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Newsletter of the Chair of Urban Water Systems Engineering

ANNUAL REPORT OF THE CHAIR OF URBAN WATER SYSTEMS ENGINEERING

2017

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Foreword

Dear Friends,

I am pleased to present our 2017 annual report. The past year brought us some personnel changes and related adjustments, but was also marked by exciting research activities and gratifying third-party funding. The staff of the chair continues to be very active in sharing their findings in scientific publications. We are especially happy for Dr. Carmen Leix and Dr. Stefan Bieber for the successful completion of their doctorates last year. The doctoral work of Dr. Max Huber was awarded with the 2017 Willy-Hager Award. Lukas Högel received the 2017 K.P. Scholz Prize for his master's thesis. Meriam Muntau was awarded the Max-von-Pettenkofer Prize for her master's thesis. We congratulate you once again.

Last year our chair was strengthened by four new doctoral candidates, who are introduced to you in this annual report. We enjoyed a direct exchange with visiting scientists from Australia, China, the Czech Republic and the USA, some of whom visited us for several months. Building on diverse discussions, we look forward to further developing these contacts through ongoing and future research activities and return visits.

In July 2017, the 45th Wastewater Technology Seminar (ATS) took place with the topic "Further Phosphorus Elimination on Municipal Wastewater Treatment Plants - Possibilities and Limits", which was organized under the leadership of Prof. Brigitte Helmreich. The 46th ATS on "Innovative strategies for the treatment of sewage sludge" is scheduled for July 4th, 2018 in Ismaning. The program can be found on our web portal, where you can also register online (www.sww.bgu.tum.de/ats). We would be very pleased to see you at the event.

Also in the past year, the chair was able to attract a number of new research projects, such as the BMBF joint project *SubµTrack* (led by Dr. Johanna Graßmann and myself), and the project *MiPaq*, funded by the Bavarian Research Foundation, both of which are dedicated to assessing the occurrence and behavior of micro-particles/microplastics in the aquatic environment and in food. In addition, we received funding commitments for the German Research Foundation (DFG) project to increase methane production in biogas plants through CO2 enrichment (led by Dr. Konrad Koch) and a new project from the German Environment Agency (UBA) to estimate the impact of unintended water reuse on the drinking water supply in Germany.

In the past year, the chair made significant contributions to the education of students in the bachelor's degree programs in Environmental Engineering and Civil Engineering, as well as in the master's degree programs in Environmental Engineering, Civil Engineering, Environmental Planning, and Engineering and Sustainable Resource Management. In addition to a large number of lectures, exercises and laboratory sessions, the staff of the chair supervised over 75 master theses, study projects, and bachelor theses. The revision of the master's program in Environmental Engineering in 2016 has once

again significantly increased interest in this degree program (more at www.umwelt.bgu.tum.de).

Nationally, our employees have been involved in several working groups of the DWA and the German Water Chemical Society (GDCh), and internationally in the NORMAN working groups at the European level, and at the International Water Association (IWA).

The year 2017 brought with it some personnel changes in important leadership functions of the chair. Due to the changed and stricter provisions of the Science Employment Act (Wissenschaftszeitgesetzes), our hands were tied, and the employment contracts for Dr. Letzel and Dr. Grassmann, who both led the Analytical Research Group, to extend beyond the current term. Furthermore, according to the provisions of this law and the Technical University of Munich, no further research proposals can be submitted by these employees, meaning there is no prospect of continuing this important working group in its current form. This development is extremely regrettable. We therefore decided to reorganize our trace organic chemical analysis laboratory at the chair. We are pleased that we were able to win Mr. Oliver Knoop to take over the leadership of this laboratory. Mr. Knoop will take over this function on April 1, 2018 after completing his PhD thesis with Prof. Torsten Schmidt in Essen. As of November 1, 2017, Dr. Bastian Herzog, who led the research group 'Microbiological Systems', left for a new position in Austria. We wish Mr. Herzog all the best in his new position. We are very glad that we were able to recompose this group, which will be led by Dr. Christian Wurzbacher as of March 1, 2018. More information on reorganizing these research activities will be provided in the next report.

On behalf of my staff, I would like to thank you for your support and interest in our students and our work. We are grateful in particular for the support of our 'Friends of the Chair' association, which makes a vital contribution to the training of our doctoral candidates and students, as well as financing conference travel and research grants.

We would be very happy if, through your generous donation, we can again provide this support for our doctoral candidates and students during this year.

We wish you a successful year, and hope you enjoy reading the report.

Sincerely,

Research Center

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The mission of the research center at the Chair of Urban Water Systems Engineering is to provide support for process validations for both drinking water and wastewater treatment technologies at laboratory and pilot scale. In addition, we are conducting studies on new materials and processes and support research and development in close collaboration with industry partners, small and medium-size enterprises, and public as well as regulatory agencies. The research center is comprised of a 400 m² pilot-scale facility and an adjacent research field, both with direct access to treated wastewater from the Garching Wastewater Treatment Plant (30,000 PE). This infrastructure enables us to conduct studies not only with drinking water, but also to examine wastewater processes fed continuously with differently treated effluent qualities. For these studies, we can conduct experiments at laboratory and pilot scale with reactor volumes between 30 and 800 L in size. This provides opportunities to upscale and validate processes from laboratory to demonstration scale. Beside Zahn-Wellens-Tests to examine the biodegradability of wastewater samples (following DEV L 25), we also conduct activated sludge simulation tests (following DEV L 41).

Regarding advanced water treatment processes, the research center is equipped with test skids for chemical oxidation (ozone, UV irradiation with hydrogen peroxide, electrochemical oxidation) and membrane filtration (ultrafiltration, nanofiltration, reverse osmosis) (Fig. 1).

Fig. 1: Pilot-scale nanofiltration test skid (80 L/min).

In addition, the center is investigating and advancing treatment processes for urban stormwater and street run-off. For these investigations, we can utilize laboratory-scale test and soil column experiments of various sizes to examine the fate and transport of heavy metals and organic contaminants. Regarding urban run-off from copper roofs, a demonstration-scale test bed is available at the center, which is comprised of a large-scale copper roof and associated sampling and monitoring devices.

The research center is directed by Prof. Brigitte Helmreich.

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Start-up phase of single stage deammonification for reject water treatment with swinging ORP

Several investigations focusing on the measurement of oxidation reduction potential (ORP) demonstrated operation stability of deammonification in a sequencing batch reactor (SBR) at loads of more than 460 $g_N/(m^3*d)$ and >92% nitrogen removal rates.

