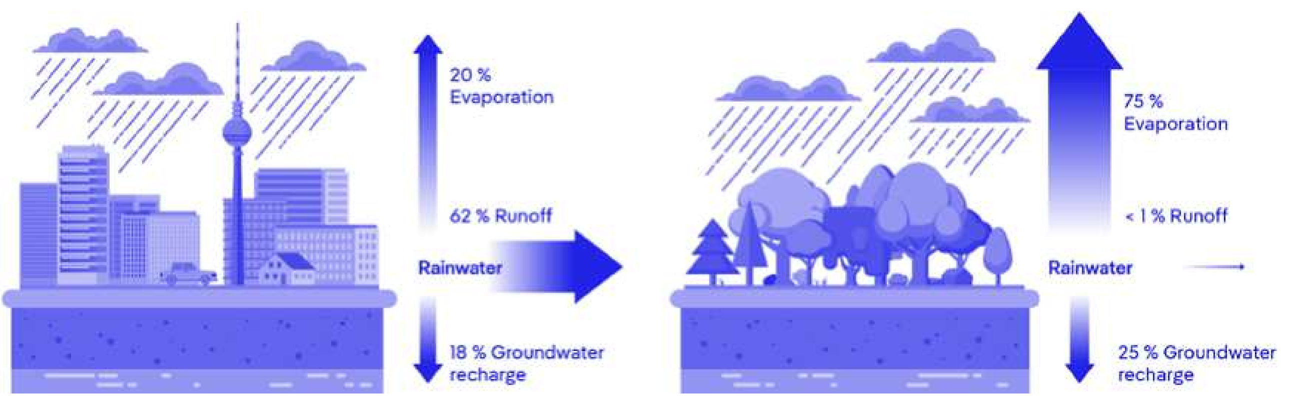
The Berlin ABIMO 3.2 water balance model is used as the basis for modelling urban water balance. This is based on a calculation of the landscape water balance by the Federal Institute of Hydrology, and was expanded to include sealed urban areas for Berlin. It uses Geoportal Berlin's spatially high-resolution boundary conditions (e.g. urban structure, sealing, soil properties) and is used by the state of Berlin to create online maps on the water balance. As part of AMAREX, the project partner Senate Department for Urban Development, Building and Housing (Geoportal) provided an open-source version of the model via the online-based version management service for software development GitHub. This allows all further developments in the project to be publicly available.

Turning cities into forests

Climate projections indicate that the frequency and intensity of extreme climatic events, such as heavy rainfall or drought, will increase significantly in the future. The negative effects of these extremes are particularly noticeable in urban areas. Compared to a near-natural forest or meadow, cities have significant greater stormwater runoff (in the sewage system) at the expense of evaporation and, to a lesser extent, greater groundwater recharge. With increasingly frequent and intense heavy rainfall events, rapid discharge of rainwater into surface waters can lead to greater water pollution and flooding. Furthermore, rainwater discharge causes a deficit in urban groundwater and surface water resources, which are particularly relevant for bridging increasing dry periods. Reduced evaporation in cities additionally intensifies urban heat islands as temperatures rise. It's not just climate change which is exacerbating these problems, but also increasing urbanisation.

In the AMAREX project, together with our project partners we are investigating options for adapting existing rainwater management (RWM) to increasing extreme loads caused by climate change. The local urban water balance will also be reviewed as an assessment indicator and potentially simple planning variable for climate impact adaptation. This should create important foundations for implementing climate impact adaptation measures in urban planning.

The aim of the project is to identify the functional expansion potential of existing RWM measures. For the RWM+ extension, additional storage space for flood prevention is considered, while the RWM+N category includes more extensive measures for use/irrigation as drought prevention. To do this, potential extension approaches are first optimised in the model and the field. Subsequently, evaluation methods for implementation potentials (competition, synergies) and impact quantification of these approaches



Evaporation: Can cities be turned into forests ?

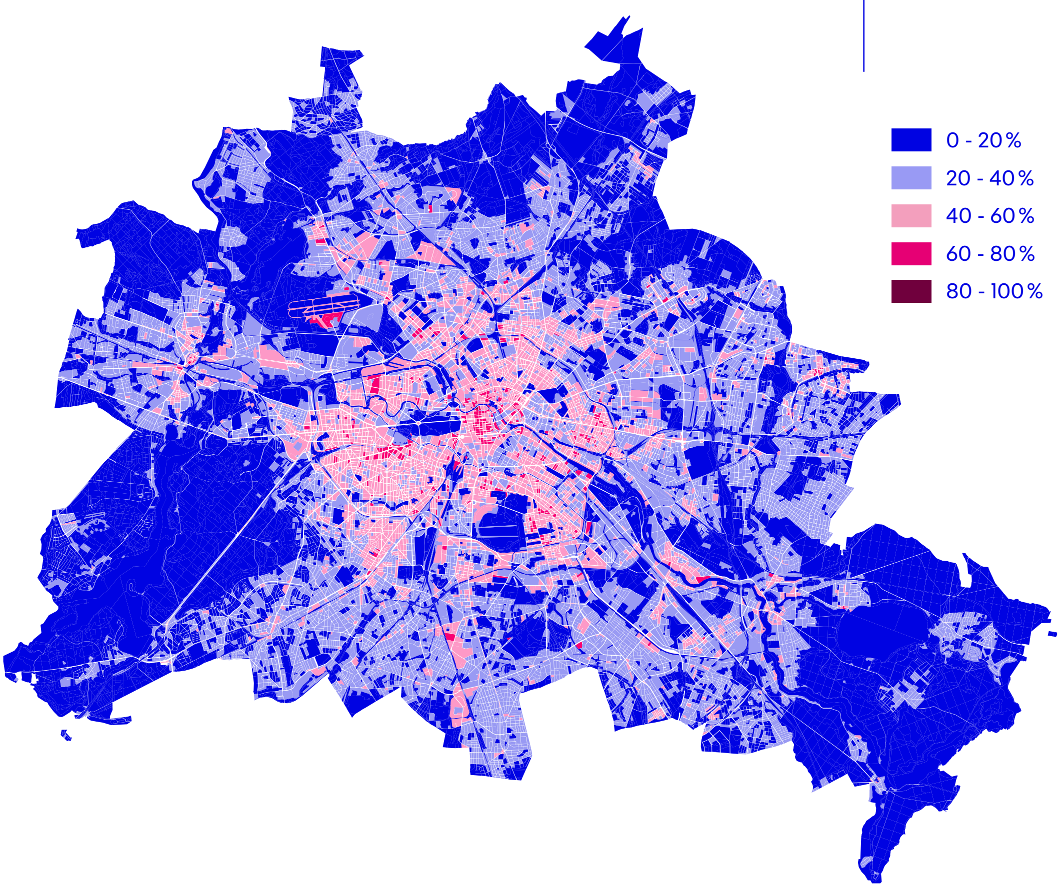
will be developed and transferred into a web-based tool to aid municipal practice. The approaches and tools are developed in close cooperation with the partner cities of Cologne and Berlin.

KWB is particularly dedicated to mapping the urban water balance in AMAREX. ▶ (1) The cumulative annual deviation of the aforementioned components – runoff, evaporation, groundwater recharge – from the natural state has been presented as an indicator of the water balance and has already been simulated for Berlin. The indicator is intended to show how far, from the perspective of the local water balance, an urban area is from a forest or meadow, which is assumed to be the natural reference state. The figure below shows that this indicator is high (> 60 %) in Berlin's highly sealed city centre. These values decrease in suburban areas and approach below 20 % in city parks, forests and lakes. In the coming months, AMAREX will examine how suitable this deviation in the annual water balance from a near-natural state is as a planning parameter for reducing the consequences of extreme climatic events via targeted measures.

KWB is further improving the AMAREX project model. The source code was adapted into the current version (3.3) so that the model can be easily run with different boundary conditions via a set of auxiliary tools (as a package developed in the programming language R). Further planned steps relate to RWM considerations, improved street mapping and adapting connection degrees to the data of project partner Berliner Wasserbetriebe. Both the latest version of the model and the associated R package are publicly available on KWB's GitHub page.

As part of the water balance evaluation for the city of Berlin, the 'cumulative deviation of the annual water balance from the natural state' indicator was introduced. This is based on the proposals of DWA M102/4 but summarises deviations for individual components. For this purpose, the amounts of deviation in the runoff, evaporation and groundwater recharge components (incl. interflow) are calculated individually and added together. The higher the percentage value, the more the local water balance differs from that of a meadow or forest area.

The water balance model will be made available to researchers, and will also be implemented in a web application in cooperation with the Technology Foundation Berlin. Simple scenarios will illustrate the effects of densification and implementation of RWM for concrete urban spaces in a user-friendly way.



Percentage deviation from the natural water balance

Circular Agronomics

Project volume
€7,021,760, financed by Horizon 2020 European Union Funding for Research & Innovation

Partners
Institut de Recerca i Tecnologia Agroalimentaries; Wageningen University; Institut für Agrar- und Stadtökologische Projekte an der Humboldt-Universität zu Berlin; Technische Universität München; Höhere Bundeslehr- und Forschungsanstalt für Landwirtschaft Raumberg-Gumpenstein; Centre de Recerca en Economia i Desenvolupament Agroalimentari-Upc-Irta; Teagasc - Agriculture and Food Development Authority; Fondazione Crpa Studi Ricerche; The Rural Investment Support for Europe Foundation; Sogesca S.r.l.; Pondus Verfahrenstechnik Gmbh; Nutrients Recovery Systems; Eastern Africa Farmers' Federation Society; Asio Spol Sro; Soepenberg Fertilizers; Eidgenössisches Departement für Wirtschaft, Bildung und Forschung

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▶ (1) Over the past two years, KWB operated a low-pressure degasification pilot unit. Various operating modes as well as fillings and perforated plates in the columns were tested. Besides operational difficulties such as column flooding, our results revealed different potentials for reducing the chemical and heat requirements of degasification. This can reduce associated environmental and economic impacts, such as the carbon footprint and the costs of the process.

Using the knowledge we gathered in Circular Agronomics, we optimised the process design and reconstructed our pilot unit. We ended up with a larger column cross-sectional area to avoid column flooding and foaming problems while keeping pressure loss as low as possible. Upstream carbon dioxide stripping before ammonia stripping reduced caustic soda consumption by about 90 %. An upstream heat recovery system from steam generated during the process also reduced the heat requirement of the process by around 90 %. These are essential steps to make the process environmentally and economically viable.

The plant was recently put back into operation to test the optimised design. We will further investigate potential optimisation of the scrubbing unit e.g. using 'cheap' gypsum by-product instead of 'expensive' sulphuric acid.

Solutions against nitrate inputs into groundwater

Agricultural residues, such as manure or digestate from biogas production, contain a lot of nitrogen, which can leach to groundwater when spread on agricultural land. In many agricultural regions of northern Germany, the limit for nitrogen in the form of nitrate in the groundwater (50 mg/l) has been exceeded, leading to restrictions or high costs of recovering groundwater for drinking water production.

The EU Circular Agronomics project is seeking solutions to make agriculture more sustainable. Technical processes to readjust nitrogen inputs into soils towards a demand-oriented scheme in order to avoid emissions are being investigated. As part of the project, KWB operates a pilot plant (Fig. A) to recover ammonium nitrogen from agricultural residues at the Berge site in Havelland (Brandenburg).▶ (1) The core of this technology is a degassing unit, with which ammonium nitrogen in the form of ammonia and carbon dioxide is extracted from digestate residues of biogas production and converted into typical fertiliser (Fig. B).

