An Initiative of the Federal Ministry of Edcation and Research

WavE

Water Technologies: Reuse

Water Technologies: Reuse

Key Results

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DECHEMA e.V.
Theodor-Heuss-Allee 25
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Contact for the BMBF funding measure “Water Technologies: Reuse” (WavE II):

At BMFTR:
Dr. Rainer Müssner
Federal Ministry of Research, Technology and Space (BMFTR)
Division Resources, Circular Economy; Geosciences
53170 Bonn, Germany

At Project Management Agency:
Dr.-Ing. Markus Delay
Project Management Agency Karlsruhe (PTKA)
Karlsruhe Institute of Technology (KIT)
Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen, Germany

Editor:
Networking and transfer project of the BMBF funding measure
“Water Technologies: Reuse” (WavE II)

Responsible in terms of press law:
Dr. Thomas Track
DECHEMA e.V.
Tel.: 069 7564-427
Fax: 069 7564-117

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WavE
Water Technologies: Reuse

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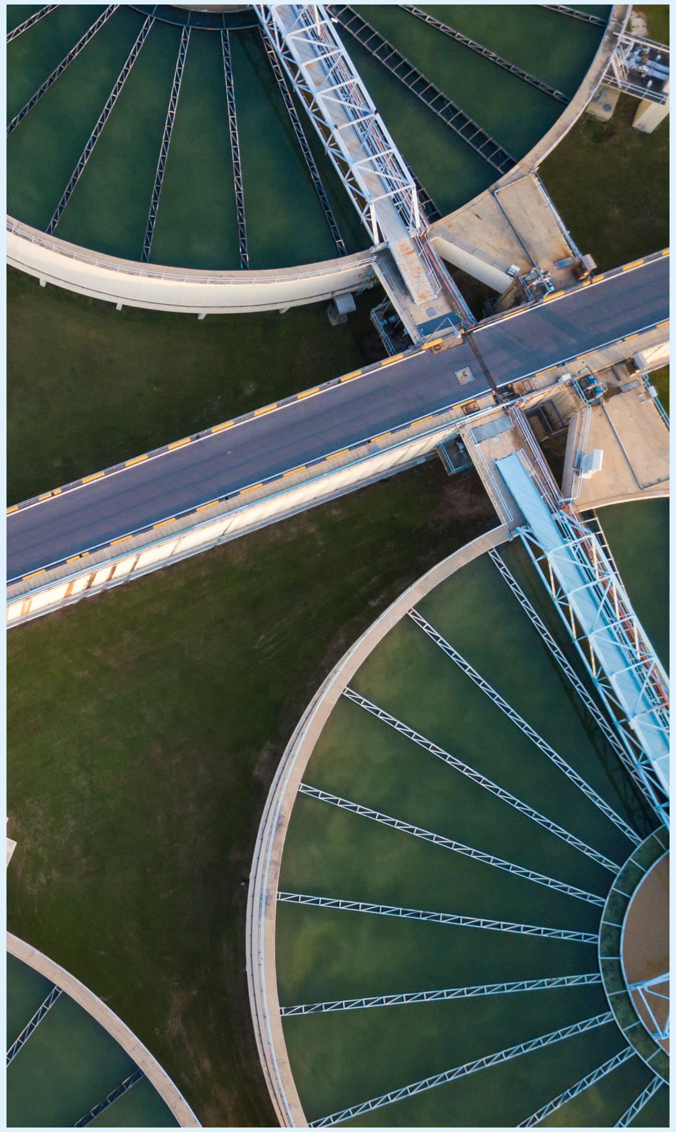
Technologies and Concepts for Water Reuse

People, the environment, and the economy depend every day on an adequate supply of clean water, yet in many regions of the world this valuable resource is becoming increasingly scarce. Even in Germany, prolonged periods of drought in recent years have locally led to crop failures and disruptions in industrial production. Global water demand is rising rapidly, driven by population growth, ongoing industrialisation, intensive agricultural use, and increasing urbanisation. At the same time, available water resources are limited, leading to conflicts over their use. Growing water scarcity threatens ecosystems and affects the economic and political stability of entire countries and regions.

There is therefore an urgent need for sustainable solutions to address water shortages in a targeted way. A key measure is the reuse of water through closed-loop systems.



This helps to ensure long-term water security and promotes more efficient resource use.

To support these measures, the Federal Ministry of Education and Research (BMBF) launched the funding initiative “Water Technologies: Reuse” which builds on the previous programme “Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination” (WavE).

The aim of both funding measures was to develop innovative technologies, operational concepts and management strategies for water reuse and desalination, with the goal of sustainably increasing water availability. In the funding measure “Water Technologies: Reuse”, real-world laboratories, standardisation and regulatory frameworks, as well as digitalisation, played a significant role.

The BMBF supported 13 joint research projects involving partners from research, industry and practice, as well as a networking and transfer initiative. Through their research and development work, these projects contributed to more efficient water use and the development of alternative water resources for various sectors. The project results are presented in this brochure. In addition, the WavE transfer project “TrinkWave Transfer” presents its findings.

Research and development activities focused on three particularly promising topics:

- Water reuse by utilizing treated municipal wastewater
- Recycling of industrial process water
- Treatment of saline groundwater and surface water

The research and developments were conducted under practical conditions and included demonstration facilities at technical scale. Particular emphasis was placed on the transferability of technological and conceptual approaches to other locations with similar conditions. This is especially relevant in terms of strengthening the international competitiveness of German companies and promoting the successful implementation of solutions “made in Germany”. This brochure presents the key results of the joint research projects.

Study Locations of the joint Projects

Water reuse by utilizing treated municipal wastewater

1. FlexTreat
2. HypoWave+
3. Nutzwasser
4. PU2R
5. TrinkWave Transfer*

Recycling of industrial process water

6. FITWAS
7. Med-zeroSolvent
8. NERA
9. ReWaMem
10. RIKovery
11. WEISS_4PN

Treatment of saline groundwater and surface water

12. HaSiMem
13. innovatION
14. SULFAMOS

* Project from the funding measure “Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination” (WavE)

TOPIC

Water Reuse by Utilizing Treated Municipal Wastewater

The reuse of treated municipal wastewater as an alternative water source is gaining increasing importance. In Europe, it is already integrated into both European and national strategies. Currently, only around 2.4 % of treated municipal wastewater is reused, although the potential is significantly higher. Within the funding measure, solutions were developed to enable the use of this alternative source for water supply across various areas of application.

The reuse of treated municipal wastewater as an alternative water resource for further use, such as in agriculture, is already common practice in many arid countries. In the EU, however, the broader adoption of such approaches faces several barriers, including limited awareness of the potential benefits and low public acceptance of multiple use. EU-wide minimum requirements for water reuse are intended to support the implementation of these measures.

In the thematic field "Water reuse by utilizing treated municipal wastewater", the BMBF funded five joint projects. These developed solutions for a range of application areas across different sectors, including agriculture, industry, municipalities, and groundwater recharge. The projects produced both technical and conceptual approaches that support flexible adaptation to reuse requirements and foster greater public acceptance of water reuse.

The most important results and products of the research projects, their application prospects, and the resulting potential for saving water and resources are summarised on the following pages.

Joint Research Projects

FlexTreat: Flexible and Reliable Concepts for Sustainable Water Reuse in Agriculture

HypoWave+: Implementation of a Hydroponic System as a Sustainable Innovation for Resource-Efficient Agricultural Water Reuse

Nutzwasser: Non-potable Water Supply and Planning Options for Urban and Agricultural Irrigation (Non-Potable Water as an Alternative Water Resource)

PU2R: Point-of-Use Re-Use: Decentralised Agricultural Reuse of Domestic Wastewater to Reduce Competing Uses

TrinkWave Transfer: Large-scale Testing of New Developments in Sequential Groundwater Recharge

Flexible and Reliable Concepts for Sustainable Water Reuse in Agriculture

FlexTreat — Making Wastewater Usable as a Resource

Water reuse has been legally regulated across Europe since 2020 (EU 2020/741). When additional legal requirements for water quality, such as the revised EU Urban Wastewater Directive (EU 2024/3019), are taken into account, synergistic treatment technologies can be selected. The FlexTreat project has tested suitable combinations of treatment processes, with a particular focus on chemical and microbiological risks.

The project investigates digital concepts for controlling and regulating treatment plants, as well as a mobile app to inform stakeholders and consumers. The project also examines public acceptance of water reuse and the transferability of technologies to international target markets for market expansion.

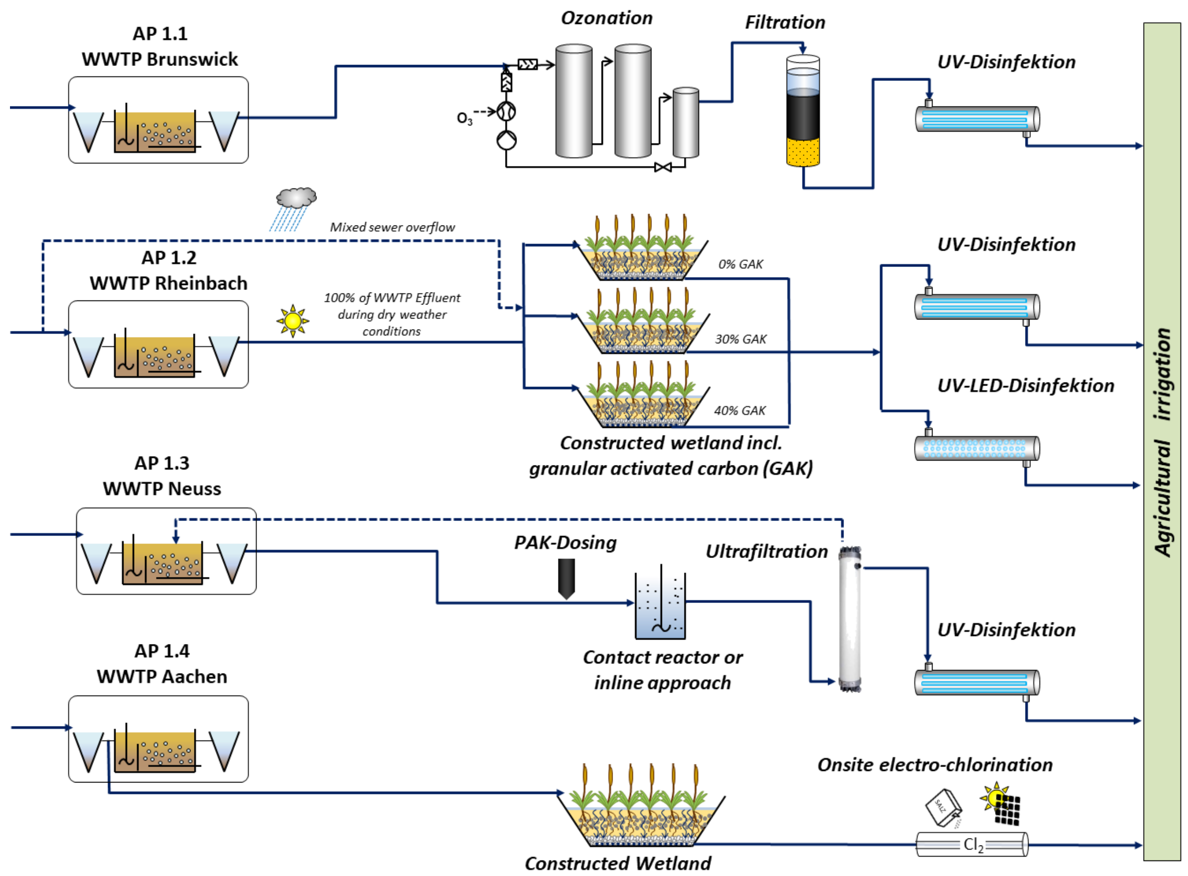
Agricultural irrigation in Braunschweig (Source: Abwasserverband Braunschweig)

RESULTS

Four different treatment processes demonstrated their suitability for combined micropollutant removal and disinfection. This confirms that common micropollutant elimination methods require only minor modifications or adaptations to also meet the quality targets for water reuse. The tested process combinations included ozone and UV, powdered activated carbon dosing with membrane filtration and UV disinfection, as well as nature-based treatment processes with electrochlorination. Innovative control strategies, such as AI-based anomaly detection, can help ensure compliance with quality targets. The "Validation Guide for Unrestricted Irrigation" developed in FlexTreat highlights key aspects for assessing microbiological purification performance. Chemical risks were analyzed using innovative non-target screening methods, while microbiological risks were examined with a focus on antibiotic resistance genes and regrowth potential. An integrated assessment includes cost and sustainability aspects. FlexTreat also evaluates the acceptance of water reuse and the transferability of treatment concepts to international target markets.