Subsequent replicate tests of the start-up phase were conducted at a 125 L SBR pilot plant, which demonstrated that single stage deammonification could be achieved within two months up to full load with only 10% deammonifying biomass in an activated sludge with 1.5 g_{MLSS}/L.

The biochemical process is controlled through ORP observation of alternating aerobic and anoxic conditions between –30 to +90 mV, and pH can be adjusted by controlling municipal wastewater influent during start-up and optimization periods as needed. Additives are unnecessary during normal conditions, and NO_2-N concentration is present at <1 mg/L. Performance enhancement can be doubled at start-up phase by increasing operating temperature from 30 to 32°C. Excess sludge is removed from the granular reactor through effluent wasting after 5 minutes of settling time, and at ideal capacity the sludge age is adjusted to 14 days.

Process control included small corrective actions for feed volume, duration of anoxic and aerobic conditions, air flow volume, settling time and temperature, according to the available amount of reject water. Control variables are limiting ORP amplitudes, pH, conductivity and dry mass content. Nitrogen concentrations were measured 2-3 times per week during normal operation.

When considering scale-up options, it is notable that operation stability will be influenced by aging reject water due to decreasing C/N rates, lower buffer capacity, and high solids content. A promptly sludge dewatering and reject water treatment is therefore recommended to minimize operational costs.

Due to the 20-30 min intervals of alternating anoxic and aerobic conditions and a very low aeration demand during the start-up period, connecting the SBR aeration system to the wastewater treatment plant main air supply is recommended only with a separate flow rate control.

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Optimization of sludge liquor treatment at wastewater purification plant Salzburg

For the treatment of incoming centrate from sludge dewatering as well as effluents from the surrounding waste company with landfill site and biowaste fermentation, a parallel sequencing batch reactor plant (SBR), with 2 x 1400 m³ capacity and a separate storage pool, started running at WWTP Salzburg Siggerwiesen in 2000. After 15 years of operation with nitritation, existing infrastructure was upgraded to allow installation of new measurement devices.

With the objective of optimizing nitrogen reduction, investigations were done on behalf of the Greater Salzburg Conservation Association to convert the existing operations to allow for deammonification. After discreet modifications to the prior process control and when considering oxidation reduction potential, it became apparent (Fig. 2) that an autonomous growth of planctomycetes had established four month after starting the research, especially on submerged surfaces. No growth was observed during the time the plant was operating with nitritation.

Fig. 2: Deammonifying biomass inside the SBR.

Due to prompt treatment after sludge dewatering, the temperature range inside the SBR is between 27 and 32 °C. Increased nitrogen reduction is expected with the growth of deammonifying biomass.

The focal points of further optimizations are preventive measures against input of external suspended and settleable solids, and therefore an exact adjustment of the essential sludge age. A minimization of nitrous oxide is possible by adapting alternating aerobic and anoxic process phases.

For process stability, the installation of a control module in case of influent and aeration supply failure will be particularly important.

Physicochemical, Analytical and Microbiological Laboratories

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A central facility of the chair and the research center is the affiliated laboratory, divided into three areas: the physicochemical laboratory led by Dr. Carolin Heim, and the analytical laboratory, led by Dr. Thomas Letzel, and microbiological laboratories, led Dr. Bastian Herzog.

The physicochemical laboratory is equipped with state-of-the-art analytical apparatus for the investigation of all relevant standard parameters in drinking and wastewater. Besides the characterization of water samples through sum parameters, such as COD and BOD, organic parameters can be further determined using 3D fluorescence and UV spectroscopy and measured quantitatively with the TOC analyzer. For analysis of anions, either photometric test methods or ion chromatography are available. Determination of metals is carried out using atomic absorption spectrometry. Traces of volatile parameters can be determined using the GC-FID gas chromatograph (Fig. 3).

Fig. 3: GC-FID gas chromatograph coupled to a headspace sampler.

In the analytical laboratory, GC/MS, LC-TOF-MS, as well as LC/MS-MS (Fig. 1) systems are available for target, suspected-target und non-target screening measurements. These are applied for characterization and identification of organic molecules in water matrices. New and established strategies enable the investigation of various molecules in water matrices.

Fig. 1: LC-QTRAP-MS system for trace analysis.

The micro- and molecular biological laboratory provides conventional cultivation as well as molecular biological techniques. The detection of fecal indicator bacteria, i.e. *E. coli* and enterococci, and pathogenic bacteria, i.e. *Pseudomonas aeruginosa*, and *Legionella* spp. to monitor water quality, is done with a panel of routine classic cultivation techniques. Additionally, molecular biological techniques, e.g. real-time quantitative polymerase chain reaction (qPCR), are employed to quantify a wide range of genes, including antibiotic resistance genes and specific bacterial groups e.g. enterococci (Fig. 6).

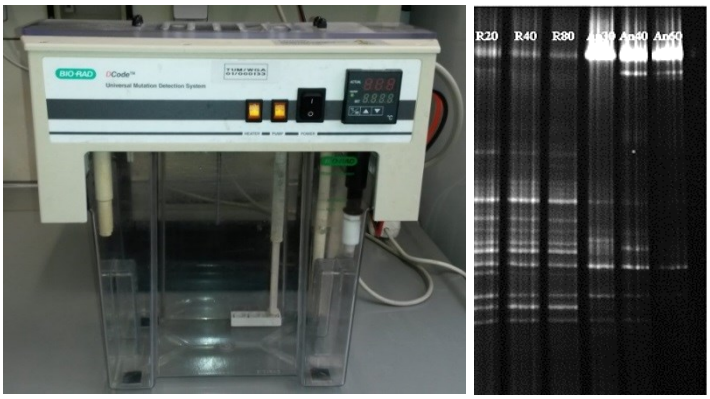

Fig. 2: Denaturing gradient gel electrophoresis system for determination of the diversity of microbial communities.

Fig. 6: PCR and qPCR systems to amplify and quantify different genes of interest.

Furthermore, fluorescence *in-situ* hybridization (FISH) combined with fluorescence microscopy is performed and used for semi-quantitative analysis of different bacterial communities that are relevant in biological wastewater treatment processes (e.g. nitrifiers, ANAMMOX bacteria, methanogens and sulfate reducing bacteria). In addition, PCR combined with denaturing gradient gel electrophoresis (DGGE, Fig. 2), as well as next-generation sequencing (amplicon sequencing on MiSeq Illumina) is used to characterize microbial community structure and function originated from natural and engineered systems.