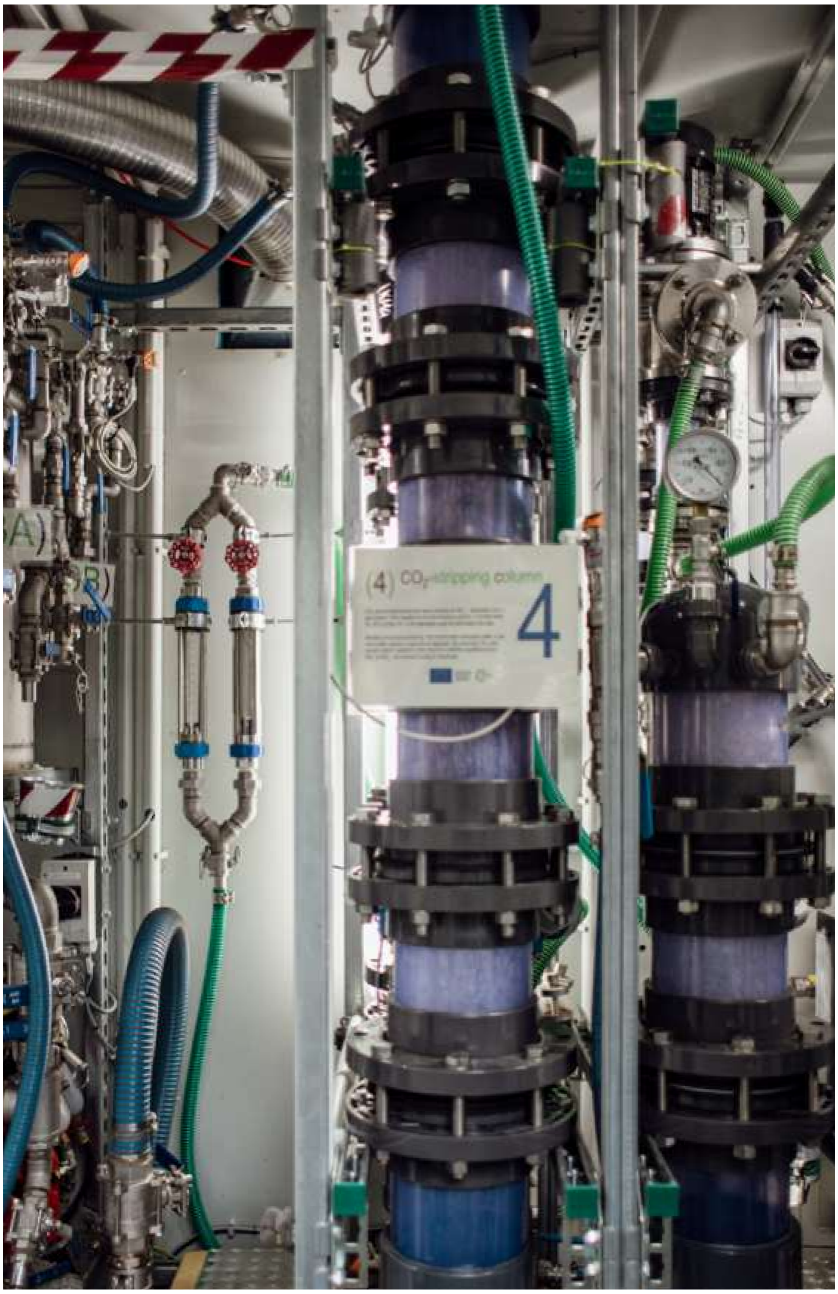
With this process, the liquid digestate is separated into two individual fractions, namely a carbon-rich residue and an ammonium mineral fertiliser. The latter can then be stored or further processed and applied to agricultural land when nitrogen is required by crops.

If there is a surplus of nitrogen in a region, the concentrated ammonium mineral fertiliser can also be transported to regions with nutrient demands. In the future, this could have a positive effect on groundwater pollution, since ammonium nitrogen can be used separately and specifically in the vegetation cycle when the crops have a nitrogen demand. The process can reduce ammonia emissions in agriculture and avoid production of greenhouse gas-intensive nitrogen mineral fertilisers.

A

In light of the current energy crisis, the circular economy of nutrients represents an opportunity to reduce Europe's dependency on imports from third countries. Since the conventional production of nitrogen mineral fertilisers is strongly linked to the availability of natural gas, there were production restrictions across Europe in 2022. This led to a significant price increase for nitrogen mineral fertilisers compared to the previous year. Regional production (of fertilisers) from residues such as manure, digestate residues, or sludge from wastewater treatment reduces Europe’s dependency on imports, reduces emissions and also contributes to the resilience of the agricultural sector.

B



IMPETUS

Project volume
€ 16,224,769, financed by Horizon 2020 European Union Funding for Research & Innovation

Partners
Fundacio Eurecat (coordination), Nelen & Schuurmans BV, National Technical University of Athens, Accademia Europea di Bolzano, Universitetet i Tromsoe - Norges Arktiske Universitet, Baltijas Vides Forums, Mediterranean Agronomic Institute of Chania, Athens University of Economics and Business - Research Center, Etaireia Ydreyseos Kai Apochetefseos Proteyoysis Anonimi Etaireia, Ministry of Environment and Energy, Mantis Business Innovation Idiotikikefalaiouchiki Etareia, Departament D'acció Climàtica; Alimentació i Agenda Rural, Universitat Rovira i Virgili, Universitat de Girona, Lobelia Earth SL, Kwr Water B.v., Water & Energy Intelligence BV, Senatsverwaltung für Umwelt, Verkehr und Klimaschutz, Berliner Wasserbetriebe, GCF - Global Climate Forum EV, Mobygis srl, Universität Bern, Consorzio dei Comuni Della Provincia di Trento Compresi Nel Bacino Imbrifero Montano del Sarca - Mincio e Garda, Cantina Toblino Sca, Troms og Finnmark Fylkeskommune, Zemgales Planosanas Regions, Jelgavas Pasvaldibas Operativas Informacijas Centrs, Thetis Spa, Sdsn Association Paris, Union Internationale Pour La Conservation de la Nature et de ses Ressources, European Science Communication Institute gGmbH

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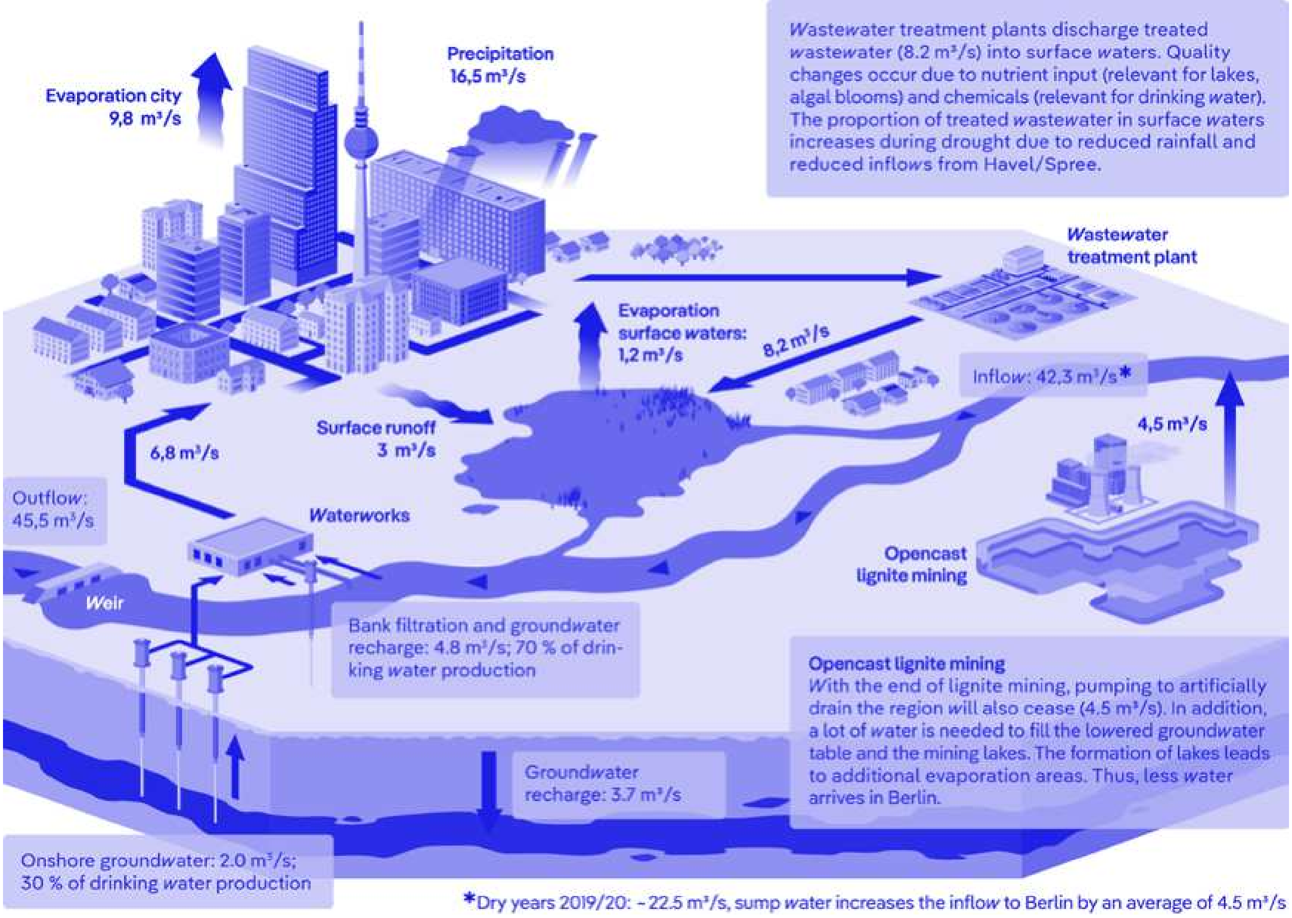
Will Berlin soon be left high and dry?

The last few years have been characterised by extreme drought and heat in the Berlin-Brandenburg metropolitan region. According to the Deutscher Wetterdienst (German Weather Service), the amount of precipitation in Berlin from March to May 2022 was only 55 l/m², almost 60 % less than the long-term average. This means that Berlin was once again the driest federal state in Germany from March to May. What this (climatic) water stress already means for surface waters in the metropolitan region can be read in countless news articles: this spring, the Panke River had already completely dried up before reaching Berlin's city limits. The water level of Lake Straussee, on the outskirts of Berlin, dropped so low this year that it had to be closed for swimming. Berlin's surface waters have so far largely been spared such dramatic changes in water level, thanks to damming and treated wastewater discharges from sewage treatment plants. However, the question remains: how long will this steady state continue, and what do these changing conditions (e.g. declining surface water inflows) mean for water use here in Berlin?