APPLICATIONS

In FlexTreat, different treatment processes were operated at four locations on a semi-industrial scale over a period of two years. At the Braunschweig site, the investigated system consisting of ozonation, filtration, and UV disinfection was equipped with extensive measurement technology, and the treated water was used for cultivation trials in raised beds as well as infiltration experiments to assess soil quality. In Neuss, an innovative process configuration for powdered activated carbon treatment combined with membrane filtration was tested. In Rheinbach, a large-scale retention soil filter with granular activated carbon admixture was examined. In Aachen, a nature-based biological treatment process with subsequent autonomous chlorination was implemented. The studies confirm the suitability of these processes for achieving the targeted water quality objectives and demonstrate their potential application in large-scale facilities pursuing water reuse.



Overview of the process chains examined in FlexTreat (Source: FlexTreat)

SAVINGS POTENTIAL

The integrated assessment carried out in FlexTreat shows that the combination of a fourth treatment stage for micropollutant elimination with the filtration and disinfection requirements specified by the EU regulation for water reuse (Quality Class A), leads to significant savings in terms of costs and CO_2 footprint. The semi-industrial and large-scale studies also successfully applied new designs for quaternary treatment stages.

These included ozonation controlled by delta-SAC (specific UV absorption coefficient), powdered activated carbon with ultrafiltration and PAC recirculation into biological treatment, RBFPLUS (an advanced retention soil filter system), and disinfection processes such as chlorine dosing or UV-LED treatment. Some of these approaches demonstrated lower operational resource requirements compared to established treatment processes.

Duration
02/2021 to 10/2024

Coordination
Prof. Thomas Wintgens
Institut für Siedlungswasserwirtschaft (ISA),
RWTH Aachen

Website
www.flextreat.de

Project Partners
- Abwasserverband Braunschweig, Wendeburg
- Analytik Jena AG, Jena
- AUTARCON GmbH, Kassel
- Bundesanstalt für Gewässerkunde (BfG), Koblenz
- Erftverband, Bergheim
- inge GmbH, Greifenberg
- Kompetenzzentrum Wasser Berlin gGmbH (KWB), Berlin
- p2m berlin GmbH, Berlin
- PEGASYS Gesellschaft für Automation und Datensysteme GmbH, Meschede
- Universitätsklinikum Bonn
- Xylem Services GmbH, Herford

Implementation of a Hydroponic System as a Sustainable Innovation for Resource-Efficient Agricultural Water Reuse

HYPOWAVE

HypoWave+ — Real World Lab Produces High-Quality Tomatoes

As regional competition for water resources increases, new concepts and technologies for water reuse are in high demand. The HypoWave project explored a water-efficient agricultural system that utilizes recycled water for hydroponic plant production. HypoWave+ is now continuing this work through scientific monitoring at the real-world lab in Weißenberge near Gifhorn. The goal is to demonstrate the market viability of hydroponically grown vegetables using recycled water, enabling future implementation at other locations.

In 2024, operations for water treatment and vegetable production began, successfully achieving the required water quality. The tomatoes produced under this system were of excellent quality, with all microbiological parameters consistently below the detection limit.

RESULTS

The first large-scale implementation of the HypoWave concept is taking place in a section of IseBauern's 1,800 m² greenhouse. Each season, 11.5 tons of tomatoes and 50,000 heads of lettuce are produced hydroponically for the regional market. Operations began in spring 2024, and the product quality of the tomatoes met expectations, with all microbiological parameters consistently below the detection limit.

To ensure high-quality irrigation water, the system utilizes effluent from a nearby wastewater pond, which undergoes multi-stage treatment by HUBER SE. The process begins with a cloth filter to remove planktonic particles, followed by an innovative activated carbon biofilter to eliminate organic micropollutants. Next, the water passes through sand filtration to remove solid particles, with final disinfection carried out using a UV system.

The tomatoes thrived under alkaline, ammonium-rich irrigation water without any yield losses. By absorbing ammonium, the plants acidified the substrate, improving nutrient availability. Additionally, dry air stimulated plant growth, highlighting further potential for water treatment optimization.

A multi-method approach—including real-world lab experiments and intensive discussions within the consortium—was used to address critical quality and risk aspects. This facilitated the submission of an application for water reuse approval in accordance with EU 2020/741 and the successful QS-GAP certification. Additionally, a comprehensive quality management concept and a market strategy were developed.

APPLICATIONS

Hydroponic cultivation combined with water reuse allows for efficient and sustainable vegetable production while minimizing water consumption. Additionally, nutrients in

View inside the IseBauern greenhouse (Source: ISOE)

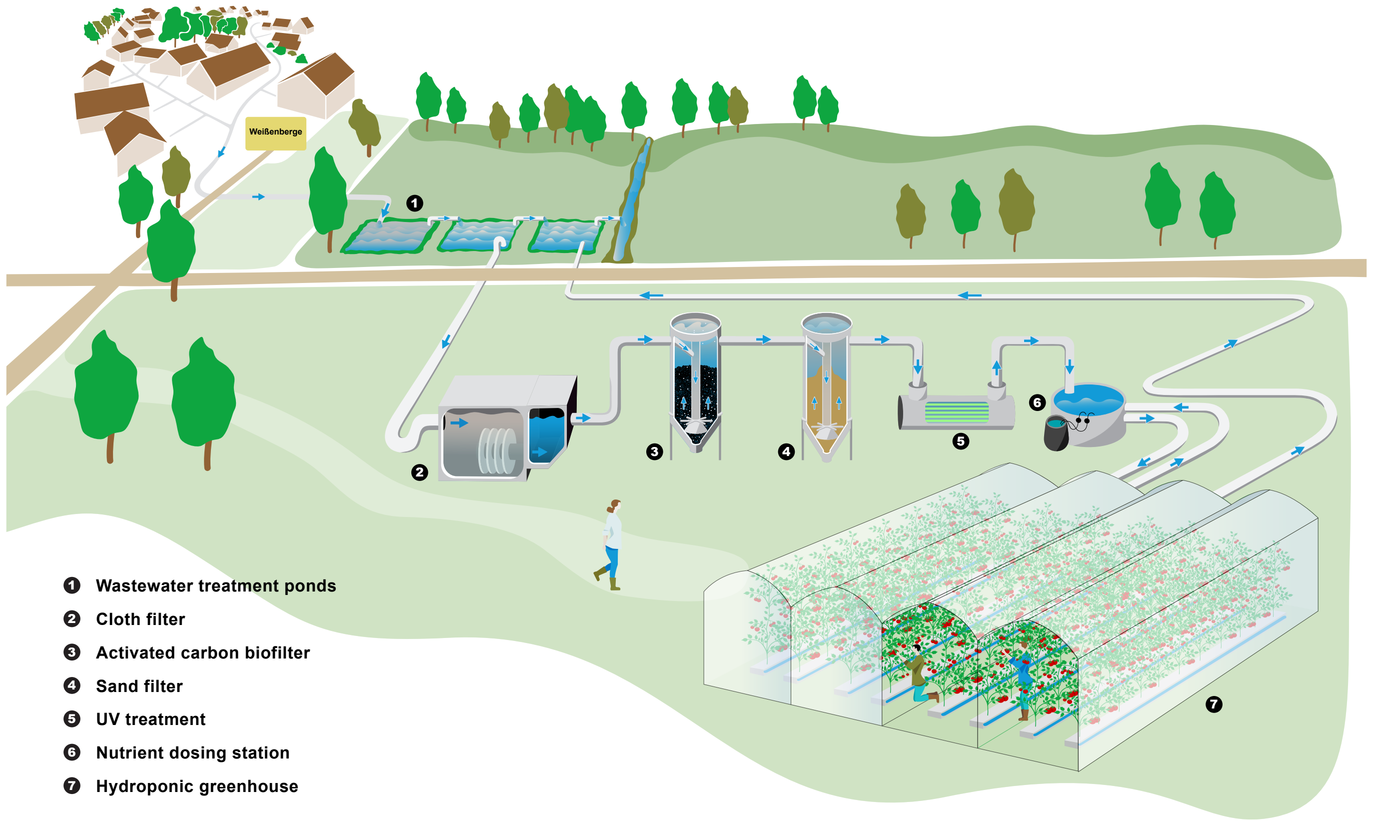


Illustration of the HypoWave concept implemented in Wahrenholz (Source: HypoWave+)

the water can be recycled for plant fertilization, reducing the impact on natural water bodies.

Potential Applications:

- Regional production of vegetables, fruits, or cut flowers
- Enhanced wastewater treatment, e.g., introduction of a fourth treatment stage
- Standalone solutions for hotels, remote farmsteads, or settlements
- Increased resilience, e.g., for irrigation associations

For widespread adoption in Germany, it is essential that such systems are not excluded from the national water reuse regulations.

SAVINGS POTENTIAL

The results show that the entire water demand for tomato production can be met through water reuse, even though operations in 2024 initially focused on two production lines. Additionally, the nutrient requirements of mature plants were fully supplied by the irrigation water.Further synergies in wastewater treatment suggest that nutrient removal may no longer be necessary.

With the selected plastic greenhouse, production from May to October 2024 was possible without additional energy costs for heating or lighting.

Duration
02/2021 to 10/2025

Coordination
Prof. Thomas Dockhorn
Institut für Siedlungswasserwirtschaft,
Technische Universität Carolo-Wilhelmina zu Braunschweig

Website
www.hypowave.de

Project Partners

- Abwasserverband Braunschweig
- Ankermann GmbH & Co. KG (EDEKA), Meine
- Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik IGB, Stuttgart
- Huber SE, Berching
- INTEGAR – Institut für Technologie im Gartenbau GmbH, Dresden
- IseBauern GmbH & Co. KG, Wahrenholz
- ISOE – Institut für sozial-ökologische Forschung, Frankfurt a.M.
- Universität Hohenheim, Stuttgart
- Wasserverband Gifhorn
- Xylem Water Solutions Deutschland GmbH, Herford
- Landvolk Niedersachsen Kreisverband Gifhorn-Wolfsburg e.V. (assoz. Partner)
- Wolfsburger Entsorgungsbetriebe (assoz. Partner)

Non-Potable Water Supply and Planning Options for Urban and Agricultural Irrigation (Non-Potable Water as an Alternative Water Resource)

Nutzwasser — Alternative Water Resource for Cities and Agriculture

In collaboration with 12 industry partners, research explored whether recycled water can serve as a safe alternative water resource in Germany. The goal was to develop flexible management strategies for urban and agricultural irrigation. A multi-barrier treatment approach and IoT-based sensor technology enabled quality assurance and demand-driven use.