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Research Group
Anaerobic Technologies & Energy Recovery

Reliable treatment of municipal wastewater for discharging without hesitation remains the main goal of wastewater treatment. However, wastewater treatment plants (WWTP) are one of the major municipal energy consumers, with only little recovered energy (mainly as methane). Using different approaches, our group investigates energy recovery from wastewater streams.

One focus of research is on increasing the efficiency of anaerobic digestion of residues. In this case, sewage sludge treated by ultrasound is tested for its suitability and is energetically optimized, whereby transferability from the laboratory to the practical scale plays a central role.

Another project goes beyond the actual main task of sewage treatment plants, namely to purify wastewater, and addresses the question of how WWTPs can also make a contribution to the energy transition. Hydrogen from surplus electricity supplied via the electrolysis of water together with CO_2 of the biogas produced during the digestion of sewage sludge is converted into methane. Thus, energy is stored in the gas network independently of time and place. Our experience from nearly 2 years of operation indicate that the microbial methanation in the trickle bed reactor and under thermophilic conditions is extremely fast and efficient.

Through cooperation with Cranfield University (UK), we have become aware of an interesting phenomenon that we were able to reproduce in our own lab. Apparently, the methane productivity of anaerobic digestion seems to be stimulated by CO_2 enrichment. Though this has already been observed by other research groups, so far only a few hypotheses have been proposed for determining the underlying mechanism. We aim to better understand this interesting phenomena in a joint DFG project with the stable isotope labeling experts at the University of Heidelberg, and the LfL microbiologists in Freising.

Fig. 7: Continuously operated biogas reactor.

FUNDING:
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GERMAN ACADEMIC EXCHANGE SERVICE

COOPERATION:
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STANFORD UNIVERSITY, USA;
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Optimizing strategies for enhanced deammonification performance and reduced nitrous oxide emissions

Deammonification is a promising process to treat high-strength ammonium-rich process water, as costs can be reduced significantly for energy, additives, and sludge disposal compared to conventional nitrification/denitrification. However, nitrous oxide (N_2O) might be formed as an intermediate or an unwanted by-product and may be emitted with the off-gas. Due to its global warming potential of 300 compared to CO_2, its long-term persistence in the atmosphere, and the ozone layer-depleting effect, emissions should be reduced to the greatest possible extent.

Therefore, strategies for an enhanced deammonification performance and reduced N_2O emissions were developed within the framework of this dissertation to enable both an ecological and an economic deammonification process. To cover as many system configurations as possible, experiments with one- and two-stage deammonification systems employing both suspended sludge operated as sequencing batch reactor (SBR) and biofilm carriers employed in a moving bed biofilm reactor (MBBR) at laboratory and pilot-scale have been conducted.

Results demonstrated that the deammonification performance of a MBBR could be enhanced by the accumulation of even little quantities of suspended biomass. For one-stage SBRs, a maximized nitrogen removal rate was predicted at settings of an intermittent feeding and aeration strategy and an initial pH value of pH 7.5. In comparison, operational settings of single feeding, continuous aeration, and an initial pH value of pH 7.8 were modelled to lead to minimal N_2O emissions. Furthermore, the aeration strategy should be adjusted to the system specific current N_2O-production in order to reduce N_2O emissions (e.g., activation of aeration only at low dissolved N_2O concentrations, etc.). As the nitrogen removal rate and the N_2O emissions exhibited a weak positive correlation under the tested conditions, both an economic and ecological operation of the deammonification process is only achievable by means of a compromise. Since N_2O emissions are subject to several influencing factors and exhibit a large variability, the catchment and incineration of the entire deammonification off-gas together with biogas would be an effective end-of-pipe solution to safely render gaseous N_2O into non-hazardous N_2 and to ensure an environmentally friendly deammonification process without a potential performance loss.

The dissertation was successfully defended in September 2017 and is available on mediaTUM at the following link:
https://mediatum.ub.tum.de/?id=1355598

FUNDING:
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COOPERATION:
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Nitrous oxide as an innovative source for energy recovery from wastewater (PANOWA)

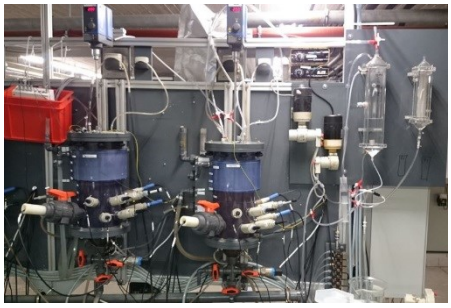

Fig. 8: Automated bioreactor system according to the design at EAWAG.

Nitrous oxide (N_2O) is an unavoidable intermediate within the biological nitrogen cycle and, as such, a common side-product from biological wastewater treatment trains. Its CO_2 equivalence of 300 makes it a potent greenhouse gas. Additionally, it catalyzes the destruction of the stratospheric ozone layer. However, the exothermal decay to nitrogen gas allows its energetic utilization together with biogas from the anaerobic stabilization of sewage sludge and parallel decomposition. To assess potential technical application, integration, operation and control strategies, as well as novel N_2O online measurement techniques are investigated.

For this purpose, the Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) developed at Stanford University has been established at TUM and operated as a double-stage bioreactor system (Fig. 8). In contrast to our colleagues in California, the system was fed by real wastewater, i.e. reject water and primary effluent, instead of synthetic substrates. In a long-term study (Fig. 9), 50 to 70% of the incoming nitrogen loads could be converted to N_2O while applying different operational strategies.

FUNDING:
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EAWAG, SWITZERLAND;
CHAIR OF ANALYTICAL CHEMISTRY, TUM

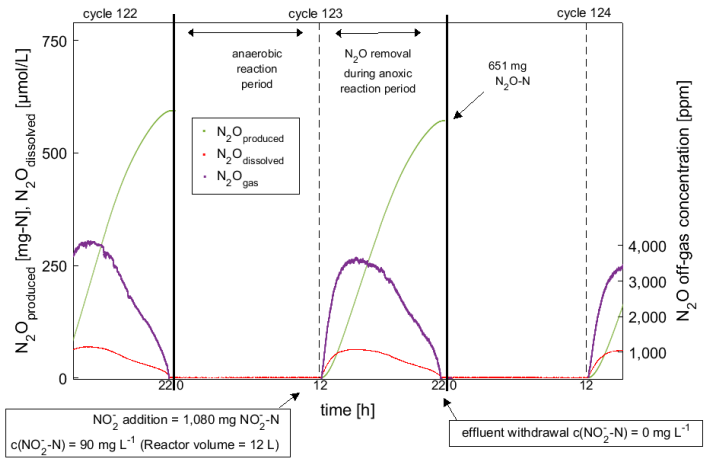

Fig. 9: N_2O production in the second stage of the CANDO process in long-term sequencing-batch-operation (Weißbach et al., 2017).