To accelerate Europe's climate adaptation strategy and achieve the goal of becoming the first climate-neutral continent by 2050, the European Commission has awarded a flagship project called IMPETUS. The goal: translate the climate commitments we have made into concrete actions to protect communities and the environment. In the case study of the Berlin-Brandenburg metropolitan region led by KWB, we address this issue together with our partners from the Senate Department for the Environment,

Dried-up Berlin Panke in the summer of 2022



Partially closed water cycle of Berlin

Urban Mobility, Consumer Protection and Climate Action (SenUMVK), the Berliner Wasserbetriebe (BWB) and the Global Climate Forum. One focus is on how the drinking water supply in the constantly growing metropolitan region can be guaranteed in the future with the aforementioned limits and boundary conditions. Since about 70 % of drinking water is derived from surface water infiltrating into the ground (primarily through bank filtration, but also artificial groundwater recharge), changes in the quantity or quality of surface water also affects drinking water production. Therefore, the project uses modelling ▶ (1) to consider various scenarios that could affect Berlin's water resources in the future due to climate change and other influences:

- Lower inflow from Brandenburg (due to repercussions related to the end of open-cast lignite mining in Lusatia) ▶ (2)
- Changing precipitation distribution (drought due to climate change)
- Higher water consumption and wastewater discharges (due to drought and population development)
- More evaporation (temperature increases due to climate change)

▶ (1) An important part of the modelling here is simulating the groundwater and surface water systems together, as the latter currently makes up about 70 % (60 % bank filtrate and 10 % artificial groundwater recharge) of Berlin's drinking water, which is exclusively produced by means of deep wells. Boundary conditions for groundwater modelling include forecasted abstraction rates by the drinking water treatment plants, groundwater recharge, and the quantity and quality of Berlin's surface waters. The latter are determined by project partners using other models that calculate scenarios for different inflow volumes and different proportions of treated wastewater and rainwater. A change in climatic boundary conditions has an impact on groundwater flow. For example, a reduction in groundwater recharge under constant surface water level conditions leads to higher shares of bank filtration, which in turn have a negative impact on raw water quality, especially in the summer when there is a higher proportion of wastewater in Berlin's surface waters. If surface water inflows from the Spree, Dahme and Havel rivers to Berlin continue to decrease in the future, this trend will continue to worsen.

The open source groundwater modelling software MODFLOW will be used for Berlin-wide modelling with a larger grid. In addition, the spatially higher resolution groundwater model FEFLOW, already used by BWB, is used within the IMPETUS framework to make even more accurate predictions for the most relevant (as determined by the MODFLOW simulation) drinking water treatment plants and catchment areas in Berlin.

▶ (2) Pumped-out groundwater or 'Sümpfungswässer' from mine drainage for the Lusatian opencast lignite mines was regularly discharged into the Spree in recent decades. However, this artificial source of water (currently approx. 4.5 m^3/s annual average) will not only run dry in the next few years when lignite

Based on the results of scenario modelling, tipping points at which a sustainable drinking water supply can no longer be guaranteed will be identified. These include, for example, minimum inflows of surface waters to Berlin, or a maximum discharge percentage of treated wastewater into surface water. The results of the various model simulations are presented and discussed in an interactive workshop format with relevant stakeholders (e.g. with SenUMVK, BWB, and also consumers from the industry and the general public) to identify possible water use conflicts, develop early stage solution approaches, and support decision making.

Matthias Schroeder

IMPETUS Project Manager of SenUMVK,
Environmental scientist and expert for geoinformation in the department of water management, water law and geology of the SenUMVK

Interview with Matthias Schroeder from SenUMVK

We are proud to have SenUMVK as an active local consortium partner for the EU Green Deal project IMPETUS. We asked Matthias Schroeder, IMPETUS project manager at SenUMVK, some questions about the cooperation and the impact of the project.

IMPETUS aims to translate climate commitments into concrete actions to protect communities and the environment. What significance does this have for the Berlin/Brandenburg metropolitan region from the perspective of the Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action?

Through our activities in IMPETUS, digital tools and/or workflows are being developed that can implement planned actions to mitigate the impacts of the climate crisis. These digital tool(s) will be developed specifically for the Berlin demonstrator site, and can also be subsequently adapted to similar regions in the EU. The importance for the Berlin/Brandenburg metropolitan region is immense. Through a variety of plans and measures such as the Masterplan Wasser, Stadtgrün Berlin, etc., there are many ideas waiting to be implemented, and we assume that progressive digitalisation will be a building block for overcoming the climate crisis and can thus directly increase quality of life in the metropolitan region.

In addition to the Berlin case study, we are leading the largest work package which demonstrates innovative climate change adaptation solutions at six other project sites in Spain, Greece, Italy, the Netherlands, Latvia and Norway. Data pooling, application of new digital approaches and testing of innovative technical and regulatory measures will contribute to the success of IMPETUS, as will the close cooperation of all project partners with local policy makers, businesses and communities.

mining in the Lusatian mining area comes to an end, but the numerous newly created post-mining lakes will provide a huge additional evaporation area (3.6 m^3/s annual average) and require large quantities of water for initial flooding. Thus, it is quite likely that the inflows to Berlin from the Spree and Dahme rivers will decline. Even now, both rivers barely bring any notable amount of water into the city during the summer.

Involvement of municipal administrations in large EU research projects has been a rarity so far. What role did KWB play in your project participation as the leader of the case study in Berlin, and how is that cooperation structured?

As a German federal state on the one hand – in this case as a city state – and as a federal capital on the other, we feel it is our duty to also support research projects at the European Union level. This can be done as a partner in a research network or via our own initiatives to investigate pressing issues in Germany's largest contiguous urban habitat. In the current IMPETUS project, KWB took the initiative on a regional case study in the Berlin/Brandenburg region and, as leader of the individual work packages, is filling this role well. The cooperation between KWB and SenUMVK has proven itself over the years and, as usual, is professional.

What are the next steps in your project work? And how are concrete measures for Berlin derived from the project's results?

The next steps in the project's work include the detailed planning of individual work steps at SenUMVK and definition of individual work in the SenUMVK, KWB, Berliner Wasserbetriebe and Global Climate Forum regional partnership. The challenges are extremely complex and require a precise planning phase. The results of all our work will find their way into a scenario generator called 'Decision Theatre'. Using this, individual measures can then be applied and a new situation simulated, for example.

KTS
Smart Cities Coordination and Transfer Office

Financing
On behalf of Federal Ministry for Housing, Urban Development and Building

Partners
Becker Büttner Held; Creative Cimate Cities; Deutsches Institut für Urbanistik, DLR Projektträger; DLR Institut für Verkehrssystemtechnik; Institut für qualifizierende Innovationsforschung und -beratung GmbH; Fraunhofer-Institut für Arbeitswirtschaft und Organisation; Fraunhofer-Institut für Experimentelles Software Engineering; ICLEI - Local Governments for Sustainability; Progos AG; Urban Catalyst

Contact
Jochen Rabe
Dr. Nicolas Caradot
Franziska Sahr

▶ (1) The city of Berlin is one of the 73 model municipalities of BMWSB's smart city funding. KWB is therefore not only active in the Coordination and Transfer Office (KTS), but is also directly involved in two Berlin projects that will be launched this year:

- Data Governance & Data Driven Management: Together with the Alexander von Humboldt Institute for Internet and Society (HIIG) and Siemens AG Data-Governance we are developing exemplary concepts for pilot areas that integrate municipal and private sector interests and processes so that they are balanced in a manner directed towards the common good.
- Smart Water – Modelling and governance: The impacts of extreme weather events are obvious, but their causes are difficult for decision-makers and the public to understand. The project models the effects of spatial heterogeneity and homogeneity on the water cycle and will develop a participatory digital wall panel.

▶ (2) one such tool for future planning is the SEMAplus sewer ageing forecasting tool developed by KWB and BWB. (S. 42).

Smart Cities as an opportunity for transformation towards a sustainable future

Digitalisation poses new challenges for German municipalities, but it also offers great opportunities for the future development of smart cities. KWB's mission is both to give water issues a more prominent position in the smart city debate, in line with their relevance, and generally demonstrate the potential of digitalisation for sustainable urban development and promote its implementation.

Since 2019, the German Federal Ministry of Housing, Urban Development and Building (BMWSB) has been funding 73 Smart City pilot projects (MPSC), which deal with the challenges and opportunities of digitalisation in urban areas and take an integrated batch approach to urban development. BMWSB has set up the Smart Cities Coordination and Transfer Office (KTS) and commissioned a consortium of renowned institutions, with whom KWB cooperates, to facilitate the transfer of knowledge to the broad municipal landscape. As part of the contract, we are responsible for scientific support and knowledge transfer, among other things. The aim is to develop needs-based digital solutions for broad municipal practice so that added value is created for all municipalities in Germany ▶ (1).

Scientific studies within the framework of the Smart Cities Coordination and Transfer Office

Against the background of significantly increasing extreme weather events and the necessary transformation towards sustainable urban development, we are particularly interested in the topic of resilience and the contribution smart cities can make to it. Together with the German Institute of Urban Affairs (Difu), we have written a report that is intended to anchor 'resilience thinking' in municipalities and specifically communicate the potential of digitalisation to strengthen urban resilience. The four essential characteristics of resilience – feedback loops, modularity, diversity and redundancy – are explained using practical examples and are intended to help make the concept of resilience more tangible for municipalities. Special attention is paid to the interplay between resilience and digitalisation, which opens new opportunities to strengthen municipalities. For example, comprehensive databases enable more precise forecasting, which can be used not only to monitor the current statues, but also to steer development in a more sustainable and resilient direction ▶ (2).

Another topic that is closely connected to the future empowerment of municipalities is foresight. In a study, KWB, the Fraunhofer Institute for Industrial Engineering and Difu are working on a Foresight Radar with the aim of identifying relevant future trends for integrated urban development of smart cities. For this purpose, the project team has identified social, technological, economic, ecological and political smart city trends, and will discuss and qualify them with experts on the basis of central criteria and key questions. Factsheets (e.g. cards) on these trends will be provided so that each municipality can initiate debate on how to address upcoming smart city trends in regards to its local circumstances and challenges, and proactively address them.

Technical advice and knowledge transfer

Using our expertise in the smart city discussion, we advise the BMWSB on its step-by-step smart city plan. This also includes a regular exchange in the National Dialogue Platform Smart Cities 3.0, in which our Managing Director Jochen Rabe is actively involved.

Of course, knowledge of smart city topics should also be disseminated to the broader municipal landscape. This December, KWB is leading a workshop on climate resilience in the smart city. The workshop will focus on how (environmental) data can contribute to making urban development climate friendly. As a kick-off event for a subsequent working and development community, the workshop is specifically aimed at the Smart City pilot projects in order to present solutions that have already been developed and network the municipalities with each other.

SEMAplus

In cooperation with
Berliner Wasserbetriebe

Contact
Dr. Nicolas Caradot
Dr. David Steffelbauer

A hydroinformatics coming-of-age story

Today, most cities face a similar problem: their water infrastructures are ageing and need extensive rehabilitation, but tight budgets don't allow them to keep up with their needs. Investment delays have real consequences, with degrading water and drainage services escalating flood risks and exacerbating severe environmental impacts. In Germany, for example, a recent national study highlighted that 20 % of the sewer network has severe defects that require short or mid-term repair, which would cost utilities more than 7 billion €.

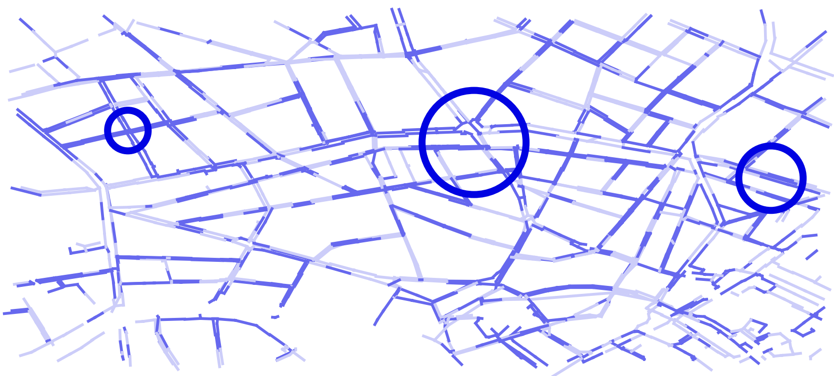
Fortunately, most utilities are sitting on valuable information which could help bolster their rehabilitation costs – namely, a big pile of already collected data. This data includes information on pipe age and properties, pipe condition retrieved through CCTV inspections, and failure and repair data. Hydroinformatics can help develop methods that utilise this data to identify the best rehabilitation strategy possible under tight financial constraints.