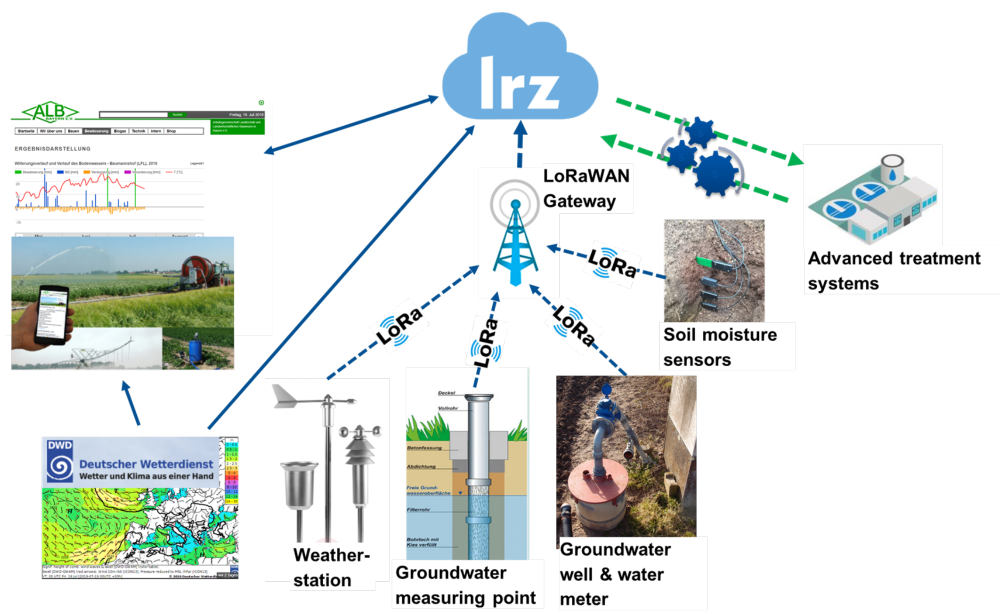
Alongside technical aspects, economic, legal, and operational models were also examined. The three-year project was structured into nine work packages, covering risk management, water quality analysis, demand forecasting, and stakeholder engagement. The results demonstrate the potential for sustainable water reuse.

RESULTS

The Nutzwasser project tested innovative water treatment technologies to provide an alternative water resource for urban and agricultural irrigation. A multi-barrier treatment system (UF, ozonation, BAC, UV) ensures water quality, while an IoT-based sensor system determines irrigation needs in real time.

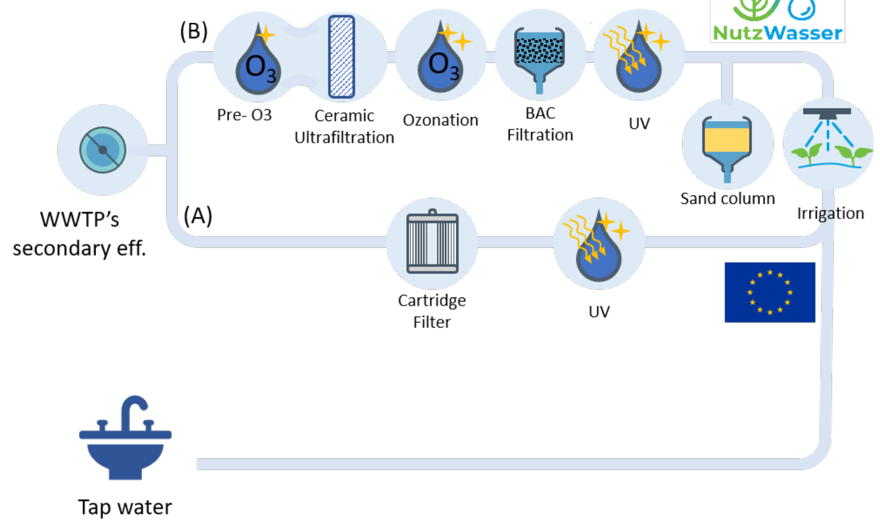
Two parallel water reuse systems were tested in large-scale trials. The legal requirements of the EU Water Reuse Regulation were taken into account, a risk management approach was developed, and concrete approval guidelines were established. The results have already been published in several scientific papers, including the study "Assuring reclaimed water quality using a multi-barrier treatment train according to the new EU non-potable water reuse regulation" in Water Research (DOI: 10.1016/j.watres.2024.122429). Another paper on chemical risk management for environmental and human health has been submitted and will be published soon.

Additionally, three upcoming publications in the Journal of Water Reuse address economic and ecological aspects, microbiological risks for edible plants, and pathogen removal using ceramic UF membranes. The project demonstrated the feasibility of safe water reuse for urban greenery, sports facilities, and agricultural land. The results were incorporated into the new technical guideline DWA-M-1200 and are intended to accelerate the transferability of these approaches to other regions.



Digitalization of demand determination and process control of water reuse (Source: Nutzwasser)

The multi-barrier treatment approach, consisting of initial ozonation, ceramic UF membranes, ozonation, and UV disinfection (B), was investigated for water reuse in the city of Schweinfurt. This treatment line was evaluated with regard to water quality and risk management for the environment and human health and compared to the EU Commission's minimum requirements (A), which prescribe a combination of cartridge filtration and UV disinfection." (Source: Nutzwasser)



APPLICATIONS

As part of the Nutzwasser project, a large-scale treatment plant (UF, ozonation, BAC, UV) was built in Schweinfurt to provide recycled water for urban and agricultural irrigation. In Gochsheim, a digital irrigation management system was developed for 60 hectares of agricultural land using IoT sensors and the ALB app.

Forecasting models for demand assessment enable water supply in a resource-efficient manner. Future applications lie in sustainable water management for regions with limited water resources. The developed technologies and management approaches can support cities and agricultural operations in using water more efficiently, adapting to climate change, and complying with the EU Water Reuse Regulation. The project thus lays the foundation for the broader implementation of water reuse in Germany.

SAVINGS POTENTIAL

The potential cost savings for green space maintenance and industry in Schweinfurt arise from the difference between the price of drinking water and reclaimed water. The drinking water price is €2.30/m³ for consumption above 15,000 m³/a.

If reclaimed water is available at a lower price, significant savings can be achieved. In Gochsheim, reclaimed water has not yet been used, but calculations indicate considerable savings potential. An additional supply of approximately 100,000 m³/year, combined with locally available groundwater resources, would be sufficient to reliably meet demand. Based on this, farmers in Gochsheim expressed a willingness to pay €30,000 per year. Reclaimed water provides long-term supply security but requires investments and operational costs for distribution. In the medium to long term, it could become a more cost-effective alternative to drinking water for industrial and agricultural applications..

Duration
02/2021 to 10/2024

Coordination
Prof. Jörg E. Drewes
Lehrstuhl für Siedlungswasserwirtschaft,
Technische Universität München, Garching

Website
www.nutzwasser.org

Project Partners
- Bayerische Landesanstalt für Weinbau und Gartenbau, Veitshöchheim
- Brandt Gerdes Sitzmann Umweltplanung GmbH, Darmstadt
- COPLAN AG, Passau
- IWW Rheinisch-Westfälisches Institut für Wasserforschung, gGmbH, Mülheim an der Ruhr
- HOLINGER Ingenieure GmbH, Merklingen
- Leibniz-Rechenzentrum der Bayerischen Akademie der Wissenschaften, Garching bei München
- Regierung von Unterfranken, Würzburg
- Stadtentwässerung Schweinfurt
- TZW:DVGW-Technologiezentrum Wasser, Karlsruhe
- Xylem Services GmbH, Herford
- Arbeitsgemeinschaft Landtechnik und Landwirtschaftliches Bauwesen in Bayern e.V., Freising (assoziierter Partner)
- Stadt Schweinfurt – Referat III Umweltschutz, (assoziierter Partner)

Point-of-Use Re-Use: Decentralized Agricultural Reuse of Domestic Wastewater to Reduce Resource Competition

PU2R

PU2R — Using Existing Infrastructure with an Innovative Approach to Tackle Current Challenges

Some sparsely populated and arid regions with an agricultural focus are already experiencing the effects of climate change. Efficient use of scarce water resources is essential. By reusing domestic wastewater from sealed septic tanks, high-quality irrigation water can be provided without the need for long transport distances. The PU2R concept integrates membrane bioreactor technology, activated carbon dosing, and UV disinfection in a decentralized treatment plant to remove pathogens and organic trace substances.

At the same time, plant nutrients remain in the water, reducing the need for additional fertilizers in demand-based irrigation. To minimize risks to human health and the environment, studies were conducted on the potential of this approach in Brandenburg and the behavior of organic trace substances in soil and plants.

RESULTS

Domestic wastewater collected in septic tanks from individual households is less diluted by rainwater and other discharges compared to wastewater transported through sewer networks to a central treatment plant. However, it does not contain industrial chemical inputs. The concentrations of trace substances are sometimes higher, and their variability in septic tanks is greater.

Therefore, the treatment process in the membrane bioreactor with activated carbon dosing must be adaptable to fluctuating loads and seasonal demands.

Expanding UV disinfection with the addition of hydrogen peroxide (H_2O_2) enables a broader degradation of organic trace substances with extended irradiation times. The uptake of these substances by plants has been studied and documented for various compounds. Simulations of degradation and transport processes in soil were conducted based on experiments and validated through field trials in lysimeter studies. Based on these findings, a predictive tool was developed for groundwater protection.

APPLICATIONS

A village in Brandenburg served as a model site with its drainless septic tanks, arable land, and agricultural areas. A risk management plan, required for the implementation of water reuse projects, considers all relevant conditions to ensure safe application. The developed forecasting tool can provide regulatory authorities with well-founded support for groundwater risk assessments. The PU2R concept is highly flexible, offering various implementation options for local stakeholders. For instance, the existing waste disposal company could operate the treatment system and supply irrigation water to farmers.

Pilot plant of the membrane bioreactor with activated carbon dosing and UV disinfection, housed in a container (Source: Aaron Bauer)

Taking soil cores from a field to investigate the water balance and transport processes (Source: Kento Ruhl)

A partially mobile implementation is also feasible, making it easier to scale the system according to actual needs. Beyond Germany, the PU2R concept could be applied across Europe and globally to decentralize wastewater treatment for irrigation—retaining both water and economic value within the region.

SAVINGS POTENTIAL

Around a quarter of Brandenburg's current irrigation water demand could be met through decentralized water reuse. Additional savings come directly from reduced fertilizer requirements, with phosphorus fertilizer offering greater savings potential than nitrogen.

Shorter transport distances for wastewater disposal from septic tanks further reduce diesel fuel consumption, which is classified as particularly harmful to the environment in several impact categories.

Moreover, the use of renewable energy—often abundant and cost-effective in dry, sparsely populated regions—further enhances the environmental benefits of the PU2R concept compared to conventional wastewater disposal.

Duration
02/2021 to 10/2024

Coordination
Prof. Aki Sebastian Ruhl
Umweltbundesamt (UBA), Dessau-Roßlau

Website
www.uba.de/PU2R

Project Partners
- FH Münster, Institut fur Infrastruktur, Wasser, Ressourcen, Umwelt (IWARU)
- Helmholtz-Zentrum fur Umweltforschung GmbH, Department Analytik (UFZ), Leipzig
- Humboldt-Universitat Berlin, Pflanzenernährung und Düngung
- Ingenieurburo Irriproject, Potsdam
- Microdyn-Nadir GmbH, Wiesbaden
- Technische Universität (TU) Braunschweig, Bodenkunde und Bodenphysik
- UV-EL GmbH & Co. KG, Dresden
- Berliner Wasserbetriebe, F&E (Assoziierter Partner)
- Technische Universitat Berlin, Wasserreinhaltung, (Assoziierter Partner)

Large-scale Testing of New Developments in Sequential Groundwater Recharge

TrinkWave Transfer — Close-to-Nature Process SMART in Large Scale Demonstration

Building on many years of experience in groundwater management and bank filtration in Germany, the BMBF joint research project TrinkWave Transfer implemented sequential groundwater recharge for water reuse on a pilot scale in a heterogeneous aquifer. Sequential Managed Aquifer Recharge Technology (SMART) can thus be used for the advanced treatment of contaminated surface water to support drinking water resources.

The key technological elements of this concept are highly efficient and space-saving infiltration via seepage trenches, as well as the in situ introduction of electron acceptors. During several months of trial operation, the establishment of controlled redox conditions for enhanced microbiological degradation of anthropogenic trace substances in the subsurface was successfully demonstrated.