Additionally, a life-cycle assessment about different alternative process schemes for water reuse demonstrated the application potential of the CANDO process, and were also compared to the deammonification process (Horstmeyer et al., 2017).

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Multi sectorial approach for management of wastewater in Addis Ababa

Addis Ababa currently has 3.5 million inhabitants and extends over 540 km^2. According to the Ministry of Water, Irrigation and Energy, the per-capita water supply to the community is about 20 L/day, totaling 70,000 m^3/day of discharged wastewater, excluding rain and percolating water. Addis Ababa Water Supply and Sewerage Authority (AAWSA) provides the city with its potable water supply, as well as the collection and disposal of wastewater.

The existing Kality and Kotebe wastewater treatment plants have a total treatment capacity of only 16,650 m^3/day. Thus, these treatment plants can only manage to treat about ¼ of the total wastewater discharge of the community. Consequently, AAWSA started to expand the existing sewer system by dividing the city into three catchment areas. By applying a centralized approach with sewer pipes leading to three new WWTPs, a total treatment capacity of 366,000 m^3/d is envisioned. Due to the topographical conditions of Addis Ababa, only part of the city is suitable for this centralized approach. In order to treat the remainder of the city's wastewater, decentralized systems are also required.

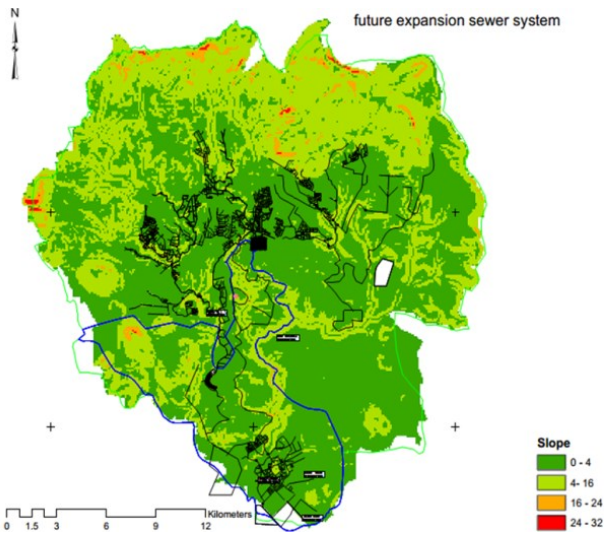

Fig. 10: Planned sewer system expansion in Addis Ababa.

The willingness of the community to participate in wastewater recycling and reuse options was determined by conducting a survey. It revealed that almost half of the community is already well informed and ready to adopt possible reuse methods. On the downside, 25% of the respondents were not interested in wastewater recycling and reuse, especially when the source of wastewater included wastewater from toilets.

With support from most of the community, schemes for decentralized wastewater treatment including water, nutrient and energy recovery will be adapted. The most promising approach will be constructed on the university campus as a demonstrative small-scale pilot plant. The abilities of a simple but efficient and resilient treatment system will hopefully be the first step towards making the beautiful capital of Ethiopia a better place to live.

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COOPERATION:
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Tailored energy supply by microbial methanation in thermophilic anaerobic trickle bed reactors

The development of new energy conversion and storage technologies becomes increasingly important with changing energy policy towards renewable resources. Within the German gas grid, currently up to 250 billion kWh, or 25% of the yearly gas consumption, could be stored for long-term. In this context, the project aims to further study and develop the microbial generation of methane, using only hydrogen (generated via electrolysis of water) and carbon dioxide (from different sources (e.g. biogas plants, industry)), for ultimate storage.

Within the project, microbial methanation is investigated in thermophilic anaerobic trickle bed reactors at pilot plant-scale (58 L). Due to the larger gas-liquid interface surface area in these reactors, an improved hydrogen mass transfer can be expected even without pressurized gas supply. The investigated system already demonstrated the capability for stable long-term operation under thermophilic conditions and, compared to previously studied systems, high methane productions rates, with methane concentrations >95%. In regards to process efficiency and applicability, periods without gas supply and their impact on the microbial community and methane generation are studied, as an essential criterion for flexible "on demand" operation. Central research challenges are the formation of organic acids as well as the production of water as an unavoidable side product, which causes continuous acidification and dilution of the trickle medium.

Fig. 11: Trickle bed reactor at half-pilot scale.

Furthermore, parallel microbiological studies by the Bavarian State Research Center for Agriculture showed significant changes of the microbial composition within the trickle bed reactor. From the mesophilic inoculum, different thermophilic, hydrogenotrophic, and methanogenic archaea roes to dominate the biomass during long-term operation. In addition, development of a methanogenic archaea biofilm on the biofilm carriers has been observed. However, even after about two years of operation the biofilm is substantially thinner compared to mesophilic systems. Thus, requirements for operation with a biofilm and its associated formation mechanisms are currently under investigation.

FUNDING:
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COOPERATION:
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Increase of energy-efficiency of wastewater treatment by means of innovative ultrasound disintegration (UltraMethane)

Wastewater treatment plants are the largest municipal energy consumers. Although wastewater theoretically contains enough energy to power the entire treatment process, in the form of biogas potential, often only a fraction of the wastewater's chemical energy is recovered. Energy recovery is generally carried out during anaerobic treatment of the sewage sludge that is produced during the purification process. However, typical degrees of sludge degradation, without pre-treatment, are only about 50% to 60%.

The target of the research project is to improve methane yields from anaerobic digestion by employing ultrasound techniques. Through ultrasound-induced cavitation, sludge flocs are disintegrated and cells of microorganisms are rupture, resulting in improved microbiological degradation and consequently, increased biogas yield. However, practical experience has shown that conventional sonotrode-based systems are susceptible to interference. Therefore, an innovative split reactor is investigated as an alternative within this project.

Fig. 12: Continuously operated biogas test system.

To ensure a design that is as efficient as possible with respect to increasing the methane yield, laboratory tests regarding reactor design optimization and energy-efficient reactor operation are conducted (Fig. 12). A computer-based simulation of the fluid dynamics (CFD) and the sound field within the reactors accompanies the lab tests to finding an ideal design. For a holistic performance assessment of the novel reactor type, the impact of the treatment on sludge dewaterability, sludge viscosity, and sludge bulking in the digesters is evaluated as well.