Almost ten years ago and long before establishing a dedicated Hydroinformatics group in Berlin, KWB and Berliner Wasserbetriebe started to develop such a method, which is now known as SEMAplus. SEMAplus is an innovative, sustainable and cost-saving software suite to guide short-term rehabilitation needs and long-term strategic investments based on advanced statistical analysis and machine learning. It consists of two packages. The SEMAplus pipe simulator (Fig. A) determines the current condition of each pipe and helps localise urgent rehabilitation needs. The SEMAplus strategy simulator (Fig. B) forecasts the long-term structural condition of the network over several decades, taking all preventive measures into account, and therefore can calculate future rehabilitation needs and their associated costs. Although SEMAplus started as a sewer and drainage network tool, it will soon be available for water distribution systems.

The excellent reputation of SEMAplus led to increased demand, which is why we decided to build up the SEMAplus community. As the community grows, the Hydroinformatics group at KWB faces a new challenge: the software solution must also grow to keep pace with the sheer size and needs of this community. What started as a stand-alone R package installed manually on our clients' computers needs to transform into a standard delivery model for many business applications and become a Software as a Service (SaaS) product. As SaaS, SEMAplus will live in the cloud, and users can access it via a web browser. This is beneficial because multiple programmers can work on the same source code that the users can automatically access without downloading and installing SEMAplus over and over if minor bug fixes occur. Additionally, through a SaaS version of SEMAplus, every community member will always have the latest version, so we can guarantee that every client has the best product version of SEMAplus available.

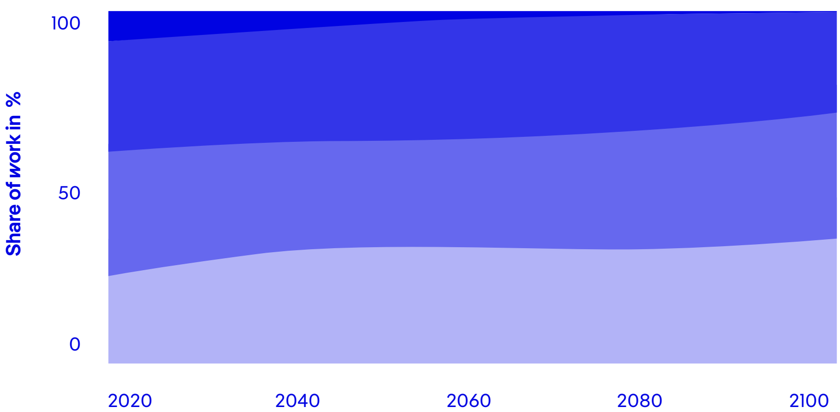
However, the development of SEMAplus doesn't stop there. In the future, the SaaS SEMAplus development will guarantee that the SEMAplus community will have the most recent algorithms and methods available to get the best out of their investments, stop their urban water systems from ageing, and keep them forever young. For example, we plan to experiment with new machine learning approaches, such as geometric deep learning, in new SEMAplus versions in the future (see page 54). With the rise of the cloud, the sky's the only limit.

Hotspots for inspections basend on the forecasted rehabilitation requirements



A SEMAplus pipe simulator

Network development



B SEMAplus strategy simulator

DWC
digital-water.city

Project volume
€5.9 million, financed by Horizon 2020 European Union Funding for Research & Innovation

Partners
Berliner Wasserbetriebe, DHI, Syndicat Interdepartmental Pour L'assainissement De L'agglomeration Parisienne (Siaap), Biofos As, Kando Environmental Services Ltd, Sofiyska Voda Ad, Universita Politecnica Delle Marche, Cap Holding Spa, Arctik Sprl, Ecologic Institut Gemeinnützige Gmbh, Fundacio Institut Catala De Recerca De L'aigua, Vragments Gmbh, Ipek International Gmbh, Universita Degli Studi Di Milano, Istituto Superiore Di Sanita, Sorbonne Universite, Strane Innovation Sas, Fluidion, Adc Infraestructuras Y Sistemas Sl, Sintef As, Institut National De Recherche En Sciences Et Technologies Pour L'environnement Et L'agriculture, Partners4urbanwater, I-Catalist Sl

Contact
Dr. Nicolas Caradot

▶ (1) SWIM:AI has been built with interoperability in mind: the architecture of the system is compatible with FIWARE, the reference architecture for smart cities. FIWARE provides the building blocks of standardised data formats and exchange protocols to ease future implementation. SWIM:AI could be just as easily transferred to a new bathing site in the Paris region as to a completely new city.

Harnessing data streams

The EU Horizon 2020 project digital-water.city (DWC) is concluding, and so much has been achieved since it began in 2019. DWC's goal was to develop new digital technologies for urban water management and to show the potential of digitalisation with concrete and tangible examples all around Europe. We've worked closely with five EU cities – Berlin, Paris, Copenhagen, Sofia and Milan – each with particular challenges and varying digitalisation levels. In theory, digital solutions such as artificial intelligence, machine learning, real-time sensors, or augmented reality have the potential to dramatically improve the management of water infrastructures. But what has been achieved in practice? How are utilities benefiting from the digital transformation?

New underwater sensors combined with SWIM:AI – a tool for data-driven prediction of water quality at bathing sites – is one of the solutions developed in DWC. Bathing water is a very promising domain of application for digital solutions. Cities are becoming greener and notable effort is going into reducing environmental impacts and improving water quality. Urban rivers and lakes are thought to have great potential for improving urban life quality. Paris, for example, has set the bar quite high, with the goal of making the Seine and Marne rivers swimmable for the 2024 Olympic and Paralympic Games. Bathing sites will open along the Marne and Seine rivers as a legacy of those Games.

A major challenge for urban bathing water management is ensuring the safety of swimmers. The quality of bathing water might broadly vary over time, as discharges from sewer overflows during intense rain events may contain high amounts of faecal bacteria and pathogens, making safe bathing temporarily impossible. Traditional practices rely on the regular collection of water samples which are sent to the lab for analysis. Often, results are available only two days later, which is too late for reporting on the water quality or warning about pollution. Therefore, in DWC we installed a new generation of floatable sensors developed by the company FLUIDION, which can analyse the bacterial concentrations of the river faster. Waiting for laboratory results is now a thing of the past – the dynamics of water quality can be monitored more rapidly, and thus bathers can be informed more quickly. The generated data can be used to benefit the general public, for instance, by letting people know where the water is safe for swimming. The device can perform up to seven measurements on a single battery charge. As it's installed in situ, it enables rapid quantification of bacterial concentrations and emits automatic alerts. In Berlin and Paris, we compared results from the device with traditional lab measurements. The results of the sensor indicated a high level of agreement with that of certified lab measurements, highlighting the relevance and practicability of such online monitoring devices for continuous bathing water quality monitoring.

ALERT System by FLUIDION

Sensors can support authorities in monitoring bathing water quality. To take this to the next level, KWB developed the open source software SWIM:AI, a tool to facilitate the development and implementation of early warning systems which provide bathing water quality predictions. SWIM:AI uses machine learning to predict concentrations of faecal indicator bacteria at river sections based on local data such as precipitation, flow, temperature, or sewer overflows. ▶ (1) Public health authorities can document the hygienic quality of bathing waters on a daily basis, including the weekend. The information can be used to support authorities in making decisions on potentially necessary bathing prohibitions based on the current risk of contamination and improve the communication of bathing water quality to the general public. SWIM:AI is currently deployed in Paris and will assist local authorities in designating new bathing sites along the Seine and Marne.

Early on in DWC, the regional Parisian sanitation authority SIAAP launched a Community of Practice (CoP) to gather institutions working on improving bathing water site quality and cities wanting to open more bathing sites together. The common challenge was to create permanent and safe swimming facilities along the Seine for the 2024 Paris Olympic and Paralympic Games and to promote urban swimming at multiple sites starting in 2025. The group has grown and now includes over 20 participants and key stakeholders including the city of Paris, the local health and environmental agencies, regional authorities, and additional cities which were also interested in opening more bathing sites. The goal of the CoP was to involve citizens and future bathing site managers in the development of digital solutions from the beginning. All stakeholders contributed to the development of two local applications: an “expert” application designed for bathing site managers which regroups all the information needed to decide whether to authorise or prohibit swimming, and a "public" application designed to inform citizens of the status and practical information of their chosen bathing site. As DWC concludes, we hope that the established CoP and the promising digital solutions tested in Paris provide a solid contribution to the ambitious political objective of swimming in the heart of our cities!

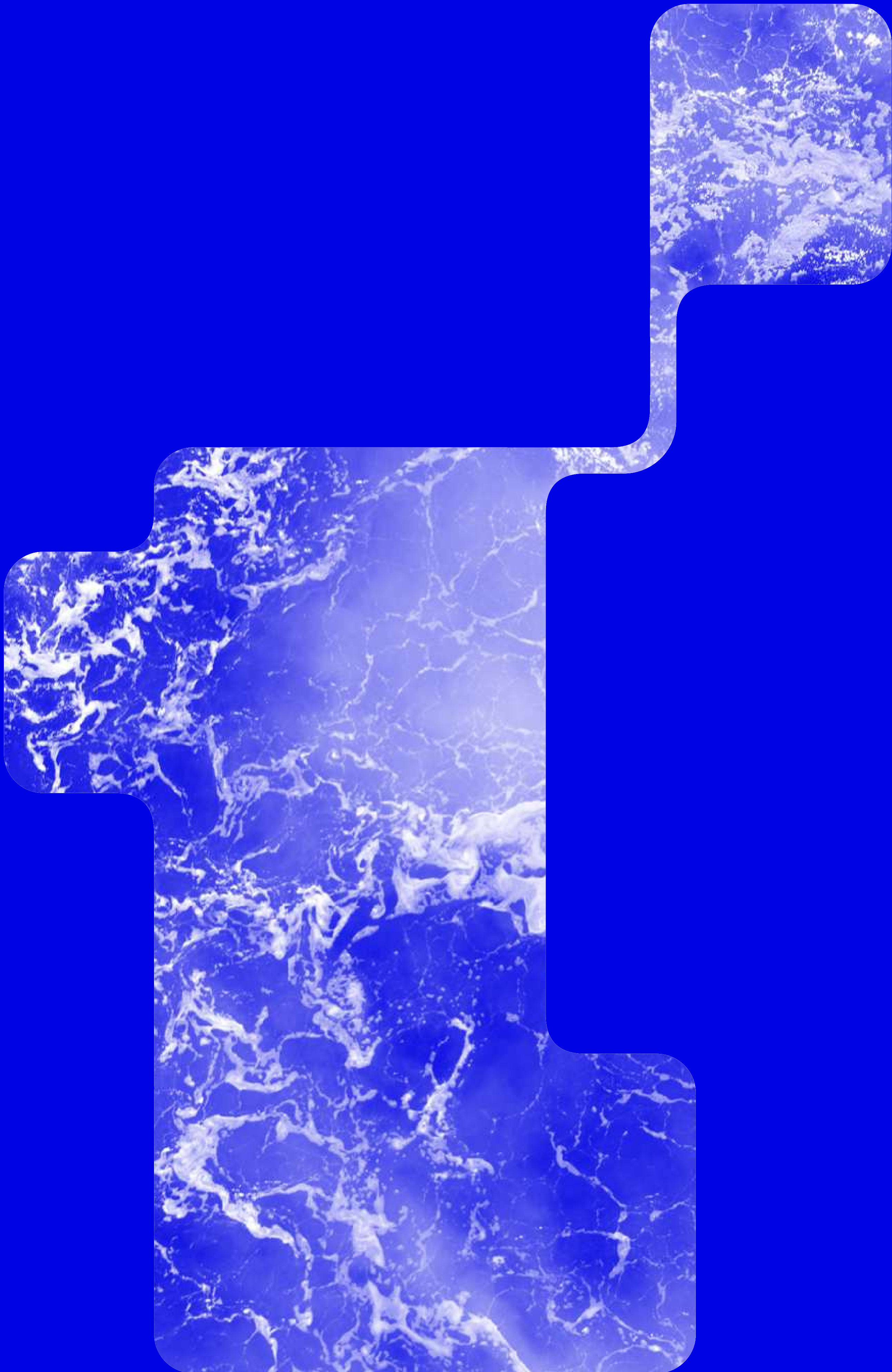
To explore the various digital solutions along the water cycle and how utilities are improving the performance of their water and sewer infrastructure by harnessing the potential of data, please visit the DWC website: www.digital-water.city