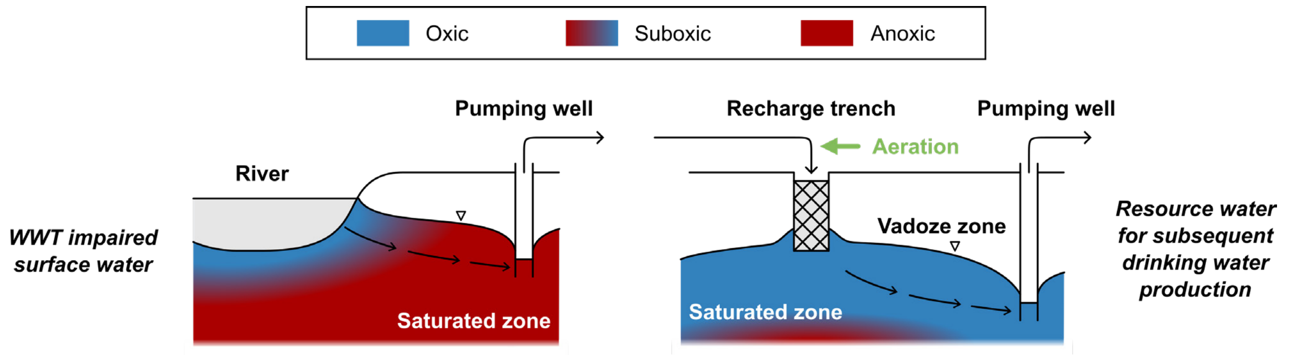
RESULTS

In mid-2023, a demonstration plant was completed, consisting of a 25-meter-long and 7-meter-deep infiltration trench, multiple measurement points, and three hydraulically coordinated extraction wells. Initially, the system was commissioned with the infiltration of drinking water (10 m³/h), before switching to treated bank filtrate in spring 2024. By changing the infiltrated water source twice, two tracer tests were conducted. These, along with prior core drillings, formed the basis for the hydraulic characterization of the heterogeneous aquifer. The findings were used to develop and validate a numerical model of the aquifer.

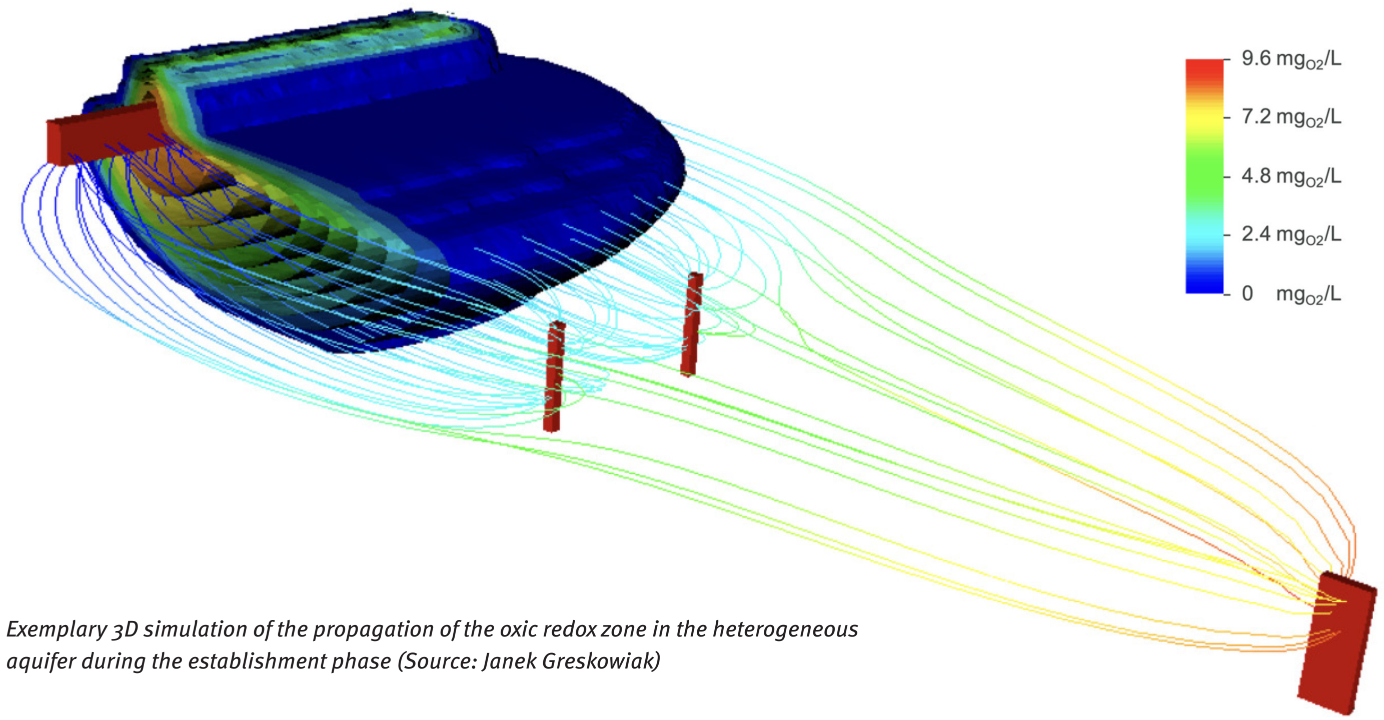
The establishment of an oxic redox zone in the subsurface was achieved through above-ground aeration of the water prior to infiltration. The expansion of this oxic redox zone depends on the hydraulic and geological conditions (depletion potential) of the subsurface. Continuous measurements of dissolved oxygen at various locations and depths confirmed the formation of a stable and well-defined oxic zone over several months. During a trial operation lasting approximately six months in 2024, the improved degradation (biotransformation) of redox-sensitive trace substances was observed.

APPLICATIONS

In a natural and heterogeneous aquifer in Berlin-Johannisthal, an extensive oxic redox zone was successfully established, and a pilot plant for targeted groundwater recharge using infiltration trench technology was constructed. The use of an overlapping drilling technique for trench construction showcased the rapid and flexible implementation of such systems. This technique allows for the adaptation to local conditions across various locations while maintaining high scalability.



Conceptual representation of sequential groundwater recharge with the aid of a percolation trench and establishment of an oxic redox zone (Source: TrinkWavE Transfer)



Exemplary 3D simulation of the propagation of the oxic redox zone in the heterogeneous aquifer during the establishment phase (Source: Janek Greskowiak)

The enhanced biotransformation of redox-sensitive trace substances was successfully observed. Additionally, valuable insights were gained regarding potential mixing effects at the production wells, which may still occur despite thorough geological and hydraulic characterization of the aquifer. Recommendations for potential adaptations or a flexible system design will be developed in the final project report.

SAVINGS POTENTIAL

Infiltration via infiltration trenches significantly reduces the land area required compared to conventional infiltration basins. Additionally, this method allows infiltration into specific depth layers, enabling targeted hydraulic connection to the aquifer. While infiltration and extraction rates can be adjusted over a wide range, the establishment of an extensive oxic redox zone for improved trace substance degradation is highly dependent on the geological and chemical conditions of a given site. In this project, a significant expansion (approximately 10 meters) of the oxic zone was observed within a few weeks to months.

Enhanced trace substance degradation was demonstrated for several compounds, with reductions exceeding 50 % for many substances, often falling below the detection limit. The final assessment of degradation potential and its transferability will be provided in the final project report.

Duration
08/2022 to 12/2024

Coordination
Prof. Jörg E. Drewes
Lehrstuhl für Siedlungswasserwirtschaft,
Technische Universität München, Garching

Website
https://www.wasser.tum.de/wasser/forschung/projekte/trinkwave-transfer/

Project Partners
- BGS Umwelt - Brandt Gerdes Sitzmann Umweltplanung GmbH, Darmstadt
- Berliner Wasserbetriebe
- Technische Universität München, Garching
- Carl von Ossietzky Universität Oldenburg

TOPIC

Recycling of Industrial Water

Water is a key production factor in industry, playing a central role as process, cooling or boiler water. In industrial contexts, wastewater is increasingly regarded and used as a potential resource. Treated wastewater that is reused and recirculated significantly reduces the demand for freshwater resources and enhances production reliability. Within the funding measure "Water Technologies: Reuse", six joint projects developed a range of solutions for the recirculation of industrial water across different sectors.

In addition to agriculture and urban areas, industry is a major water user. The recycling of industrial process water is gaining importance, particularly in the context of the EU Circular Economy Action Plan. The focus of industrial wastewater management is increasingly shifting from “treatment and disposal” to “reuse, recycling, and resource recovery”. Recycling can improve cost efficiency, and recovering by-products may open up new business opportunities.

In the topic “Recycling of industrial Water”, the BMBF funded six joint projects. These projects developed technologies and management approaches tailored to sectors such as the steel, chemical, and automotive industries, medical technology, large-scale laundries, and the drinking water sector. The key outcomes and products of these research projects, their application prospects, and their potential to reduce water and resource consumption are summarised on the following pages.

Joint Research Projects

FITWAS: Reuse of Filter Rinse Water from Groundwater Treatment to Secure Drinking Water Supply

Med-zeroSolvent: New Approaches in Medical Technology Water Management - Establishment of Innovative Methods for Wastewater-Free Production through Energy-Efficient Treatment of Highly Contaminated Process Water from Membrane Production

NERA: Zero-Emission Raw Water Production in the Automotive Industry

ReWaMem: Recycling of Laundry Wastewater for Reuse by means of Ceramic Nanofiltration

RIKovery: Recycling of Industrial Saline Waters by Ion Separation, Concentration and Intelligent Monitoring

WEISS_4PN: Integrative Application of Innovations and Digital Cooling Capacity Management to Reduce the Amount of Water Required in Steel Production

Reuse of Filter Rinse Water from Groundwater Treatment to Secure Drinking Water Supply

FITWAS — More Efficient Use of Groundwater Resources in Drinking Water Treatment

When groundwater is treated to produce drinking water, between 1 % and 4 % of the water volume results in filter rinse water. These rinse waters containing solids are currently, as a rule, discharged into surface waters after the sludge has settled and are thus lost to drinking water production. .

In FITWAS, various ultrafiltration concepts were investigated for the reuse of this filter rinse water. The treated rinse water is to be returned to the waterworks as raw water, thereby increasing the availability of drinking water.

In pilot tests, all investigated membrane processes (vacuum/pressure operation, polymer/ceramic membranes) provided very good filtrate quality, which allows for recirculation. However, the maximum achievable filtrate flux (filtrate flow in relation to membrane surface area) depends on the specific composition of the filter rinse water as well as on the membrane used.

RESULTS

The treatment of filter rinse water using ultrafiltration proved to be technically feasible. Both polymeric hollow fiber membranes and ceramic plate membranes provided very good

Pilot plant with two ultrafiltration modules with polymeric hollow fiber membranes (Source: OOWV)

filtrate quality (hygienic and chemical-physical), so that the water can potentially be recycled as raw water. Membrane filtration can serve as an initial step in a sludge recycling chain. A new treatment concept based on submerged ceramic plate membranes offers a clear alternative to established polymer membranes. In this process, backwashing with short pulses (backpulse) is advantageous, enabling very high yields (up to 99 %). At the Hamburg site, the ceramic membranes provided a filtrate flux three times higher than polymer membranes, leading to comparable specific treatment costs despite the higher price of ceramic membranes.

The composition of the filter rinse water determines how high the maximum possible stable filtrate flux is. Piloting at the respective site is therefore highly recommended. As a further important result, the treatment of mixed filter rinsing water (without upstream sedimentation) is recommended, as this leads to more stable operation.

APPLICATIONS

As project partners in FITWAS, two water supply companies conducted pilot tests at three waterworks. The results provide a solid foundation for evaluating large-scale implementation of rinse water treatment.

At HAMBURG WASSER, all 17 waterworks are currently being assessed for their suitability for rinse water recycling. This includes, among other factors, the amount of rinse water generated and any upcoming modernization efforts. Expanding rinse water recycling is being considered, for example, in planned measures such as the renovation of sedimentation basins at priority sites.

Pilot tests in the waterworks, with the test container in the center and two tanks containing concentrate from the membrane filtration of filter rinse water (Source: OOWV/DVGW research center TUHH)

The OOWV is assessing the large-scale feasibility of membrane-based rinse water treatment for its pilot site and additional waterworks. Currently, three waterworks require a review of rinse water treatment and sludge dewatering, including sludge reuse. This is driven, on the one hand, by regulatory requirements and, on the other hand, by new construction projects, where traditional sludge ponds are not possible due to local conditions.