Besides the experiences in lab-scale, large-scale implementation in selected wastewater treatment plants will deliver valuable information on the performance of the novel reactor concept in practice.

FUNDING:
FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY

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Increasing Methane Productivity in Anaerobic Digesters by CO_2 Enrichment

Wastewater treatment plants use about 20% of municipal energy consumption and emit roughly 3 million tons of CO_2 every year. Improving the balance between energy demand and energy production, by reducing the CO_2 footprint of wastewater treatment plants, is a crucial research objective. Currently, the chemical energy bound in wastewater is partially recovered in the form of energy rich methane gas, produced during anaerobic digestion of sewage sludge. During anaerobic treatment, CO_2 is produced as a byproduct.

Recent studies reported increased methane yields when using CO_2 as a flush gas in the digester headspace (see Fig. 13). However, the transformation pathways that lead to an increased methane formation by CO_2 conversion have only been hypothesized. The following assumptions of possible effects leading to the bioconversion of CO_2 to methane have been proposed in recent studies:

1. Increased substrate turnover
2. Redox reactions
3. Change in the carbon acid equilibrium
4. Reduced ammonia inhibition

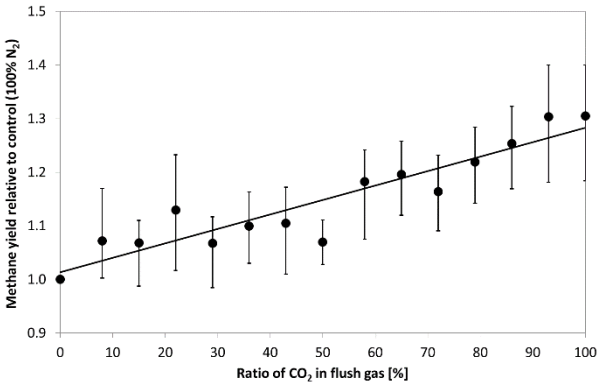

Fig. 13: Methane yield at different purge gas - CO_2 concentrations relative to the control (100% N_2).

This project aims to identify the main mechanisms of bioconversion, by applying stable isotope labeling of the injected CO_2 and comprehensive microbial analysis of the digested sludge. Continuous anaerobic digestion tests will be conducted in two laboratory-scale biogas test plants. The continuous operation of the test plants enables comparable conditions representing those of large biogas digesters. This way, findings from these studies will be more easily transferable to full-scale industrial digesters.

FUNDING:
GERMAN RESEARCH FOUNDATION

COOPERATION:
HEIDELBERG UNIVERSITY;
BAVARIAN STATE RESEARCH CENTER FOR AGRICULTURE

The results will help determine the best full-scale operation conditions to increase the methane formation by CO_2 enrichment in the digester headspace. Using the "waste product" CO_2 in anaerobic digestion to exploit the potential for energy production from waste streams can therefore make a substantial contribution to advancing the energy transition.

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Since August 2012, the Analytical Research Group (Analytische Forschungsgruppe-AFG) has been part of the Chair of Urban Water Systems Engineering. Until mid 2017, the AFG group was comprised of –including external PhD students- nine members (as well as bachelor and master students), and has received third-party funding, including BMBF, EU, BFS, AiF/BMWi, WiFö, as well as foundations and donations from private industry.

The end of 2017 brought about the conclusion of the AFG's work, as several co-workers (most after successfully defending a Ph.D. thesis) took on new analytical jobs and challenges. Therefore, analytical tasks at the chair will be conducted differently in 2018.

Until now, the key aspects in research covered technological, analytical-methological and analytical-chemical methods, for application in water and wastewater analysis, in other relevant environmental matrices, food analysis, and beverage and plant extract analysis, among others. A special focus was on chemical analysis with simultaneous functionality analysis using mass spectrometric detection.

Targeted aspects were:

1) Analytical platform development for the targeted analysis of organic molecules in complex matrices (‚Target Screening'),
2) Analytical platform development for the analysis of expected organic molecules in complex matrices (‚Suspected-Target Screening' including databases like 'STOFF-IDENT'),
3) Analytical platform development for the non-targeted analysis of organic molecules in complex matrices ('Hidden-Target Screening'),
4) Analytical platform development for the analysis of organic molecules in complex matrices with simultaneous functionality analysis by mass spectrometric detection,
5) Software development of modular working-out tools for data analysis (‚Retention Time Index RTI', ‚Achroma' and ‚FOR-IDENT'),
6) Application of analytical platforms (1-3) in the research area of oxidative treatment of water and the development of sustainable strategies,
7) Application of analytical platforms (1-4) in the research area of ingredient analysis and the search for biofunctional active compounds in environmental samples, after treatment, in plant extracts and beverages.

Additionally, the projects in our voluntary initiative ‚Wissenschaft vermitteln' included visits to elementary schools via ‚Kinderuni on Road', basic analytical courses for young apprentices, and the Chemnixblog:
(http://www.sww.bgu.tum.de/wissenschaft-vermitteln/).

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Mass spectrometric investigation of enzymatic reactions – characterization, miniaturization and the application for environmental samples

Trace organic chemicals (TOrC) are carbon compounds which can be found ubiquitously in the aquatic environment in quantities between 10 and 100 ng/L. The spectrum of these substances is broad and includes TOrCs derived from pharmaceuticals, health care products or pesticides. Due to persistence, bioaccumulation and toxicity there is a need to develop efficient and economic removal techniques. For these purposes the targeted use of enzymes can be a convenient approach, since they often possess a broad substrate spectrum and are able to catalyze versatile reaction types. Thus, enzymes offer a widespread application spectrum and open up new possibilities for environmental technologies, especially for biological water treatment processes. Some studies already utilized the potential of oxidative enzymes such as peroxidases or laccases to degrade TOrCs. Very recently it was shown that enzymes such as amidases, monooxygenases and carboxylesterases seem to be involved in degradation of TOrCs.

In addition to spectroscopic methods, e.g. photometric or fluorescence detection, it is also possible to couple enzymatic reactions with mass spectrometric detection. The direct coupling allows cost-efficient and simultaneous mass spectrometric characterization of all ionizable assay components, in particular substrate(s), product(s) and intermediate(s).