Interface of SWIM:AI

Swimming out

We swim out with you and dare to look into the future. Learn more about how augmented reality makes groundwater visible, what Geometric Deep Learning is all about, and how we're helping to shape the future of water reuse.

The following articles will take you into the future:



Making groundwater visible through augmented reality

Dr. Christoph Sprenger

Our cities' water infrastructure often is invisible to the naked eye. Sewers, drinking water pipes and wells are located underground and cannot be directly observed. In addition to the technical infrastructure, an important natural water resource is also hidden beneath the earth's surface: Groundwater.

Groundwater is ideally suited for drinking water supply. Part of the global water cycle, groundwater is naturally recharged through precipitation and bank filtration. It flows through layers of soil, reaches deeper layers of rock, and is naturally purified and enriched with valuable minerals.

Groundwater processes, such as flow direction and flow velocity, or retention of pollutants in groundwater aquifers, are usually simulated and represented with schematic visualisations, physical sandbox models, or numerical models. In the EU project digital-water.city (DWC), led by Kompetenzzentrum Wasser Berlin (KWB), a new system was developed that allows users to interact with geological and hydrogeological data and visualise them with augmented reality (AR). An prototype of an app – "Grundwasser sichtbar machen" ("Making groundwater visible") - which can be installed on AR-enabled smartphones or tablets was created. This digital solution extends traditional visualisations into spatial, interactive views for a wide audience. A beta version of the app is available for free download in the iOS App Store.

What is Augmented Reality?

AR and virtual reality (VR) are commonly used terms to describe how technologies create or change reality. VR means that virtual objects are tied to a location in virtual 3D space. In contrast, objects in AR are represented in the physical world. Rauschnabel et al. (2022) describes AR experiences as a kind of continuum that, based on the degree of local presence of the digital objects, ranges from 'assisted reality' to 'mixed reality'. In 'assisted reality', the digital content is perceived as clearly artificially overlaid and thus as not physically present. In 'mixed reality', on the other hand, the digital objects appear as if they were actually present in their physical environment, e.g. the projection of a painting onto a physical wall in the room. The purpose of 'assisted reality' applications is to gain better understanding of the physical environment, not to merge digital objects with the physical world. Following this definition, the 'Making groundwater visible' app lands somewhere in the middle. It is neither about better perception of the physical environment nor about merging digital objects with the physical world. AR visualisation is used to experience a hybrid world of digital objects in a physical environment. Compared to virtual reality, augmented reality offers an attractive and intuitive learning environment.

Augmented reality in the geosciences

Immersive visualisations enable geoscientists to communicate with each other and with other groups from different disciplines and to better understand complex issues. Geoscientific applications based on AR or VR exist in many forms. On the one hand, there are applications conveying geoscientific content aimed at a professional audience. This includes, for example, the app GeoXplorer, which can be used to visualise terrain surface models and geological structures with AR. On the other hand, there are applications which take a narrative approach and are aimed at a lay audience. This includes the WWF Free Rivers app. This app uses an interactive AR narrative to show how the natural resources of a landscape can be used sustainably to generate energy. The 'Making groundwater visible' app is a mixture of both approaches. It uses data from actual models to deliver learning content to a general audience in an interactive narrative format.

AR applications in the geosciences can be implemented as local or telepresence applications. In local presence (on-site) applications, for example, the on site geology at the location of a well can be displayed on a smartphone or tablet (Fig. A). With telepresence (off-site), digital objects are visualised at the respective location of the viewer. This is less about the transmission of information and more about the perceptual proximity that the viewer experiences through the digital content in the physical world (Fig. B).

Local presence applications must overcome a number of technical hurdles, such as target recognition, camera position estimation, scalability and motion tracking. Due to these technical hurdles, the development of a local presence application in the project was rejected. ▶

Fig. A: On-site (local presence) AR application

Fig. B: Off-site (telepresence) AR application

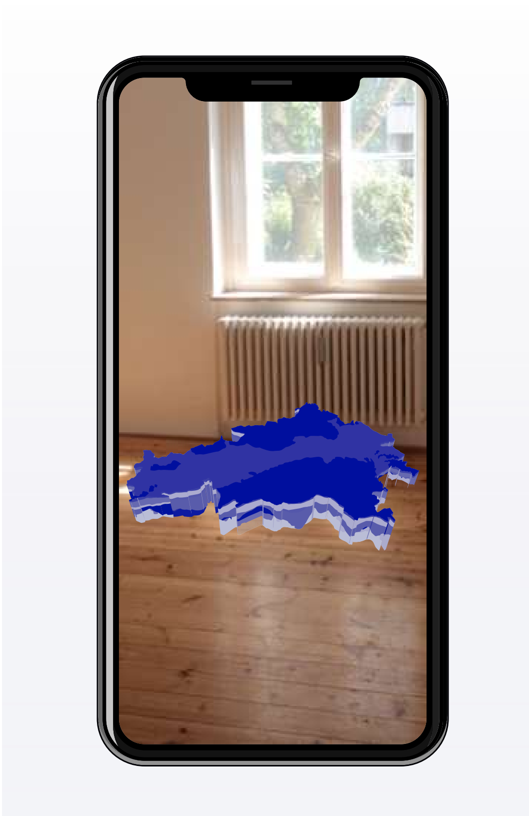


Fig. C: Screenshot Berlin 3D Geology

Scan to go to the app in the App Store

Diving into groundwater using augmented reality

The ‘Making groundwater visible’ app combines a geological 3D model of Berlin with groundwater simulations of a numerical flow model. The app was developed under the lead of the Berliner Wasserbetriebe (BWB) together with KWB, Vragments and the Ecologic Institute. KWB pushed the technical development and provided data for the geology and groundwater simulation. Vragments was responsible for the integration of the hydrogeological data as well as AR software development. The Ecologic Institute addressed issues of governance, market research and iterative development through testing with user groups.

The app aims to inform the interested public about the important function of groundwater in an appealing and educational way. From the very beginning, BWB employees offering guided tours at drinking water treatment plants were involved in the development of the app as a potential user group. The app's main target group is young people and adults in the general public. Questions such as the following were collected in workshops with representatives from the target and user groups: where does Berlin's drinking water come from? How does water flow into wells? What is an aquifer? What is a cone of depression? What rock layers exist in the subsoil and how do they influence the transport of water? How is water purified during transport? These questions were then used to define the communication goals. One such example was a vivid depiction of the geological subsurface of Berlin. The app starts in a Berlin-wide view and shows the geological subsurface in the form of layers (Fig. C).

In AR mode, the entire freshwater stock (i.e. the water available as drinking water) is shown from the ground surface to a maximum of 300 metres below ground level. Users interact with the app through a simple menu system that allows them to select the content they want. In this view, geological layers are shown as geoscientific time units. ‘Making groundwater visible’ allows you to immerse yourself in the geological subsurface, in which individual layers can be turned on or off. The underlying model was created from the ‘Geologischen Landesmodell für das Quartär und Tertiär’ (Geological State Model for the Quaternary and Tertiary) of the Berlin Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action (SenUMVK). It is based on evaluations of an extensive drilling archive and represents the currently valid representation of Berlin's geology (SenUMVK, n.d.). In addition to geology, the app offers short texts on Berlin’s drinking water treatment plants.

Another important goal of ‘Making groundwater visible’ is to show the flow of groundwater and how a well works. To do this, the user can switch to a detailed representation of a drinking water treatment plant. Here, the menu design is implemented in such a way that you can move through scenes that appear one after another in the form of an interactive narrative. The individual scenes deal with topics such as groundwater-conducting and groundwater-bearing layers, the principle of bank filtration for drinking water production, the structure and mode of operation of a well, and the flow behaviour of groundwater.

“New approaches to visualising and presenting complex information will be crucial for communicating geoscientific concepts and reproducibility of research results.”

The data required to represent groundwater flow is calculated from numerical simulations using MODFLOW modelling software. MODFLOW is a widely adopted open-source tool that is used for a variety of tasks in groundwater flow modelling. Both model creation and processing of simulation results from MODFLOW are carried out using FloPy code. The advantages of this approach include the flexible creation of flow models, fast readout of simulation results and, above all, the potential to calculate data sets not directly provided by MODFLOW. These datasets are then integrated into UNITY to create Vragments' AR experience. UNITY is a runtime and development environment for games. The rendering phase is the final phase in the creation of the augmented effect, and is the phase in which the visible model is created (Fig. D).

Although development of the workflows is based on the UNITY engine, emphasis was placed on a modular approach with generic functionalities so that other AR engines may also be supported in the future.

The future of augmented reality in the geosciences

New approaches to visualising and presenting complex information will be crucial for communicating geoscientific concepts and reproducibility of research results. In view of the increasing complexity of models – e.g. large unstructured grids and dynamic boundary conditions in space and time – it is foreseeable that the visualisation of model data and results will also become increasingly complex. AR will offer new approaches in this context by adding a new quasi-physical dimension to complex numerical models. Thanks to AR, model systems can be used to visualise geoscientific data in an immersive way for both experts and the general public. KWB will continue to participate in this development in the future. ●

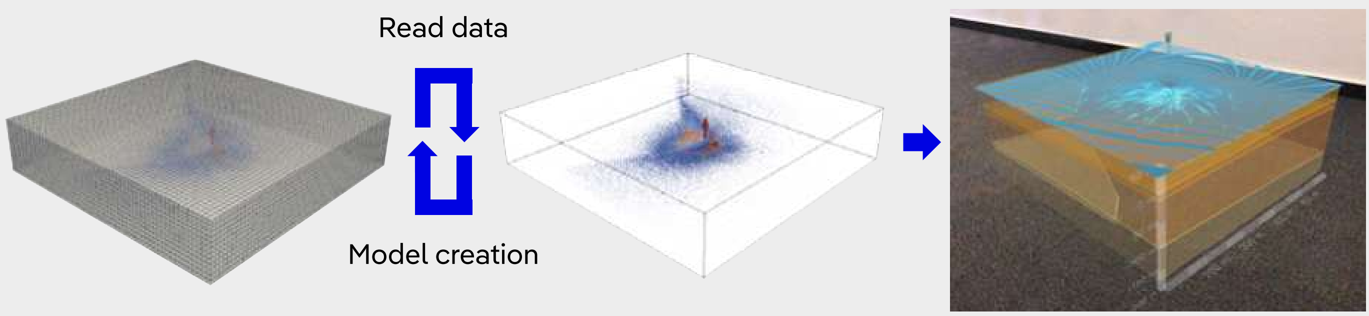


Fig. D: Data processing scheme

Geometric Deep Learning

A paradigm shift *w*ithin artificial intelligence revolutionises *w*ater research

Dr. David Steffelbauer

Data – the 21st century oil fueling digital twins

The digital revolution provides the water sector with massive amounts of data produced by new information and communication technologies (ICT), such as the Internet of Things (IoT). This field has evolved through the convergence of three drivers: more affordable sensors, cheaper storage solutions, and highly energy-efficient communication devices. The new data sources continuously generate new insights into our water and wastewater systems, and these insights allow us to manage our systems more efficiently and at lower costs. We've experienced this revolution already in all the research disciplines at KWB, as every group works with a notably growing amount of data, and digital tools and data handling skills have become more important in our daily research lives.