SAVINGS POTENTIAL

Although filter rinse water accounts for only 1 % to 4 % of the extracted groundwater treated in waterworks, this amounts to 1.5 million m³ per year at both HAMBURG WASSER (HW) and OOWV.

At the pilot sites, approximately 58,000 m³/year (OOWV) and 140,000 m³/year (HW) of water could be recovered, replacing the need for additional groundwater extraction. The main drivers for recovery are scarce groundwater resources, water rights constraints, increasing water demand, and high utilization of waterworks.

An estimate for rinse water treatment at the HW pilot site shows an energy demand of approximately 0.2 kWh/m³ (including filtrate recirculation and mixing of filter rinse water). By comparison, groundwater extraction at HW requires between 0.1 and 0.3 kWh/m³, meaning that rinse water treatment is energy-competitive.

A cost estimate for both sites is included in the FITWAS contribution to the Essen conference (GWA Volume 259, Aachen 2025, ISBN: 978-3-938996-65-2).

Duration
02/2021 to 09/2024

Coordination
Dr. Barbara Wendler / Prof. Mathias Ernst
DVGW-Forschungsstelle TUHH, Hamburg

Website
www.tuhh.de/wwv/fitwas

Project Partners
- CERAFILTEC Germany GmbH Blue Filtration, Saarbrücken
- Hamburger Wasserwerke GmbH (HW)
- Oldenburgisch-Ostfriesischer Wasserverband (OOWV), Brake
- PHL Substratkontor GmbH & Co. KG, Friesoythe
- Umweltbundesamt (UBA), Berlin

New Approaches in Medical Technology Water Management – Establishing Innovative Methods for Zero-Liquid Discharge Production Through Energy-Efficient Treatment of Highly Contaminated Process Water from Membrane Manufacturing

Med zero Solvent

Med-zeroSolvent — Energy-Optimized Solutions for Biological Solvent Degradation

Solvents such as dimethylacetamide (DMAc) and N-methyl-2-pyrrolidone (NMP) are used in the production of dialysis membranes for renal replacement therapy. Although significant efforts are made within the production process to recover these solvents, solvent-laden residues still accumulate and must be treated externally or thermally disposed of, depending on their concentration. The goal of this project was to develop a process for on-site biological treatment of solvent-containing wastewater, allowing for internal reuse following an additional membrane-based purification step. The focus was on energy-efficient, nature-based solutions (two-stage vertical filters), advanced biofilm processes (MBBR), and anaerobic treatment methods.

MBBR pilot plant for the degradation of DMAc (Source: Thomas Schalk, TU Dresden, Professur für Siedlungswasserwirtschaft)

RESULTS

Pilot tests conducted as part of process development demonstrated that the investigated combination of MBBR and vertical filters is capable of meeting the treatment requirements. However, findings also indicate that using both processes together is not necessary, as comparable results can be achieved by optimizing the operation of either process individually. The ecotoxicological potential present in untreated process water was successfully eliminated by both processes, as verified through various bioassays. For the additional treatment step required for water reuse, dry-installed ion-selective membrane modules were selected, with a key focus on minimizing residual nitrate concentrations after biological treatment. To monitor DMAc concentrations in the influent and effluent of the wastewater treatment plant, an online UV-Vis-based method was developed. Anaerobic tests revealed that, unlike DMAc, NMP is highly resistant to anaerobic degradation, making its technical treatment significantly more challenging.

Pilot plant for the degradation of DMAc - in the foreground: MBBR container, in the background: vertical filter system (Source: Christian Koch, TU Dresden, Professur für Siedlungswasserwirtschaft)

APPLICATIONS

The developed process can be modularly integrated into existing plants, with biological treatment as its core component. The type and extent of further treatment depend on the intended use, allowing for stepwise implementation. As a first step, the purified wastewater is discharged directly or indirectly after biological treatment. This approach was chosen for the Berggießhübel site, where the construction of a two-stage vertical filter is currently being prepared. The reuse of biologically treated wastewater can be achieved via a reverse osmosis module, initially for peripheral systems without direct contact with fiber production. For reuse in the direct production process, it is also advisable to integrate existing water recovery systems. However, the greatest potential for water reuse lies in facilities without solvent and water recovery, as larger water volumes are in circulation.

SAVINGS POTENTIAL

The near-natural biological treatment of diluted DMAc mixtures reduces external disposal costs and, at one of the investigated model sites, lowers electrical energy demand by 26.4 MWh/a through the decommissioning of the currently used distillation unit for wastewater pre-treatment. Biogas production is possible through the co-treatment of DMAc in anaerobic stabilization plants, provided that a technical solution ensures safe integration into the digestion process and that in-house measures prevent production-related plastic residues from entering the wastewater. The energy potential of the concentrates produced at the model site amounts to 335 MWh/a, from which 111–134 MWh/a of electrical energy can be generated. This transforms what was previously a waste product into a viable energy source.

Duration
04/2021 to 10/2024

Coordination
Prof. Peter Krebs
Technische Universität Dresden, Institut für Siedlungs- und Industriewasserwirtschaft

Website
www.medzerosolvent.de

Project Partners
- B. Braun Avitum Saxonia GmbH, Radeberg
- CUP Laboratorien Dr. Freitag GmbH, Radeberg
- DAS Environmental Expert GmbH, Dresden
- ILK - Institut für Luft- und Kältetechnik gGmbH, Dresden
- Me-Sep, Dresden
- Technische Universität Dresden, Institut für Hydrobiologie
- wasserWerkstatt Ingenieurbüro für ökologische Wasserwirtschaft, Dresden

Zero-Emission Raw Water Production in the Automotive Industry

NERA — Emission-Free Recovery of Raw Materials from Metal-Containing Industrial Wastewater

In metal-processing industries, wastewater treatment typically involves the addition of acids, bases, and precipitation/flocculation chemicals to remove heavy metals and phosphates. While this method is considered cost-effective, it generates non-recyclable hazardous waste, reduces the economic viability of process water recovery, and relies on a supply chain for treatment chemicals. The NERA research consortium has developed a new electrochemical process that enables the removal of heavy metals and phosphates with minimal salt input—eliminating the need for conventional water treatment chemicals. The resulting sludge can be repurposed in the metallurgical industry, while the purified wastewater can be efficiently treated to produce high-quality process water with high recovery rates. When powered by renewable energy, this approach allows for a truly "zero-emission" water cycle.

RESULTS

The NERA project partners have developed a new electrode material, which serves as the basis for a novel precipitation reactor concept and treatment process. The developed cathode material consists of a graphite-polymer compound with the special property of enabling deposit-free precipitation.

Proof-of-concept pilot plant (Source: CUTEC)

The corresponding manufacturing process was also developed as part of the project. A full-scale electrolysis reactor was designed, incorporating rotating cathode disks to ensure low-maintenance and trouble-free operation. Optimized design and process parameters were identified to enable energy-efficient operation.

The developed treatment process allows for the complete precipitation of heavy metals in an alkaline pH range and the neutralization of treated wastewater using only electric current—without chemical additives. For wastewater from phosphating plants, a multi-stage electrolysis process was developed to separately recover heavy metals and phosphate with low heavy metal content. By utilizing concentrates from reverse osmosis systems, the process remains entirely "chemical-free."

APPLICATIONS

The techniques developed in NERA were tested on more than 20 different wastewater batches, each approximately 1 m³, from a Volkswagen AG component production plant. All wastewater batches were effectively treated with an electrolysis input of 0.5 to 2.0 kWh/m³. The potential for over 90% process water recovery was demonstrated using a two-stage membrane treatment process, equivalent to the process water treatment from drinking water used in the plant. The results show that the new process is particularly resource-efficient (no waste, no chemicals, high water recovery) and economically attractive compared to widely used precipitation/flocculation methods. The developed modular concept, which allows for both parallel and series connections of electrolysis reactors, is also suitable for treating large wastewater volumes at automotive production sites.

These techniques are generally applicable for hydroxide precipitation of metals and hardness-forming compounds such as magnesium and calcium. This is particularly relevant for concentrates from membrane systems, as it increases water recovery while also enabling raw material recovery.

VW plant: Current wastewater treatment plant at the VW plant in Braunschweig (Source: VW plant Braunschweig)

SAVINGS POTENTIAL

The project site serves as a model for hundreds of production facilities worldwide. It generates approximately 100,000 m³ of wastewater from metal processing per year, 90 % of which can be recovered as fresh water.

This recovered water can fully cover the site's annual process water demand of around 80,000 m³. Currently, around 100 tons of acid, alkali, lime, and flocculants are used annually for wastewater treatment—these could be completely eliminated under the new process. Additionally, the site currently disposes of 100-150 tons of precipitation sludge per year as hazardous waste.

Under the new process, only about 30-50 tons per year would be produced, which could instead be repurposed as a raw material. However, the electricity demand is significantly higher, averaging approximately 1.5 kWh per m³ of wastewater. Nevertheless, the cost savings from reduced purchases of fresh water and chemicals, as well as lower waste disposal costs, outweigh the additional electricity costs. The required investment costs for full-scale implementation remain to be determined.

Duration
02/2021 to 10/2024

Coordination
Prof. Michael Sievers
CUTEC Forschungszentrum der TU Clausthal

Website
www.projekt-nera.de

Project Partners
- Common-Link AG, Karlsruhe
- Eisenhuth GmbH & Co. KG, Osterode am Harz
- Institut für Chemische und Elektrochemische Verfahrenstechnik der TU Clausthal (ICVT)
- Volkswagen AG (assoziierter Partner), Braunschweig

Recycling of Laundry Wastewater for Reuse Using Ceramic Nanofiltration

ReWaMem — Precise Treatment and Efficient Recycling of Laundry Wastewater

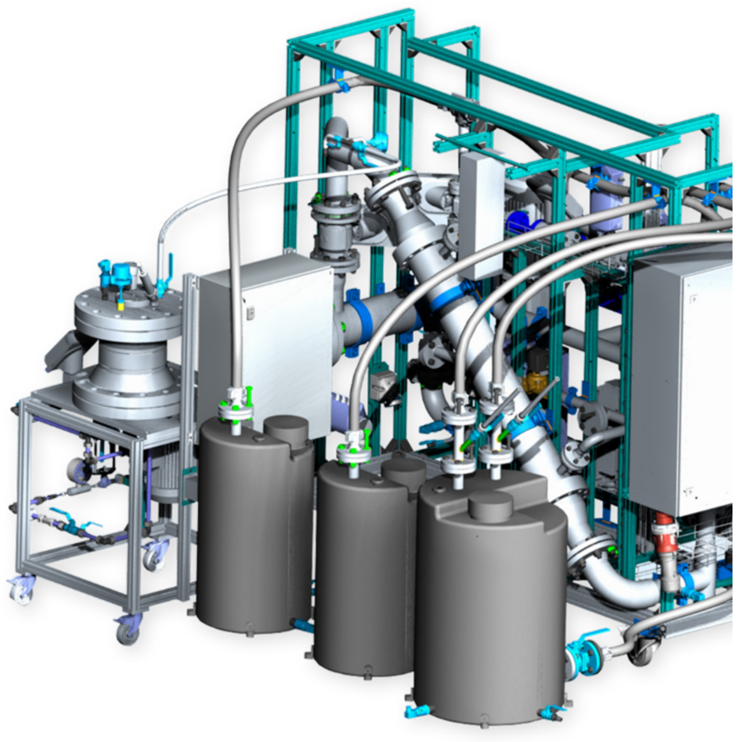
According to the German Textile Cleaning Association, around 3,600 businesses operated in Germany in 2021, experiencing significant fluctuations in electricity, water, and heat consumption. These variations result from the wide range of textiles being laundered, such as hospital, nursing home, and retirement home linens, hotel and catering laundry, and workwear, as well as the individual operational and process structures of each company.