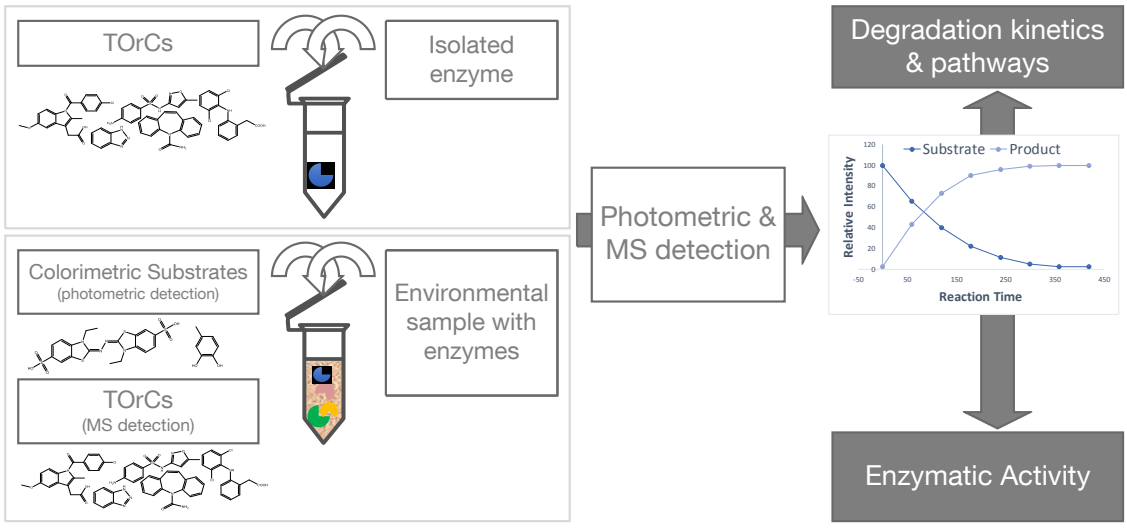

Fig. 13 Procedure for investigating enzymatic reactions in model systems and environmental samples.

Investigating the enzymatic activity in biological filtration systems (Therese Burkhardt)

In order to benefit from enzymes as TOrC metabolizing catalysts, the establishment of a method to measure the enzymatic activity in environmental samples is a basic requirement. To establish a sensitive method two different approaches, i.e. in situ measurement and an extraction procedure, were investigated for their applicability and efficiency. The enzyme dependent substrate conversion was photometrically examined. However, to distinguish between real enzymatic activity and substrate conversion by other mechanisms, a negative control is needed. Therefore various treatment procedures were investigated. Additionally, the transformation of TOrCs by extracted enzymes of the biological filtration system was investigated using direct pump infusion coupled to mass spectrometric measurement. Results indicate that substrate oxidation in the probed sample is affected by the applied method, pH, substrate and used co-substrate. Due to the complexity of the probed sample, a general statement regarding a best practice negative control experiment cannot be made. Nevertheless, mass spectrometric measurements to investigate the transformation of TOrCs have been successfully established. The optimized photometric approach together with an appropriate negative control will serve as basis for assessment of enzymatic activity in biological filtration systems and offers the possibility to investigate the transformation of a variety of TOrCs using mass spectrometry.

Monitoring enzyme-based degradation and product formation of TOrCs with different MS-workflows (Lara Stadlmair)

A further objective is to investigate the potential of selected enzymes to degrade and transform TOrCs using MS-based *in vitro* enzyme assays. Rapid screening of enzymatic degradation is carried out with a chip-based robotic nano-ESI-MS tool. The TriVersa NanoMate® functions as an external ionization source for MS and can control reaction conditions such as incubation time and temperature. So far, three laccases, two tyrosinases, and two peroxidases were studied for their capability to degrade ten pharmaceuticals (carbamazepine, gabapentin, metoprolol, primidone, sulfamethoxazole, and venlafaxine) and benzotriazole. The peroxidase from horseradish and a laccase from *Trametes versicolor* appeared to be the most efficient enzyme system. In a next step, high-flow experiments using direct infusion via an injection valve to investigate enzymatic conversion in TOrC- and/or enzyme mixtures (Multiplex-assays). Targeted and non-targeted transformation product characterization and identification are conducted with two MS-workflows: (1) Reversed-phase liquid chromatography (RPLC) coupled to MS/MS and (2) RPLC-hydrophilic interaction liquid chromatography (ToF)-MS.
The rapid screening of degradation potential and efficiency of enzymes can contribute to optimize suitable removal techniques to diminish TOrCs. Furthermore, the characterization of reaction mechanisms will help to understand chemical behaves of TOrCs especially in WWTPs.

FOR-IDENT – New strategies and workflows in the 'Hidden-Target-Screening' approach

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The project FOR-IDENT (FI) is a multi-year BMBF funded project and continues the activities of the former RISK-IDENT project (2012-2014) related to the establishment of guidelines and the integration of the database STOFF-IDENT into an extended platform. In this 'FOR-IDENT' platform, additional software tools and databases are implemented to provide workflows for the evaluation of LC-MS/MS data.

New strategies and workflows should support non-target screening approaches to allow easier and faster identification of organic molecules.
Currently two established workflows are integrated in the platform. The liquid-chromatography coupled to mass spectrometry for either polar and very polar molecules (HILIC), or mid- to non-polar molecules (RPLC).

Fig. 15: Illustration of the FOR-IDENT platform info in current research journals.

The database STOFF-IDENT, which was developed within the RISK-IDENT project, plays a key role (https://www.lfu.bayern.de/stoffident/#!home). In this database, the amount of suggested molecules returned during water sample analysis can be reduced by various filter categories. Analytical MS/MS-databases like MassBank and prediction tools like MetFrag and EnviPath, are already integrated. This allows simultaneous application of biological, chemical, physico-chemical and analytical metadata during sample analysis. Within the FOR-IDENT project, further linkages are planned, such as with ecotoxicological databases. The project funding was extended until 2019, by which time FI will permanently reside at https://water.for-ident.org/ as product of an international 'open data concept'. Several (international) cooperations to extend the functionality of the database are ongoing (i.e. NORMAN Network).

FUNDING:
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and
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COLLABORATION:
BWB, HSWT,
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Parallel detection of very polar and nonpolar trace organic compounds in water samples by SFC

Trace organic compounds are of emerging concern for the analysis of water samples. These compounds are residues of pharmaceutical, everyday-chemicals, pesticides or others and can be found in waterbodies in concentration ranges from ng/L to µg/L. For the analysis of trace organic compounds, mainly reversed phase chromatography, coupled to mass spectrometry is utilized. This technique is well established, and suitable for the separation and detection of medium to nonpolar compounds.

Fig. 16: SFC with mass spectrometric detection.