"Besides Convolutional Neural Networks, a whole 'zoo' of deep learning architectures has evolved, each tremendously successful in the niche for which it was invented."

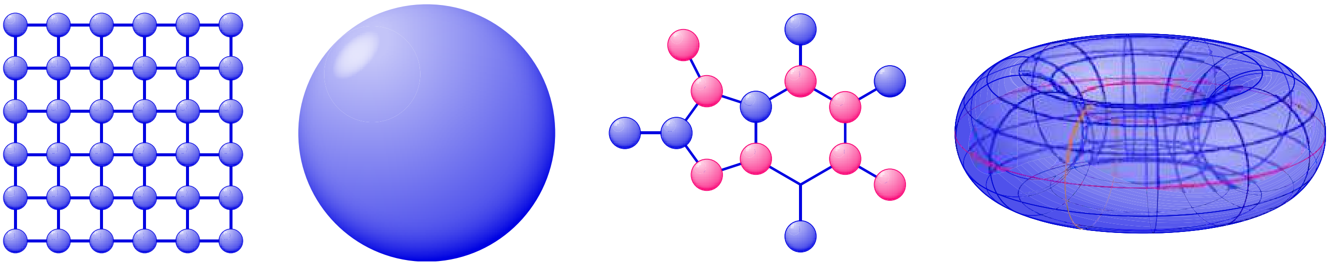
The IoT is just the beginning of the digital revolution, as it enables new technologies on the horizon to quickly enter the market due to the unprecedented amount of water data available. Digital twins are a prominent example of novel model-based approaches enabled by the IoT: they're simulation models that mimic reality through an interface to the physical world via continuous calibration on measurements. This way, the constant data stream breathes life into static hydraulic simulation models. Digital twins will have many applications in water management. For example, anomaly detection: if the behaviour of the digital twin deviates from its physical counterpart, something must have happened in the system, and hence, the twin can be used to identify and localise the error.

Moreover, the data can be used to simulate water systems without using a hydraulic model at all – through so-called data-based modelling approaches. Instead of simply feeding data to our hydraulic models, machine learning scientists successfully circumvent the complex hydraulics themselves, building digital twins without them. In most cases, these data-based digital twins are based on deep learning algorithms, where in most cases, troves of data are shovelled into artificial neural networks (ANNs).

The deep learning revolution

ANNs are at the heart of deep learning and have been around since the 1940s, but have just recently become mightier through the advent of more data and modern computer hardware. Their name and structure are inspired by the human brain, mimicking how biological neurons signal to each other. A complex network – built by a connection of layers of relatively simple neurons – can theoretically compute any mathematical function (the so-called universal approximation theorem) and hence, can simulate any physical object or solve computationally complex problems like recognising images or having actual conversations, skills attributed to intelligent behaviour. That's why deep learning, especially ANNs, has become a synonym for artificial intelligence (AI).

However, ANNs have many drawbacks: (1) they are significantly data hungry; (2) they need a lot of computer power to be trained; (3) and they act as black boxes, making the interpretation of the results almost impossible, which affects trust of decisions proposed by the neural nets. Consequently, pure data-driven techniques without proper domain knowledge can be catastrophic in domains where safety is critical, such as urban water systems. But recent fundamental discoveries in AI are going to change that. ▶



The 4Gs of geometric deep learning –
(1) grids (e.g., images), (2) groups (e.g., spheres),
(3) graphs (e.g., nodes and their connections),
(4) geodesics & gauges (e.g., 3D meshes)

Piggy-backing on mathematical symmetries – The field of geometric deep learning

Significant progress in deep learning has been made in the past years, by developing new model architectures customized to specific use cases based on the type of data available. These model architectures encode inductive biases utilising inherent symmetries of the data or the problem domain itself to give the model a helping hand. For example, convolutional neural networks (CNNs) exhibit symmetries, called translational equivariance, which results in their high success rates in image or video processing. In the water domain, CNNs are used to build new ways of measurement by utilising, for example, webcams as an affordable alternative to conventional flow measurement devices in sewer channels (Meier et al., 2022).

Besides CNNs, a whole zoo of deep learning architectures has evolved, each tremendously successful in the niche for which it was invented: recurrent neural networks (RNNs), gated recurrent unit (GRU), and long-short term memory (LSTMs) networks for time series analysis; auto-encoders (AE), variational auto-encoders (VAE), deep belief networks (DBNs) and generative adversarial networks (GANs) for anomaly detection or imputing missing data; transformers for natural language processing and computer vision; or deep sets for permutation invariant meta-learning.

Michael Bronstein et al. (2021) recently introduced the field of geometric deep learning to unify all former mentioned deep learning architectures within a framework based on mathematical symmetries. He called the endeavour to unify machine learning “The Erlangen programme of ML” – in honour of Felix Klein’s original Erlangen programme of 1872 that unified the different fields of geometry that popped up at the end of the 19th century (e.g., Euclidean versus non-Euclidean geometries like Riemann geometry). Although the old Erlangen programme only dealt with fundamental mathematical problems, its impact has been immense in other fields. Especially in physics, symmetry investigations allowed us to derive conservation laws from first principles, which ultimately led to breakthroughs in quantum physics and the discovery of new elementary particles, or the theory of relativity. And similar breakthroughs are expected (and already manifest themselves) in computer science from Bronstein’s new Erlangen project.

Bronstein classified deep learning into four different fundamental categories – The 4Gs of geometric deep learning – (1) grids (e.g., images), (2) groups (e.g., spheres), (3) graphs (e.g., nodes and their connections), (4) geodesics & gauges (e.g., 3D meshes). The 4G generalisation has already led to new developments in computer science and the rapid advancement of one field in particular: the development of graph neural networks (GNNs) – deep learning architectures specialised in learning on data structured as mathematical graphs. Since social networks and the internet are best represented as graphs, Silicon Valley big-tech companies like Meta and Google were particularly interested in further developing this field. Enormous progress has been made in the last five years, making it one of the most successful machine learning topics to this day, and, coincidentally, this rapidly progressing field is also the most relevant for the water sector.

Graph neural networks for the water sector

All water networks (drinking water, wastewater, and urban drainage) can be described mathematically as graphs consisting of nodes (e.g., sensors, tanks, consumers, manholes) and links (e.g., pipes or sewer channels). That is why recent advancements in GNNs provide a remedy for the drawbacks of training ANNs (i.e., the hunger for data, computational costs, and the black box problem). By combining sensor data with topological information in the form of mathematical graphs (e.g., from GIS), GNNs lay the foundation for more sophisticated, interpretable, and flexible reasoning within machine learning.

"Within the last years, many applications of graph neural networks on water systems have been published, ranging from anomaly and leakage detection, to sensor placement, state estimation, to transfer learning."

GNNs can be used for water networks, which have two main advantages over traditional ANNs: (i) the topological boundary conditions tremendously improve the convergence of the algorithms, which makes them faster and more economical concerning data, and (ii) learned GNN features are inherently connected to physical objects in the graphs (pipes, sensors, manholes, consumers, etc.), which immensely increases their interpretability. Straightforward fields of applications of GNNs in the water sector include: (i) developing computationally efficient surrogate models (aka data-based digital twins) through network simplification by enforcing sparse latent GNN representations; (ii) increasing network resilience by identifying the most vulnerable parts and automatically suggesting structural alternatives; or (iii) providing deeper insights in the complex mathematics of network analysis.

Within the last years, many applications of GNNs on water systems have been published, ranging from anomaly (Deng & Hooi, 2021) and leakage detection (Zanfei et al., 2022), to sensor placement (Peng et al., 2022), state estimation (Xing & Sela, 2022), to transfer learning (Bentivoglio et al., 2022) – training models on networks with a lot of data and applying them to solve problems on systems which lack data.

And these application domains are not exclusive to the research community: there's significant potential for applying GNNs at KWB. The first thing that comes to mind are the challenges we're dealing with at our Urban Systems department in the domain of infrastructure networks (i.e., drinking water and sewer networks). For example, GNNs can be extremely useful within SEMAplus, e.g. for transferability, filling missing data, or developing new condition forecasting algorithms (see the article on SEMAplus on p. 42). However, GNNs can also be applied in other departments and groups at KWB, like in our Process Innovation department, where chemical reactions and processes can be modelled as mathematical graphs. That's why GNNs are a crucial future research topic for the cross-cutting Hydroinformatics group. We'll work with all departments and groups at KWB to solve urgent water-related problems by utilising the most recent algorithms and tools developed within the rapidly progressing field of geometric deep learning. So, stay tuned for the next annual report, where we'll report on our next big plans. ●

Water reuse

A model for the future

Dr. Ulf Miehe
Dr. Veronika Zhiteneva
Sandra Banusch
Elisa Rose

Large area sprinklers in agriculture

2022 marks the end of another year of drought, where the issue of water scarcity in Germany took on a new meaning for the various actors in the water sector as well as the population. In August 2022, the European Drought Observatory reported that 47 % of Europe was under a drought warning, with 17 % of the area already in an alarming condition (Toreti et al., 2022). In addition to crop losses in agriculture, this situation also threatens ecosystems such as wetlands and forests. The consequences of acute drought phases are compounded by systemic water deficits. Germany has already been losing water from Lake Constance over the last 20 years (Roth, 2022).

"Water reuse can make a valuable contribution to counteracting existing and future water shortages caused by climate change."

Due to increased evaporation as a result of rising temperatures and subsequently falling water levels, groundwater is being increasingly used as a water resource, while only being replenished to a limited extent. Especially in Berlin-Brandenburg – with lots of surface water but very little precipitation – this trend of declining water resources is clearly visible. Water reuse can make a valuable contribution to counteracting existing and future water shortages caused by climate change.

Water reuse as an adaptation strategy

In general, water reuse denotes the advanced treatment of treated wastewater. Widely used advanced treatment technologies include filtration and disinfection. The final product is then called reclaimed water. This water is mostly used for agricultural irrigation, but urban or industrial uses (e.g. for irrigating parks or as cooling water) are also increasing. Reclaimed water can also be used to supplement drinking water supplies. However, the latter is subject to high treatment demands and stringent risk management to exclude any human health risks. A distinction is also made between direct potable reuse (DPR) and indirect potable reuse (IPR). In IPR, the reclaimed water is discharged into water bodies or reservoirs and undergoes natural transformation processes before it is taken up by drinking water treatment plants. With DPR, on the other hand, the reclaimed water is directly sent to the drinking water plant or drinking water distribution network without an environmental buffer (see Fig. A on p. 63).