The project aimed to reduce freshwater consumption through systematic, membrane-based wastewater treatment integrated into a tailored process chain (point of origin). Innovative ceramic base geometries (tubular/rotary discs) and membranes were developed and tested. Retention rates of up to 90 % for COD and recovery rates of up to 80 % were achieved. However, energy consumption has not yet been fully optimized.

RESULTS

As part of the project, a process concept for the treatment of typical laundry wastewater streams (mat and towel wastewater) using ceramic nanofiltration was developed, implemented in a pilot plant, and successfully tested. The filtration system is equipped with an advanced measurement and control system, making it particularly suitable for assessing the filtration behavior of various wastewater samples under adjustable process conditions. These pilot tests serve as a qualitative and quantitative evaluation of the process, providing a basis for implementing energy- and resource-efficient concepts.

The practical filtration system can also be integrated into continuous operations near the process, handling temperatures of up to 60 °C and feed flow rates of up to 1.5 m³. Additionally, the project introduced new support geometries for tubular membranes with increased membrane surface area and developed rotating membrane discs for industrial applications. Both element types are available as micro-, ultra-, and nanofiltration membranes for customer inquiries.



Pilot plant on a pilot plant scale (Source: E.S.C.H. GmbH)

APPLICATIONS

Preliminary tests with various real wastewaters were initially conducted at the technical center of E.S.C.H. GmbH. The filtration behavior of different membrane types and geometries (pH: 8 - 12, COD: 1,300 - 4,500 mg O_2/L, σ: 1,400 - 2,700 µS/cm) was evaluated. The process required a specific energy input of 1.5 to 20 kWh per m³ of treated wastewater, achieving a COD retention rate of 90 %. Subsequent trials were carried out on-site at the project partner CHMS in Rödental. Using a bypass system with continuous flow, up to 800 L/h of wastewater from floor mat cleaning was successfully treated. With a recovery rate of 80 %, the process produced reclaimed water with a 90 % reduction in COD. The minimum energy demand was 6 kWh per m³. Production-scale systems are expected to operate more energy-efficiently. The recovery rate has not yet been fully optimized, and the process currently results in 20 % wastewater relative to the initial volume.

On-site tests at CHMS with mat wastewater (Source: E.S.C.H. GmbH)

The transferability of the project results has already been demonstrated through real industrial inquiries and preliminary tests.

SAVINGS POTENTIAL

During process testing, it was demonstrated that the developed and tested process concept can reduce wastewater flows by at least 20 %. A large proportion of the treated process wastewater (>80 %) can be reused as process water at suitable points within the laundry facility. Depending on the specified quality requirements for individual washing processes, part of the fresh water supply can be replaced. By integrating the treatment technology and utilizing the high process temperatures (>45 °C), the efficiency of the process stage can be further increased (due to viscosity effects). Additionally, returning a "hotter" permeate as process water can contribute to reducing thermal energy consumption.

The quality of the permeate suggests that some detergent components remain in the permeate, which could potentially reduce the need for additional detergent upon reuse. However, this would require the involvement of detergent suppliers.

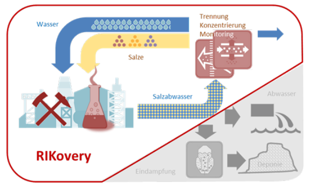
Duration
02/2021 to 07/2024

Coordination
Sebastian Auer
Kompetenznetzwerk Wasser & Energie, Hof

Website
www.rewamem.de

Project Partners
- Coburger Handtuch- und Mattenservice GmbH & Co. KG (CHMS), Rödental
- E.S.C.H. Engineering Service Center und Handel GmbH, Unterwellenborn
- Frauenhofer Institut für Keramische Technologien und Systeme (IKTS), Hermsdorf
- Hochschule für Angewandte Wissenschaften, Hof
- Rauschert Kloster Veilsdorf GmbH, Veilsdorf
- ZAE Bayern – Bayerisches Zentrum für Angewandte Energieforschung e.V., Garching

Recycling of Industrial Saline Waters by Ion Separation, Concentration and Intelligent Monitoring



RIKovery — Reusing Saline Industrial Water Streams

The increasing scarcity of water makes it essential to reuse saline water while also recovering the removed substances. This applies to both industrial process wastewater and saline water from stockpiles or saline groundwater.

In the RIKovery project, recycling concepts were developed to enable the recovery of salts from water streams and the reuse of the treated water. These processes help improve resource efficiency, prevent the discharge of substances into the water cycle, and reduce the demand for primary water sources.

RESULTS

Using real-world examples with membrane modules on a technical scale, it was demonstrated that innovative technologies for ion separation and concentration significantly expand the possibilities for concentrate treatment:

- Operating nanofiltration above the standard pressure of 41 bar (HPNF) proved particularly advantageous. It was shown that separating sulfates and chlorides is feasible even in nearly saturated salt solutions.
- The concentration of monovalent neutral salts using Ultra-High-Pressure Low Salt Rejection Reverse Osmosis (UHP-LSRRO) is achievable at an application pressure of 120 bar, reaching up to 15 % by weight—surpassing the limits of high-pressure reverse osmosis (UHPRO).
- It was demonstrated that forward osmosis, through well-designed process concepts, can achieve concentration up to the point of crystallization with minimal energy consumption.
- Flow-Electrode Capacitive Deionization (FCDI) could be used to separate and concentrate chloride ions from sulfate ions in a single step.

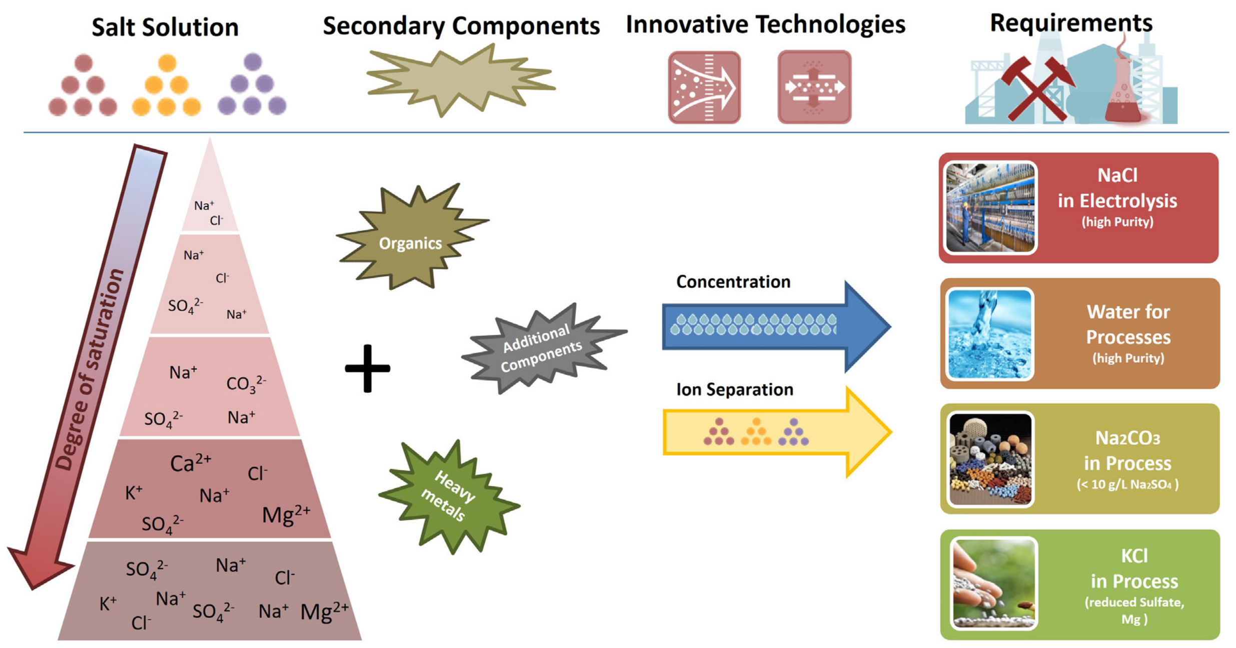
For the reuse of salts and water, specific parameters must be met to ensure safe operation. Concepts and analytical methods have been developed to determine organic trace substances in highly saline solutions.

APPLICATIONS

To achieve widely applicable project results, the project consortium has focused on industrially relevant applications that encompass major discharge sources (polymer chemistry, specialty chemicals, and the mineral industry). Although these sectors differ significantly in their challenges, they collectively account for the majority of industrial salt discharges.

The need to reduce salt emissions into surface waters calls for the advancement of energy-efficient processes for ion separation and concentration. This reduction should occur with little to no increase in the CO_2 footprint. Following this premise, the full application of membrane-based processes presents a logical and effective approach, successfully demonstrated in RIKovery. This opens up new perspectives for industrial brine processing in the context of resource recovery and water reuse.

RIKovery team (Source: K+S)



Tasks for the reuse of salt-containing industrial water streams in RIKovery (Source: RIKovery)

SAVINGS POTENTIAL

An innovative UHPRO/UHP-LSRRO membrane process (designed for 120 bar operating pressure) was developed for the concentration of monovalent salts, enabling the energy-efficient concentration of saline water (up to NaCl concentrations of 170 g/L). A pilot plant for continuous operation (feed: 2.5 m³/h) was constructed and deployed at the Leverkusen site (Covestro). This advanced technology can achieve up to 60% energy savings compared to evaporation.

Simultaneous ion separation and concentration from a $NaCl/Na_2SO_4$ mixture using FCDI was successfully demonstrated at RWTH Aachen University and Evonik. The process achieved a sodium chloride concentration of 150 g/L in the concentrate stream, with a separation efficiency more than 20 times higher for chloride ions compared to sulfate ions.

For the treatment of complex high-salinity waters in the potash industry, an innovative and energy-efficient process combination of HPNF-FO was developed. This approach allows for the separation and concentration of monovalent and multivalent ions with an energy demand of approximately 7 kWh/m³.

Duration
02/2021 to 12/2024

Coordination
Dr. Yuliya Schießer
Covestro Deutschland AG, Leverkusen

Website
www.rikovery.rwth-aachen.de

Project Partners
- AFIN-TS Analytisches Forschungsinstitut für Non-Target Screening GmbH, Augsburg
- BWS Anlagenbau & Service GmbH, Oberndorf a.N.
- Evonik Operations GmbH, Hanau-Wolfgang
- K+S AG, Unterbreizbach
- RWTH Aachen
- Technische Hochschule Köln
- TZW: DVGW – Technologiezentrum Wasser, Karlsruhe

Integrative Application of Innovations and Digital Cooling Capacity Management to Reduce the Amount of Water Required in Steel Production

WEISS_4PN — Potential for Reducing the Water Footprint of the Steel Industry

Steel production and processing require substantial water resources, as evaporation losses from processing and cooling circuits must be regularly replenished to prevent rising salt concentrations in process water. These losses can reach 200 m³/h or more per steel production site.

The project successfully tested various strategies to enhance water cycle efficiency and explored the use of wastewater streams as a substitute for freshwater through desalination technologies. Digital software solutions were implemented to balance water demand and availability, while various membrane technologies were piloted for desalinating water streams at steel sites. Additionally, anti-fouling coatings were tested to improve the efficiency of membrane processes.

RESULTS

The pilot plant was successfully operated at two locations, yielding valuable insights. During preliminary planning, it is essential to capture all site-specific parameters and tailor the process technology to the particular production operations and local water characteristics. The tested water exhibited different behaviors in the processes (e.g., silicate precipitation or deposits formed by phosphates or fluoride compounds). However, stable operation was achieved in all cases through appropriate operating parameters and adapted pre-treatments.

Changing the membrane on the reverse osmosis system (Source: SMS)

- Ultrafiltration with yields of 90–95 %
- Low-pressure and high-pressure reverse osmosis with yields of 85–90 %
- In-situ anti-fouling membrane coating was applied and showed promising results
- Membrane-based capacitive deionization achieved yields of up to 83 % with an energy demand of 0.57 kWh/m³ (flexible operation possible)
- Low-temperature distillation, when thermal energy is available via waste heat carriers, can operate with an electrical energy demand of 2.5 kWh/m³

Additionally, a promising forecasting tool for water availability was developed. This tool can proactively detect potential shortages and compare them with databases of production-dependent water demands.