The separation and detection of polar to very polar compounds is hardly possible, using reversed phase chromatography. Since very polar compounds occur in waterbodies and are environmentally relevant, new techniques for their detection have to be developed and assessed. One option here is supercritical fluid chromatography or SFC, a separation technique, which uses carbon dioxide above or near the critical point as mobile phase.

At the Chair of Urban Water Systems Engineering, SFC is investigated on its applicability for the separation and detection trace organic compounds with time of flight mass spectrometry (Figure 1). It could already be shown that SFC is well suitable for the separation of polar to very polar compounds, but additionally also can be used to separate medium to non-polar compounds.[1] As a result, trace organic compounds which have so far been separated and detected by reversed phase chromatography and even more polar ones can be detected by SFC. The application of SFC so allows to broaden the polarity range of detectable compounds significantly. The knowledge about the basic mechanisms of SFC separations is currently limited. In contrast to liquid phase separations, SFC separations are influence by several additional factors. Impacts on separations and interactions between the factors are not fully understood, yet. In order to improve the understanding about SFC mechanisms, intensive studies are currently conducted at the Chair of Urban Water Engineering.

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Non-Target Screening Workflows Using RPLC-HILIC-MS

Analytical chemistry has improved greatly in the last decades, however a comprehensive identification of the organic content in waters is still challenging, especially considers the thousands of different possible water contaminants, coupled with their metabolic and transformation products.

Until now most of compound screening approaches for water samples have been targeted. It is only recently, with the advances in high resolution mass spectrometry, that the idea of non-target screening of samples, though not novel, has become popular to provide a more complete view of the organic contents of different water bodies.

These organic compounds that are present in a sample are deemed “Hidden Targets” in literature, as they are known in the chemical literature or MS reference databases, but unknown to the researcher analyzing a specific sample.
Surface water samples and wastewater treatment plant effluents are analyzed by RPLC-HILIC-MS in order to detect the various (very) polar and non-polar organic compounds. Then, the Non-Target Screening is applied, with the help of the STOFF-IDENT database. For (very) polar compounds (logD<0) the extracted exact masses from the HILIC region of the obtained chromatogram are loaded into the database. The returned results are then filtered and any suggested compounds with a positive logD are rejected.

For the compounds with a positive logD, the results are obtained from the database by using the exact mass as well as the retention time index (RTI), which takes advantage of the known retention time and logD correlation in RP chromatography, returning much more probable results. Additionally, the results of the STOFF-IDENT database can be validated by using MS/MS spectra in the new platform FOR-IDENT.

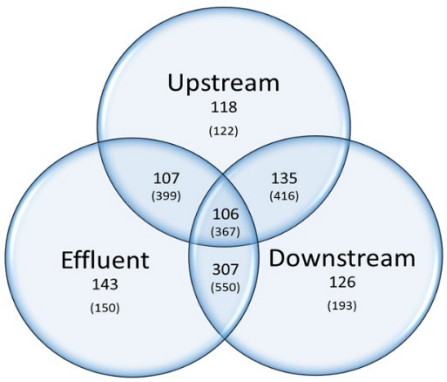

Fig. 17: Number of (very) polar and nonpolar molecules recorded with the new analysis technique in different water samples.

FUNDING:
PHD
SCHOLARSHIP:
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Novel Analytical Strategies for Anthropogenic Compounds in Plants: Vegetable Biomonitors for Contaminants in the Environment

Plants play an important role in maintaining life. They transform CO_2, provide food, and are considered to have a pool of new metabolites which can be used for treatment of various diseases. Moreover it has been shown that plants are capable of cleaning water of pharmaceuticals like diclofenac, which occur in ground and surface water in concentrations up to µg/L levels (Fig. 18). The assilimated pharmaceuticals stored in vacuoles inside plant tissues. The focus of this research is to further the knowledge of plant metabolite pathways, the involved enzymes, and the resulting transformation products.

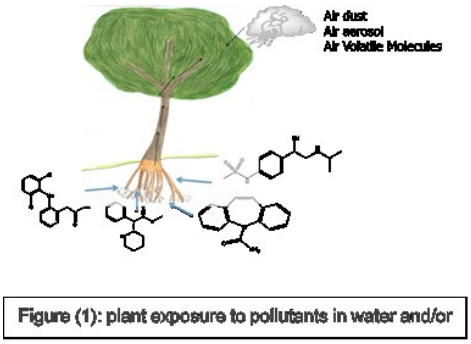

Fig. 18: Illustration of plant uptake.

A focus will be determination of pollutant capability to influence the plant's biosynthesis cycle by generating numerous substrates for a particular pathway, which are subsequently taken up by the plant. The final goal is to determine whether the biological degradation pathways can be reflected by analytical data obtained from polarity extended RPLC-HILIC-MS analysis.

This study aims to contribute to the field of known secondary metabolites in leaf and root extracts of various plants, by exploring new or modified secondary metabolites that appear after addition of pollutants.

To the best of our knowledge, no prior research surveyed the changes in the plant metabolite pathways of constructed wetland plants (CWP). Moreover, along with growth in CWP, due to possibly accumulated contaminants there is increasing concern about how those plants must be treated further in terms of disposal considerations.

The aim of the project is to provide a conceptual theoretical framework based on analysis of different plant extracts before and after exposure to different pollutants, using novel RPLC-HILIC-ToF-MS technique. The plants are initially exposed to different pollutants in the laboratory, and after reaching maturity, are exposed to pollutants for a few days. To establish the concept, comparably high concentrations of pollutants were applied initially.

Finally, an open access database of plant metabolites will be created (PHRAGMITES-IDENT) and implement into the existing FOR-IDENT analytical platform (https://water.for-ident.org/).

FUNDING: BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

COOPERATION: RESEARCH UNIT ENVIRONMENTAL GENOMICS, HELMHOLTZ ZENTRUM MÜNCHEN

Analysis and environmental behavior of microplastics

Two new microplastic research projects were launched in 2017. Microplastic is a global environmental problem, the extent and effects of which have not yet been sufficiently researched. The projects will develop innovative analytical methods and investigate the environmental behavior of microplastics.

SubµTrack – Innovative Analysis Methods for Submicroplastics

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The Chair of Urban Water Systems Engineering is coordinating a new research project on microplastics, funded by the Federal Ministry of Education and Research. Due to the lack of analytical methods and toxicological data, currently it is not possible to assess especially small microparticles (submicroparticles <1 µm). Due to their possible cell permeability and their comparatively larger specific surface area, however, these submicroparticles have potentially higher (eco-)toxicological relevance. Innovative and networked approaches are needed to gain knowledge about the abundance and effects of these particles in the environment.