Internationally, water reuse is an established component of integrated water management as well as an important building block of local and national adaptation strategies. In Montebello Forebay (USA), for example, infiltration of surface water and treated wastewater into the subsurface to support groundwater recharge has been occurring since 1962. In Windhoek (Namibia), the world's first DPR plant was commissioned in 1968. In Europe, water reuse has been practised for more than 30 years, especially in agriculture, and countries such as Spain, Cyprus and Greece even have their own water reuse legislation. In Cyprus (Fluence, 2021), as well as in some regions of Spain, almost 90 % of municipal wastewater is reused.

Due to a lack of legal basis, intended water reuse in Germany has so far only been possible at individual locations with special historical permits (e.g. Braunschweig). However, this could change in the near future due to the new EU regulation. ▸

New EU regulation changes the rules of the game

Passed in 2020, Regulation (EU) 2020/741 sets minimum EU-wide quality requirements for the reuse of municipal wastewater for agricultural irrigation. The regulation will come into force on 26 June 2023. The necessary treatment targets (classes A - D) are based on the type of crop or its intended use (e.g. crops for direct consumption, processed food crops, or non-food crops like animal feed or industrial and energy crops) as well as irrigation methods. The regulation also requires a detailed risk management plan for the reuse process to be created.

Currently, all authorities are working at full speed on the national framework conditions of the EU regulation. A number of questions came up during this process: 1) the definition of responsibilities for authorising water reuse; 2) measures for groundwater and soil protection against undesirable substances potentially present in the water (e.g. heavy metals or trace organic substances); and 3) the establishment of appropriate risk management for safe water reuse. To help with this, guidelines on the application of the EU regulation for member states were published in August 2022 (European Commission Directorate-General ENV, 2022). A series of leaflets on the technical aspects of water reuse for the German market is currently being prepared by a DWA working group (M1200 1 - 3).

Another crucial element is public acceptance, which requires extensive pre-planning and continuous involvement of all stakeholders in the process. This can only be achieved through clear, honest communication on both the benefits (including climate resilience, (land) economy, and water supply) and the risks (e.g. transfer of trace substances into the environment, reduced flows in rivers, risks to human health) of reuse.

Water reuse for drinking water supply: is the EU missing an opportunity?

The most sophisticated type of water reuse is the use of reclaimed water for drinking water production. This is being intensively pursued, particularly in the USA, in research projects and at demonstration scale in numerous locations. Sites for investigating and implementing IPR were started as early as the 1960s (e.g. Orange County Water District) and have been consistently improved through many years of cooperation between operators, authorities and research institutions. DPR projects planned or in operation include, for example, Big Springs in Texas and Cloudcroft in New Mexico.

“Due to the enormous relevance of water reuse, be it in agriculture or potentially also for drinking water, KWB is working on a wide range of innovative solutions in various research projects.”

The EU has not yet issued any regulations on the quality of water for reuse as drinking water. In some countries, such as Spain, DPR concepts are even excluded by law. The only DPR plant in Europe was commissioned in 2019 in Öland (Sweden). In contrast, de facto IPR via the use of bank filtration for drinking water treatment is practised in many central European cities, especially along the Danube River (in Vienna, Budapest, and Belgrade), as well as in Berlin. The only European facility for intended IPR is in Torreele (Belgium), which has been operational since 2002. On the one hand, this shows that such installations can certainly be approved in the EU, but due to the lack of a European legal framework, implementation depends primarily on individual local authorities.

The visible changes in water quality caused by the different treatment stages as part of the DeWaReST project

KWB's activities in water reuse

Due to the enormous relevance of water reuse, be it in agriculture or potentially also for drinking water, KWB is working on a wide range of innovative solutions in various research projects. Among other focuses, reuse is currently being investigated in these projects:

FlexTreat: *Flexible and reliable concepts for sustainable water reuse in agriculture*
The Trace Substance Strategy of the German Federal Government aims to introduce treatment stages for the removal of trace substances. In the FlexTreat project funded by the Federal Ministry of Education and Research (BMBF), we are following this strategy to develop treatment trains for removing trace substances which can also offer a high synergy potential with possible water reuse. The focus of treatment is particularly on microbial indicators (e.g. *Escherichia coli*), which may only be present in very small concentrations in the water for agricultural use. For the required reduction of E. coli concentrations by 99.99-99.999 %, multi-barrier treatment is usually used and tested in the project.

DeWaResT: *Decentralised wastewater treatment and water reuse for regions with seasonal drought stress*
In this project, which is also funded by the BMBF, a new type of constructed wetland is being developed and tested on a rural camping site. The aim of the project is to develop a compact system with a vertical multi-layer design that allows decentralised water reuse for the irrigation of trees. In the nature reserve where the camping site is located, very high demands are placed on the treated wastewater and space is limited. The targeted irrigation strengthens the resilience of the natural monuments endangered by drought, and the local tree populations and is carried out with very low energy consumption.

ULTIMATE: *Building synergies between the industrial and water sectors*
The Horizon 2020 EU project ULTIMATE is investigating ways to reuse municipal wastewater in the industry. For this purpose, conventionally treated wastewater is further treated in a membrane pilot plant (ultrafiltration followed by reverse osmosis). Due to the high proportion of non-degradable organic substances and the high concentrations of calcium, hydrogen carbonate and sulphate, wastewater represents a major challenge for membrane plants. The wastewater treated with the membrane plant should meet the requirements for reuse as cooling water and/or for steam generation so that the water requirement of the industry decreases overall. ▶

QRMA Online-Tool:
To facilitate the planning and assessment of treatment trains for water reuse, KWB has developed a freely available online tool for quantitative microbial risk assessment (QMRA). It enables the estimation of the risk of infection for three reference pathogens (rotavirus, *Campylobacter jejuni* and *Cryptosporidium parvum*) for different water resources and treatment scenarios. Different treatment trains can be compared directly with each other.

Our projects pursue interdisciplinary technical approaches in combination with integrated risk assessment concepts and contribute to advancing the further development and implementation of water reuse both in Germany and Europe. KWB, therefore, works on an important pillar of national and European climate adaptation strategies and measures and supports both agriculture and municipal water management on the way to a climate resilient future.

The future of *w*ater reuse in Germany

From our point of view, three essential pillars are necessary to accelerate the implementation of water reuse in Germany:

1) In Germany, there is a lack of experience with the planning, approval and operation of water reuse sites. Pilot- to large-scale demonstration projects should be established jointly by operators, authorities and research institutes with the help of public funding, such as in the current BMBF funding measure WavE. These can serve as platforms for better understanding and confidence in new approaches to water management and as blueprints for cost allocation between different water uses.

2) Despite the high maturity and prevalence of water reuse in many countries, there are a number of research questions that still need to be addressed. Questions remain in particular about chemical risk assessment for both humans and the environment, e.g. the transfer of trace substances via the soil into groundwater. There are also knowledge gaps in microbial risk assessment, especially in regard to the handling of antibiotic resistant bacteria, which are currently not included in quantitative risk assessment methods.

“K*W*B is a confident pioneer in the field of *w*ater reuse. After almost 10 years of *w*ork at the European level, *we*’re no*w* pleased to also push *w*ater reuse for*w*ard in Germany.”

3) In addition to solving technical issues, successful implementation of water reuse projects requires, above all, public and regulatory acceptance. The key ingredients for a successful reuse project, therefore, include cooperation with all relevant stakeholders, high technical competence, targeted public engagement and trust building. Additionally, planning certainty should be ensured through legal frameworks, which, so far, exist only in the field of agriculture in the EU and Germany.

KWB is a confident pioneer in the field of water reuse. After almost 10 years of work at the European level, we’re now pleased to also push water reuse forward in Germany. ●