APPLICATIONS

The process concept of the WEISS_4PN project offers flexible adaptation, enabling not only the treatment of various water sources but also fundamental solutions for water management:

- Reducing fresh water demand during periods of water stress
- Ensuring compliance with discharge regulations (⟶ ZLD solution)
- Economical production of fresh water

Piloting container and concentrate collector (Source: SMS)

Setting operating parameters on the ultrafiltration (Source: SMS)

The key components include pre-treatment steps (microfiltration, ultrafiltration, softening), desalination technologies (two-stage reverse osmosis, optionally membrane-supported capacitive deionization), and evaporation in the final process stage to complete a fully closed Zero Liquid Discharge (ZLD) system.

The knowledge gained in this project is directly applied by the industry partners to further develop mCDI technology, optimize membrane-based systems, and implement complete ZLD solutions in the steel industry.

SAVINGS POTENTIAL

It is difficult to quantify potential savings in general terms, as the efficiency and economic viability of the system are highly dependent on local conditions. For example, the conductivity of fresh water at an alpine steel site is below 100 µS/m, whereas surface waters in the lowlands—downstream of mining or industrial regions—can have average conductivities of 800 µS/m, reaching peaks of over 2000 µS/m during extreme summer heat periods. In the alpine case, a water recovery system is typically not economically viable, though it may be essential to maintaining production during periods of water scarcity. In contrast, in the second scenario, a ZLD process can achieve fresh water savings of 50 %, which can increase to over 80 % during summer months.

Duration
04/2021 to 10/2024

Coordination
Stefan Schmidt
SMS group GmbH (SMS), Hilchenbach

Website
www.sms-group.com/de-de/innovation/funding-projects/weiss-4pn

Project Partners
- aixprocess GmbH, Aachen
- ArcelorMittal GmbH, Eisenhüttenstadt
- Technische Universität Berlin
- Universität Duisburg-Essen (UDE)
- VDEh-Betriebsforschungsinstitut (BFI), Düsseldorf
- WEHRLE Umwelt GmbH, Emmendingen

TOPIC

Treatment of Saline Groundwater and Surface Water

Drinking water scarcity and rising water demand are pressing challenges in many regions worldwide. The intrusion of seawater into coastal areas and the depletion of freshwater resources are driving the need for efficient desalination processes. This funding measure supported the development of solutions for using saline groundwater and surface water as alternative water sources for various applications.

Further research is clearly needed in the treatment of saline groundwater and surface water. Key challenges include reducing operating and maintenance costs, increasing energy efficiency, environmental responsible disposal or reduction of the resulting brine, and the targeted management of interfering substances and raw materials. Significant potential lies in dynamic process management as well as in the monitoring and optimisation of desalination plants and processes.

Desalination technologies are increasingly used to produce drinking and process water, particularly in arid and semi-arid regions, but also in temperate climate zones. Decentralised treatment of saline groundwater and surface water presents several challenges. These include reducing operating and maintenance costs, increasing energy efficiency, managing the resulting brine in an environmentally responsible way, and reducing and specifically handling the residual materials produced.

In the topic of "Treatment of saline groundwater and surface water", the BMBF has funded three joint research projects. These have developed future-oriented technologies and concepts for decentralised applications. The effectiveness and service life of membrane systems have been improved; an innovative modular system for autonomous drinking water production enables the desalination and removal of arsenic from groundwater, brackish water, and seawater.

The key results and products of the research projects, their application potential, and the resulting opportunities for saving water and resources are summarised on the following pages.

Joint Research Projects

innovatION: Selective Removal of Monovalent Ions from Saline Waters for Groundwater Recharge and Drinking Water Treatment

HaSiMem: Water Recovery from Tailings Leachates using Membrane Distillation Processes Coupled with Crystallisation

SULFAMOS: Sulphate Removal by Forward Osmosis and Hollow Fibre Immersion Modules

Selective Removal of Monovalent Ions from Saline Waters for Groundwater Recharge and Drinking Water Treatment

innovatION — Energy-Efficient Selective Desalination with mMCDI

Freshwater influenced by marine, geogenic, or anthropogenic salt deposits contains elevated concentrations of monovalent ions (e.g., sodium, nitrate, and chloride) as well as multivalent ions (e.g., sulfate and calcium). Traditional desalination processes typically remove monovalent ions from saline groundwater and surface water through full desalination, which can be resource-intensive.

To achieve a more energy-efficient and resource-conserving reduction of monovalent ions, selective membranes were tested within the innovatION project for use in monovalent-selective membrane-assisted capacitive deionization (mMCDI).

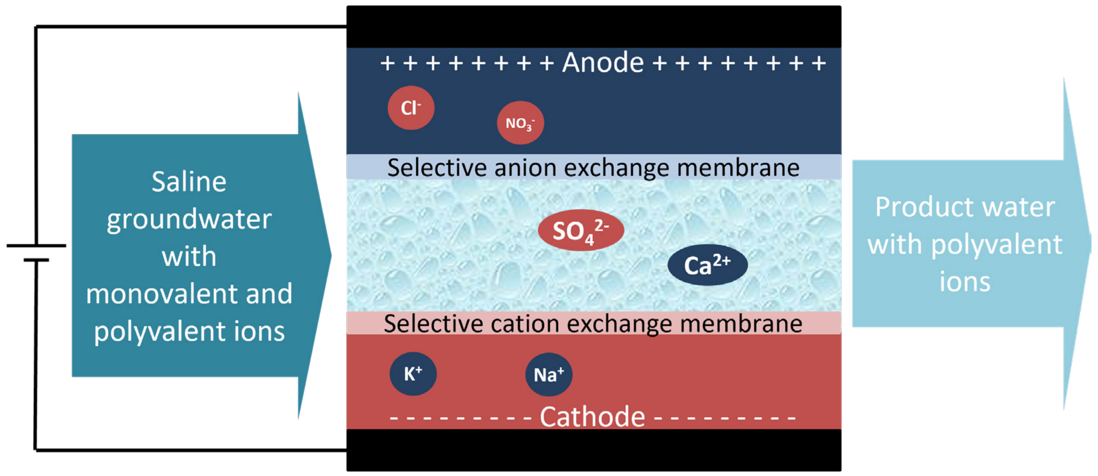
RESULTS

mMCDI is an energy-efficient electrochemical partial desalination process for the removal of monovalent ions from low-salinity waters. The desalination process can adapt to conditions such as power availability, required yield, and desalination performance. By using newly developed monovalent-selective membranes, monovalent ions like sodium, nitrate, and chloride can pass through the membranes and adsorb onto the capacitive electrode of the mMCDI cell. Under optimal process conditions (low electrical voltage and high flow rate), multivalent ions cannot pass through the membrane and remain in the product water. In laboratory and pilot tests, mMCDI achieved up to ten times higher removal of monovalent ions compared to divalent ions. Both capital and operational costs were lower than with comparable conventional desalination technologies.

APPLICATIONS

In the future, mMCDI can be used where monovalent ions exceed regulatory limits for drinking water or irrigation or where groundwater recharge with partially desalinated water is required. Studies have shown that partially desalinated water is better suited for groundwater recharge than fully desalinated water. Compared to conventional desalination, mMCDI offers an energy advantage for low-salinity waters, such as the nitrate-rich groundwater at the Nienburg District Association for Water Management site, where the total salt content is 0.3 g/L. At higher salinity levels, such as at the Oldenburgisch-Ostfriesischer Wasserverband site on Langeoog, mMCDI showed higher energy consumption than nanofiltration, but required less chemical cleaning.

Since no antiscalant additives are needed, the handling of concentrate for further concentration, reuse, or disposal is less problematic. However, long-term application remains limited by the material properties of the electrodes.

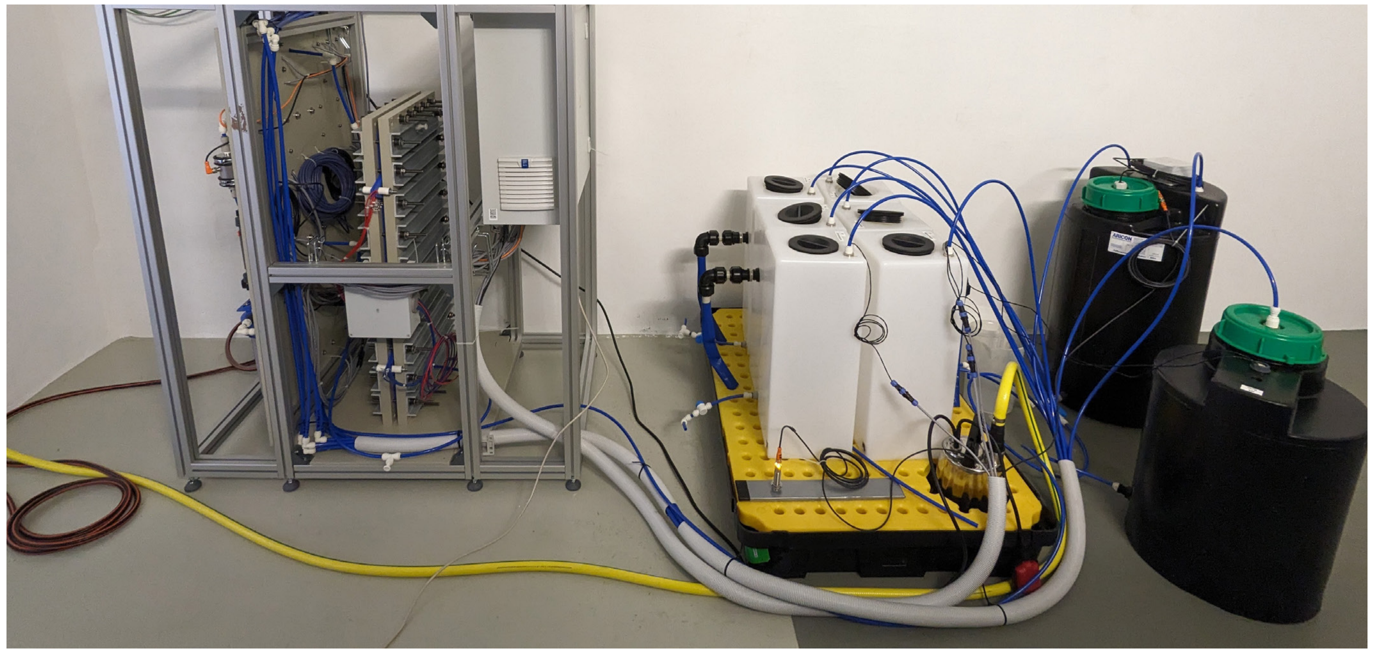


Functional diagram of the mMCDI for the treatment of saline water (Source: Hanna Rosenreter, TU Dresden)

SAVINGS POTENTIAL

For selective nitrate removal using mMCDI, under optimized process conditions, an energy consumption of 0.05–0.10 kWh/m³ was measured at a feed concentration of 0.3 g/L, which is up to 50 % lower compared to traditional desalination processes. At a feed concentration of 1.3 g/L, mMCDI showed similar energy consumption to nanofiltration but required significantly fewer chemicals. For desalination, mMCDI achieved a yield of up to 90 %, albeit with higher energy consumption.

The results on selective nitrate removal have been submitted to Water Resources and Industry. A review on the production, application, and sustainability aspects of monovalent-selective ion exchange membranes has been published (https://doi.org/10.1016/j.desal.2024.118412). The findings on the suitable infiltration of monovalently partially desalinated water have been submitted to the Journal of Hydrology.



mMCDI pilot plant from DEUKUM GmbH and elkoplan staiger GmbH for the selective removal of monovalent ions on Langeoog at the Oldenburgisch-Ostfriesischer Wasserverband (Oldenburg-East Frisian Water Association) (Source: David Schödel, TU Dresden)

Duration
02/2021 to 10/2024

Coordination
Prof. André Lerch,
Technische Universität Dresden, Professur für Verfahrenstechnik in Hydrosystemen

Website
www.innovat-ion.de

Project Partners
- Carl von Ossietzky Universität Oldenburg, AG Hydrogeologie und Landschaftswasserhaushalt
- DEUKUM GmbH, Frickenhausen
- elkoplan staiger GmbH – Automation für die Umwelt- und Verfahrenstechnik, Nürtingen
- FUMATECH BWT GmbH, Bietigheim-Bissingen
- Kreisverband für Wasserwirtschaft Nienburg
- Leibniz-Institut für Polymerforschung Dresden e.V. (IPF)
- Oldenburgisch-Ostfriesischer Wasserverband (OOWV), Brake
- Technische Universität Dresden, Professur für BWL, insb. Nachhaltigkeitsmanagement und Betriebliche Umweltökonomie
- United Nations University, Inst. for Integrated Management and Material Fluxes and of Resources, Dresden (assoziierter Partner)
- KWR Water B.V., Nieuwegein, Niederlande (assoziierter Partner)

Water Recovery from Tailings Leachates using Membrane Distillation Processes Coupled with Crystallisation

HaSiMem — Process Combination of Membrane Distillation and Crystallization for the Treatment of Brine from Salt Stockpiles

Precipitation on salt industry stockpiles generates highly concentrated brine, which is collected in peripheral ditches and drainage systems before being disposed of. At the stockpiles of the project partners K+S and LMBV (Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft), more than 2.5 million m³ of brine accumulate annually.

The project aims to investigate a process combination of crystallization and a membrane-based distillation process (MD). The focus is on the stability of hydrophobized ceramic membranes when exposed to saturated salt solutions.

RESULTS

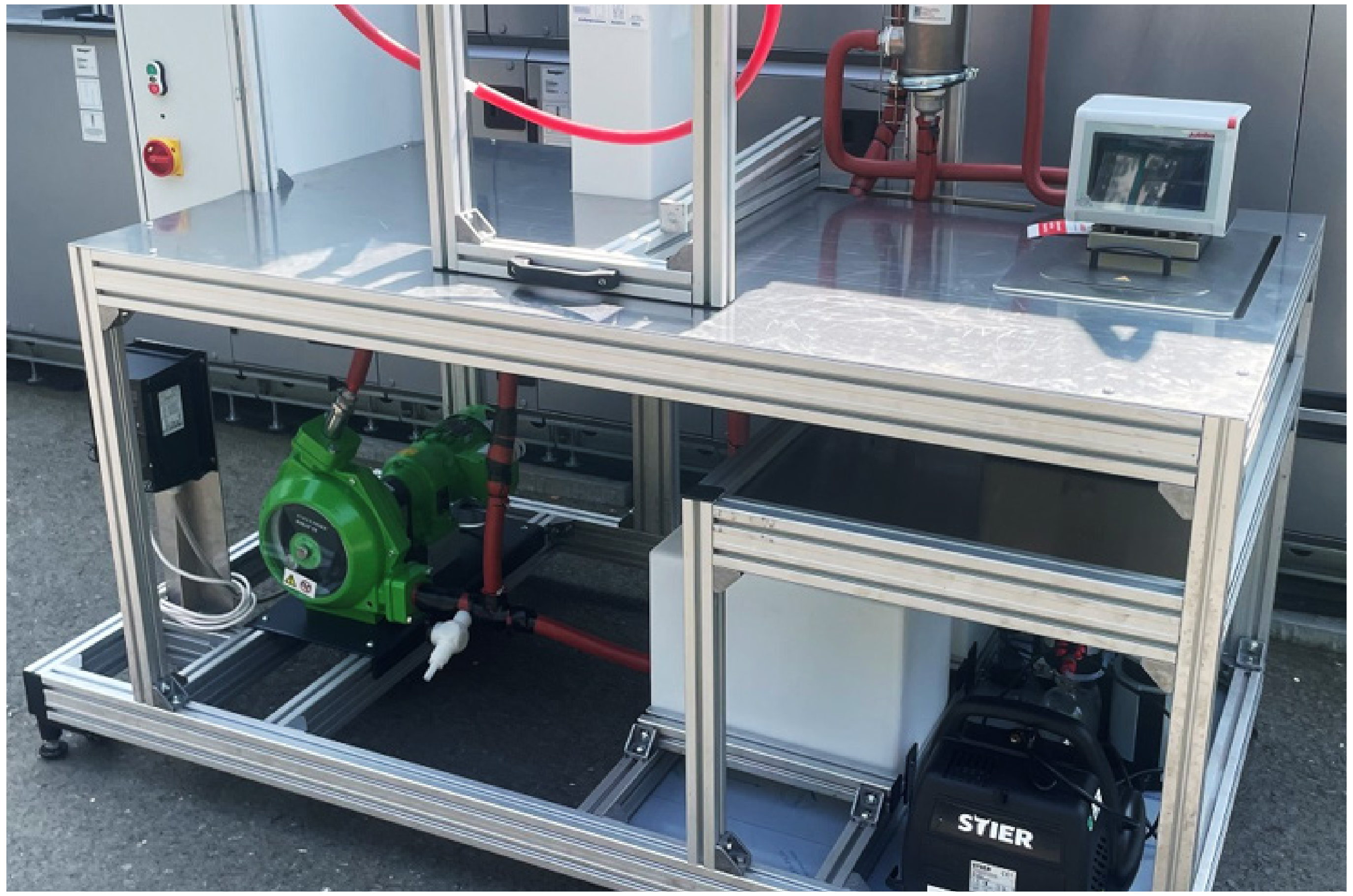
The treatment process works as follows: A heated salt solution flows past a hydrophobic membrane, where water evaporates from the solution. The membrane separates the feed chamber from the distillate chamber, preventing the passage of the salt solution while allowing only water vapor to diffuse through. This increases the salt concentration, leading to supersaturation. The extracted water is virtually salt-free, while salt crystals form in a crystallizer as the supersaturated solution continues to circulate. The concentrated brine flows between the membrane and crystallizer until the desired amount of water has been removed.Experiments with polymeric membranes failed due to membrane clogging caused by salt crystallization on the membrane surface. However, this issue did not occur with functionalized ceramic membranes, making them suitable for use with saturated salt solutions. To optimize distillate yield, membranes with different channel configurations were fabricated, coated, and initially tested at laboratory scale using synthetic brine. In the final phase of the project, successful pilot-scale experiments were conducted with real brine from salt stockpiles. The results of this study are currently being evaluated.

Ceramic 7-channel and 19-channel tubes for membrane distillation (Source: Fraunhofer IKTS)

APPLICATIONS

The developed process was tested at pilot scale using brine from salt stockpiles. Originally designed for the concentration of brine, the results also suggest potential applications for the concentration of various types of saline waters. Compared to industrial evaporation, membrane distillation allows for significantly more compact system designs due to the separation of the salt solution and the distillate chamber, enabling a smaller distillate chamber.

This makes the process particularly advantageous in cases where evaporation needs to occur at low absolute pressures, as conventional evaporators would require large-scale installations due to the low density of water vapor. Since salts lower the vapor pressure of aqueous solutions, and the investigated process remains applicable even when salts crystallize, this technology offers promising potential for the salt-processing industry.



Membrane-side plant section for testing the process combination of ceramic membrane distillation and crystallization (Source: Fraunhofer IKTS)

SAVINGS POTENTIAL

By treating brine from salt stockpiles, salt loads in receiving waters can be reduced, salt can be stabilized for storage, and water demand can be minimized. Compared to conventional evaporation systems, membrane distillation physically separates the concentrated salt solution from the distillate chamber, allowing for a significantly smaller and more compact design. At the same time, the membrane shields the distillate chamber from the corrosive saline solution, a protection that conventional evaporation processes do not provide.

This enables the use of lower-cost materials and could lead to potential investment cost savings in the future. A multi-stage system can further reduce energy consumption, for example, by 50 % in a two-stage process and 67 % in a three-stage process. In this study, the stability of the membranes in contact with real, particle-laden salt solutions was successfully demonstrated. However, the ceramic membranes used are still under development, and significant cost reductions are expected through scaling up to larger industrial membrane geometries. The actual extent of possible savings could not yet be fully determined within this project and remains an area for future research.

Duration
02/2021 to 12/2024

Coordination
Bernhard Neupert
K-UTEC AG Salt Technologies, Sondershausen

Website
www.hasimem.de

Project Partners
- Fraunhofer Institut für Keramische Technologien und Systeme (IKTS), Hermsdorf
- K+S Aktiengesellschaft, Kassel
- SolarSpring GmbH, Freiburg

Sulphate Removal by Forward Osmosis and Hollow Fibre Immersion Modules

SULFAMOS

SULFAMOS — Sulfate removal by means of forward osmosis and hollow fiber immersion modules

One of the long-term consequences of lignite mining in Germany is the widespread contamination of groundwater and surface water with iron and sulfate. At the same time, the phase-out of lignite will lead to a shortage of gypsum, a raw material for the construction industry that was previously produced in power plants through flue gas desulfurization. The SULFAMOS joint project developed a combined process to address both challenges: By reducing sulfate pollution, affected water bodies can once again be used for drinking and industrial water supply. Additionally, gypsum is recovered from residual materials.

Installed SULFAMOS pilot plant at the field site of a water treatment plant. Right: Module for forward osmotic sulfate enrichment, left: module for sulfate separation by means of precipitation as gypsum (Source: G.E.O.S.)

RESULTS

The project team developed new, specially surface-treated hollow fiber membranes with high sulfate retention, which were then tested in custom-designed modules. Laboratory tests showed that pure water can be extracted from heavily sulfate-contaminated groundwater using forward osmosis, allowing the resulting concentrate to be processed into gypsum of construction-grade quality. The test results contributed to the design of a pilot plant consisting of a membrane and precipitation module, which was directly supplied with effluent from a groundwater treatment plant and successfully tested in continuous operation.

The project results confirmed that the developed process combination is fundamentally suitable for treating sulfate-contaminated water from sources affected by open-cast mining. Water suppliers and mining facility operators are increasingly facing the challenge of declining water

View of the felling cascade (Source: G.E.O.S.)

availability and the corresponding rise in sulfate concentrations in already contaminated sources. Over the course of the project, G.E.O.S. was able to establish contact with many potential users.

APPLICATIONS

Potential technology users include:
- Water suppliers with wells that were taken out of operation due to high geogenic sulfate concentrations in raw water but need to be reactivated in the future to ensure supply security during dry years.
- Operators of mine water treatment plants struggling to meet effluent quality standards for sulfate.
- Cities and districts in post-mining regions that require strategies for the sustainable management of their water resources.
- Mining operators extracting gypsum rock who also need to treat associated leachate.
- Users of conventional membrane processes seeking viable methods for handling sulfate-rich concentrates.
- Facilities producing electrolysis feed water for hydrogen generation within Power-to-X concepts.

SAVINGS POTENTIAL

The wide range of potential users highlights the significant technological potential of this approach, making it applicable to various challenges. There are numerous reasons to implement this method for reusing water from sulphate-contaminated sources, such as:
- Protecting water bodies by further treating wastewater before discharge into receiving waters,
- Achieving a substantial reduction in sulphate loads, thereby significantly improving the chemical and ecological status of water bodies,
- Ensuring the sustainable management of water sources,
- Creating value from residual materials instead of disposing of them, while promoting sustainable resource use through closed-loop processes,
- Making an important contribution to both active and preventive environmental protection.

Duration
05/2021 to 04/2024

Coordination
Dr. Roland Mayer,
G.E.O.S. Ingenieurgesellschaft mbH, Halsbrücke

Website
www.sulfamos.de

Project Partners
- fluvicon Industries GmbH, Frickenhausen
- Fraunhofer-Gesellschaft, Institut für Grenzflächen und Bioverfahrenstechnik (IGB), Stuttgart
- HTW Hochschule für Technik und Wirtschaft Dresden, Lehrgebiet Wasserwesen
- MionTec GmbH, Leverkusen
- Zweckverband Wasser/Abwasser Bornaer Land, Borna

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