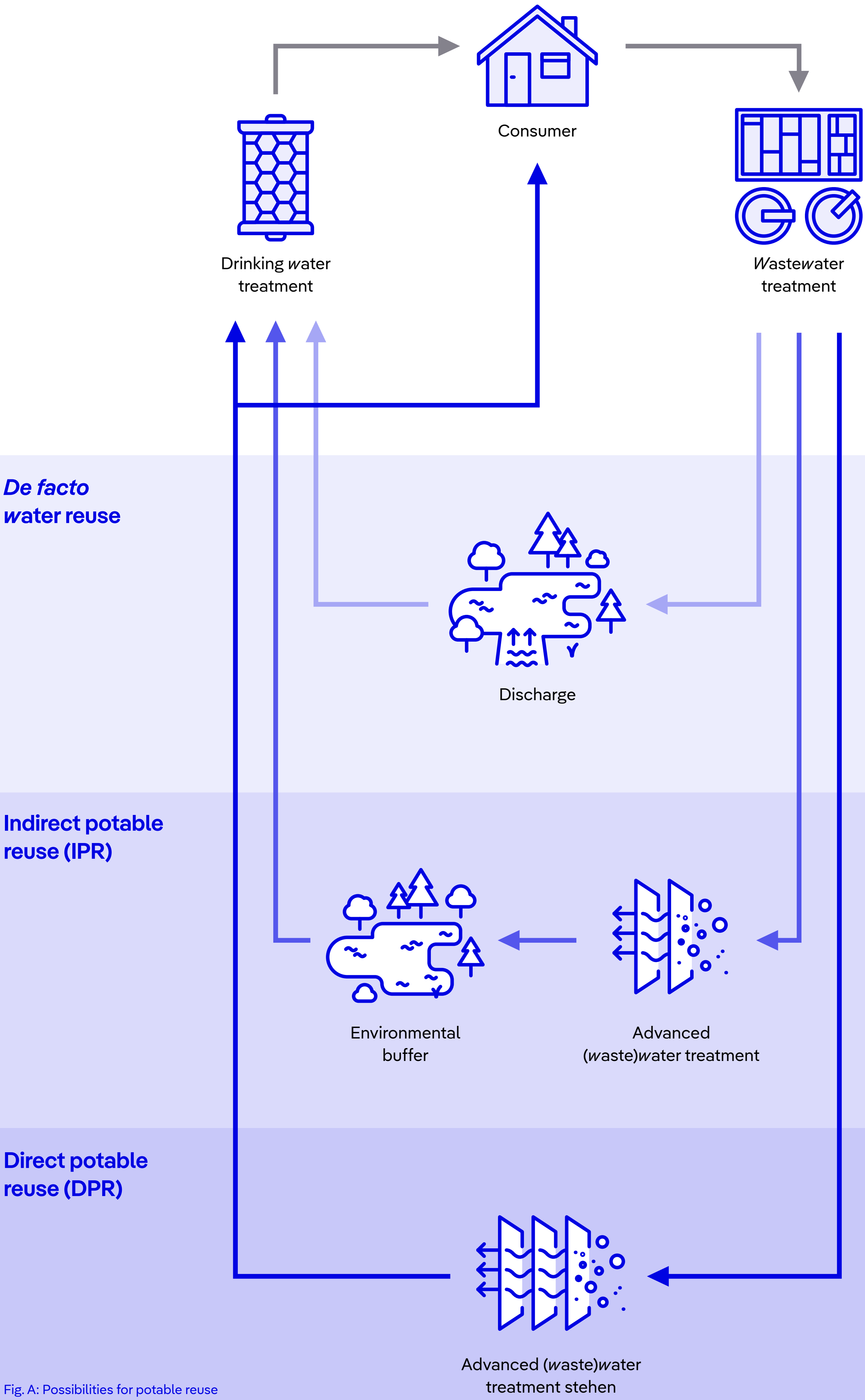
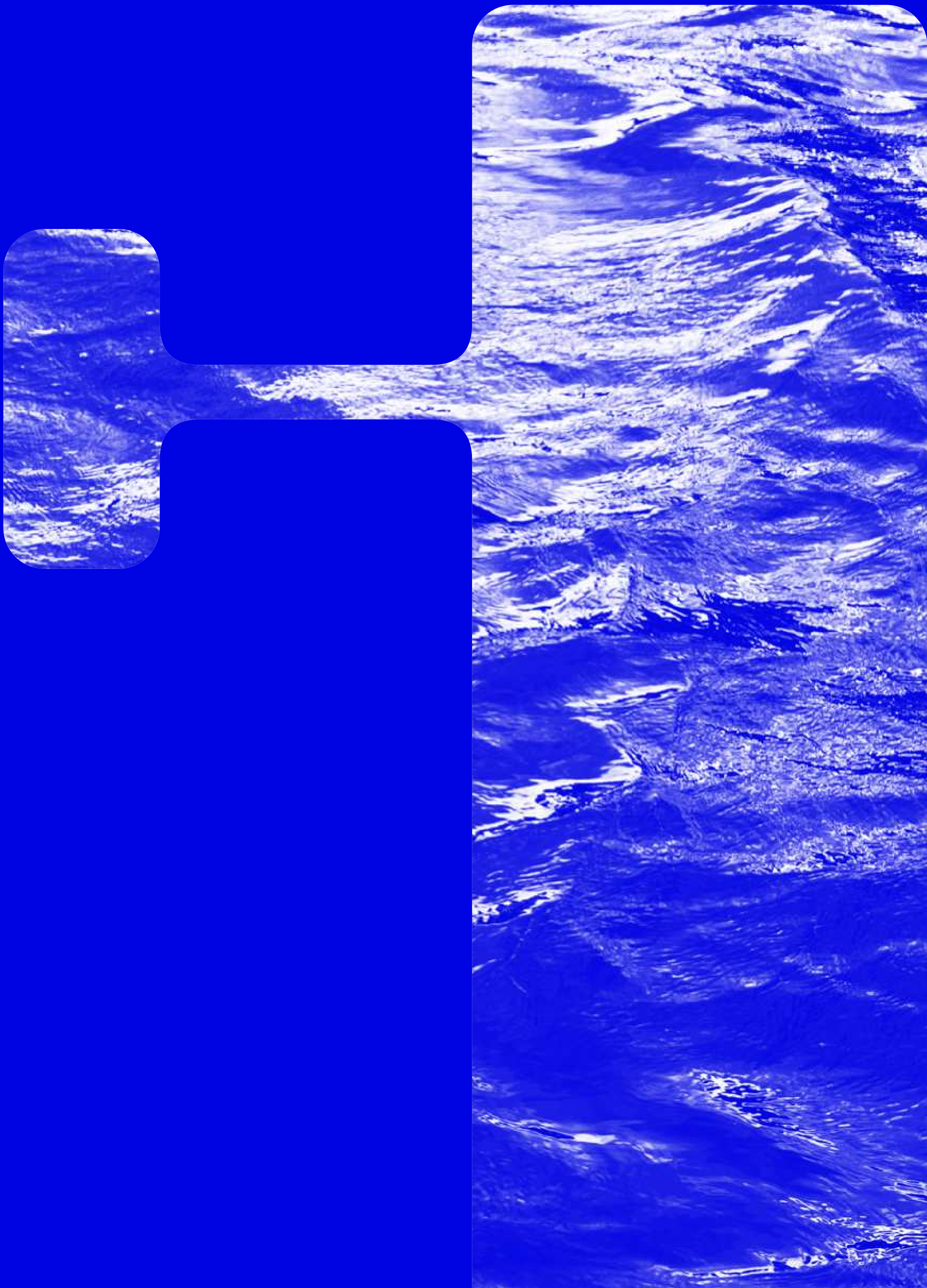


Fig. A: Possibilities for potable reuse

Docking

We’re entering calmer waters again and docking. On the following pages, you can look at our new team photos, see our applied research in action, and check out how our last company outing went. You’ll also get an overview of ongoing projects and our publications.

Docking together – with the following sections:



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Trainees

KWB is supported by a wealth of up-and-coming talent from a wide range of specialisations. Not only are we proud of being able to provide them with support (such as by assisting them with their numerous final projects), we're also benefit ting from their future-oriented ideas.

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Research and play

This year, photographer Iryna Dazhura from Ukraine accompanied and took photos of us with her special flair and eye for detail. You can see it not only in the new team photos, but also in the pictures of us in the midst of our applied research and on our company outing playing beach volleyball. Here is a small excerpt.

Project overview

Overview projects 2022

Title	Subject	Funding sources	Duration	Project management	Department
Abluft-2/2.1	Evaluation of the Treatment of Exhaust Air in the Aeration Tank	BWB	Nov. 18 - Jul. 23	Anne Kleyböcker	Process Innovation
AD4GD	All Data 4 Green Deal - An Integrated, FAIR Approach for the Common European Data Space	EU Horizon Europe	Sep. 22 - Aug. 25	Malte Zamzow	Urban Systems
AMAREX	Adaptation of stormwater management to extreme events	BMBF	Feb. 22 - Jan. 25	Andreas Matzinger	Urban Systems
BLUE PLA-NET 22-23	Online conferences "BLUE PLANET Berlin Water Dialogues"	BMUV, SenWEB	Jan. 22 - Dec. 23	Moritz Lembke-Özer	Communi-cations
CircAgro	Efficient Carbon, Nitrogen and Phosphorus cycling in the European Agri-food System and Related Up- and Down-stream Processes to Mitigate Emissions	EU H2020	Sept. 18 - Feb. 23	Fabian Kraus	Process Innovation
Cyber-security	Analysis of the future evolution of the water and sewer infrastructure and asso-ciated cyber risks	BWB	June 21 - March 22	Nicolas Caradot	Urban Systems
Data Governance	Data & Smart City Governance applied to the topic of air quality management	Land Berlin	June 22 - May 25	Nicolas Caradot	Urban Systems
DeWaResT	Decentralized wastewater treatment and water reuse for regions with seasonal drought stress	BMBF	Aug. 21 - Jan. 24	Jeannette Jährig	Process Innovation
DWC	digital-water.city: Leading Urban Water Management to its Digital Future	EU H2020	June 19 - Jan. 23	Nicolas Caradot, Hella Schwarzmüller	Urban Systems, Groundwater
FlexTreat	Flexible and reliable concepts for sustainable water reuse in agriculture	BMBF	Feb. 21 - Jan. 24	Michael Stapf	Process Innovation
GeoSalz	Dynamics of saline water migration for early detection of wells at risk and quantifi-cation of the hydraulic discharge potential	BWB	Aug. 21 - July 24	Hella Schwarzmüller, Christoph Sprenger	Groundwater
GrünesGas	Cross-sectoral Energetic Use of Biomethane and Hydrogen from Sewage Treatment Plants	BENE, BWB	June 20 - Feb. 22	Christian Remy	Process Innovation

Title	Subject	Funding sources	Duration	Project management	Department
iBathWater	Advanced Urban Water Management to Efficiently Ensure Bathing Water Quality	EU LIFE	Sept. 18 - Sept. 22	Pascale Rouault, Wolfgang Seis	Urban Systems
IMPETUS	Dynamic Information Management Approach for the Implementation of Climate-resilient Adaptation Packages in European Regions	EU H2020	Sept. 21 - March 25	Daniel Wicke, Andreas Matzinger	Groundwater, Urban Systems
KEYS	Smart Technologies for Sustainable Water Management in Urban Areas as Key Contribution to Sponge Cities	BMBF	Aug. 18 - Jan. 22	Kuangxin Zhou	Process Innovation
LASSO	Development and proof of concept to measure nitrous oxide emissions from conventional activated sludge tanks	BWB	Nov. 21 - July 23	Anne Kleyböcker	Process Innovation
LIWE	Large-scale implementation of tertiary treatment and phosphate recovery in Lidköping, Sweden	EU LIFE	July 18 - June 23	Fabian Kraus	Process Innovation
LoopSee	Thermal Use of Surface Waters Using the Example of a Rainwater Treatment Plant	BWB	Apr. 21 - Dec. 21	Franziska Knoche	Urban Systems
MBR4.0	Development of digital solutions for the optimisation of membrane bioreactors	BMBF	Aug. 19 - Dec. 22	Kuangxin Zhou	Process Innovation
MISA4	Strategic planning of blue green infrastructure to reduce water pollution from combined sewer overflows	SenUMVK	Jan. 22 - Dec. 22	Franziska Knoche	Urban Systems
NetWORKS 4+	Planning Criteria for Climate-just Cities	EU H2020	Jul. 20 - March. 22	Pascale Rouault, Andreas Matzinger	Urban Systems
NextGen	Investigation of water reuse, nutrient recovery and energy recovery from wastewater	EU H2020	July 18 - Nov. 22	Anne Kleyböcker	Process Innovation
PROMISCES	Preventing Recalcitrant Organic Mobile Industrial chemicalS for Circular Economy in the Soil-sediment-water system	EU H2020	Oct. 21 - March. 25	Veronika Zhiteneva	Process Innovation
R2Q	Resource Planning for City Districts	BMBF	March 19 - Feb. 22	Andreas Matzinger	Urban Systems
R-Rhenania	Production of Modified Phosphate from Sewage Sludge Ash	BMBF	July 20 - June 23	Fabian Kraus	Process Innovation
safe Crew	Climate-resilient management for safe disinfected and non-disinfected water supply systems	EU Horizon Europe	Nov. 22 - Apr. 26	Christoph Sprenger	Groundwater

Title	Subject	Funding sources	Duration	Project management	Department
SCOPE3M	Compiling and accounting organisational greenhouse gas emissions in upstream and downstream processes	BWB	Oct. 22 - Dec. 23	Christian Remy	Process Innovation
Sema-Berlin 2/2.1	Support of Sewer Inspection and Investment Strategies by means of Deterioration Models	BWB	May 18 - Feb. 22	Mathias Riechel, Pascale Rouault, Nicolas Caradot	Urban Systems
Smart-Control	Smart Framework for Real-time Monitoring and Control of Subsurface Processes in Managed Aquifer Recharge Applications	BMBF	Feb. 19 - Jan. 22	Christoph Sprenger	Groundwater
SmartWater	Agile planning of stormwater management with a focus on urban green and blue	Land Berlin	Nov. 22 - Sept. 26	Andreas Matzinger	Urban Systems
Suleman	Technical Treatment of Groundwater Featuring Elevated Sulphate Levels	BMWK, BWB	June 18 - Feb. 22	Jeannette Jährig	Process Innovation
ULTIMATE	Industry and Water-Utility Symbiosis for a Smarter Water Society	EU H2020	June 20 - May 24	Anne Kleyböcker	Process Innovation

Abbreviations of funding sources:

BENE	Berlin Programme for Sustainable Development
BMBF	Federal Ministry of Education and Research
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BMWK	Federal Ministry for Economic Affairs and Climate Action
BWB	Berliner Wasserbetriebe
EU H2020	EU Horizon 2020
SenWEB	Berlin Senate Department for Economics, Energy and Public Enterprises
SenUMVK	Senate Department for the Environment, Urban Mobility, Consumer Protection and Climate Action

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