The new research project will develop innovative analytical and evaluation methods that allow the analysis of plastic particles of various sizes in different samples and processes, and assessment of their toxicity. In addition to the coordinating Chair of Urban Water Systems Engineering (Prof. J. Drewes), the Chair of Analytical Chemistry and Water Chemistry (Prof. M. Elsner), the Chair of Aquatic Systems Biology (Prof. J. Geist), the Chair of Animal Physiology and Immunology (Prof. M. Pfaffl) and the Professorship of Science and Technology Policy (Prof. R. Müller) of TUM are involved. Other partners are the Institute of Groundwater Ecology at the Helmholtz Zentrum München, the Institut für Energie- und Umwelttechnik e.V. (IUTA) in Duisburg, the Bavarian Environment Agency and the German Federal Environmental Agency. Postnova Analytics GmbH and BS-Partikel GmbH are involved as industrial partners.

The aim of this joint project is to develop innovative methods for analytical detection and toxicological assessment of submicroplastic and to consider its significance as a social problem. The project focuses on three main areas: First, technologies allowing the reliable analysis of submicroplastic are to be developed. This includes establishment and validation of sampling and sample preparation, and the development of analytical methods for separation, sizing, detection and identification. In addition, investigations are carried out to reveal whether and to what extent submicroplastic particles adsorb pollutants, and whether this adsorption influences the environmental impact of submicroplastic. The environmental impact is comprehensively analyzed in the second focus area, which deals with toxicological assessment. Submicroplastic particles are studied in terms of their effects on microorganisms, the aquatic environment and human health. A third focus is on social, political and legal aspects. Here, negative social perceptions are collected and the scope for action is explored along with investigations

regarding possibilities of implementation by means of legislation. Finally, validated analytical methods and toxicological data will be available, which will allow risk evaluation together with social and legal scientific assessment, and can serve as a basis for the development of action strategies.

Homepage: www.wasser.tum.de/submuetrack

MiPAq - Research project on microplastics in waterbodies and foodstuffs

This project, funded by the Bavarian Research Foundation and coordinated by the Chair of Aquatic Systems Biology, focuses on the comparison of particles of biodegradable plastics, non-degradable plastics and natural particles.

In contrast to existing studies on microplastic, this research project considers the use of biopolymers as a substitute for conventional plastics. In addition, this project is characterized by a holistic view of this topic from the environment to food. By means of combination of analytical and engineering expertise as well as scientific-ecological consideration, a transdisciplinary and objective evaluation of the topic will be carried out in order to develop technological solutions that can be applied in the food industry. Therefore, besides scientific partners, numerous partners from industry are involved.

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Research Group
Sewer Systems and Rainwater Management

The research group Sewer Systems and Stormwater Management deals with strategies for condition assessment and rehabilitation of sewer systems, especially with sustainable stormwater management. The challenges of climate change and demographic change mean that new concepts need to be developed in order to react sustainably to these changes. One focus is the decentralized management of stormwater runoff for impervious surfaces, in order to counteract intense stormwater peaks and thus mixed water overflows, but also to detect and dispose of contaminants from the runoff.

Fig. 19: Sampling location at an experimental site.

Decentralized treatment plants for metal roof and traffic area runoffs are developed and evaluated for this purpose. In this framework, tests of treatment plants for metal roof runoff according to the "Test criteria for preliminary assessment of infiltration systems for the retention of metal ions from precipitation discharges of metal roofs" of the Bavarian State Office for the Environment (LfU) of 30.6.2008 (AZ: 66-4402-26060 / 2008) for companies will be conducted.

At the moment, investigation of the operating behavior of selected decentralized treatment plants within the framework of a research project is conducted, financed by the Bavarian State Office for the Environment in cooperation with the City of Munich. These investigations are very valuable for the new leaflet of the DWA-M 179, which deals with such decentralized treatment plants.

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Development of a strategy to use stabilized ammonium fertilizer to improve the P supply to young plants from poorly soluble P-fertilizers and the P-soil stock to minimize the input of N and P from agricultural land into water bodies

In agriculture, the elements phosphorus (P) and nitrogen (N) are essential for plant nutrition. Nitrogen, in the form of ammonia and after nitrification as nitrate, is available to plants, increasing the risk of its loss via leaching, which contributes to groundwater quality deterioration. In contrast, the P-content in the soil is mostly immobilized. One consequence of this is that particle transport (erosion) causes P to be displaced from the soil surface, leading to the eutrophication of water bodies.

In recent years, so-called nitrification inhibitors have been developed, which can stabilize the ammonium phase of a fertilizer for 4 to 6 weeks to mitigate loss. There is initial evidence that spatial proximity of ammonium, the nitrification inhibitor, and sparingly soluble phosphate in the fertilizer or soil could generate further benefits, namely better recovery of sparingly soluble P compounds. However, the detailed knowledge about the reaction mechanisms, also in connection with so-called biostimulants, are still largely missing.

An important aspect is the use of the pH dependence of the P-supply in the soil solution (optimally pH 5 to 6.5).

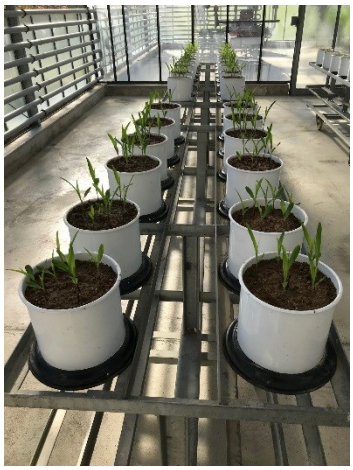

Fig. 20: Greenhouse experiments with corn (Zea mays) and oilseed rape (Brassica napus) plants in different soils.

Three overall economically and ecologically relevant goals can be achieved through this research:

1) The use of previously poorly plant available P;
2) The reduction of P-reserves in soils and, associated surface water pollution by leaching; and
3) The use of alternative P-sources to achieve partial closure of the P-cycle.

COOPERATION:
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Practical experience in handling decentralized stormwater quality treatment devices for traffic area runoff

In sustainable groundwater management, traffic area runoff is increasingly managed through on-site percolation. Due to traffic-related emissions, atmospheric pollutions and temporary point emissions (accident/construction site/event) the traffic area runoff can be heavily polluted with heavy metals or organic substances.

Fig. 21: Testing facility for traffic area runoff treatment.

In urban regions, natural retention of runoff by vegetated topsoil must be provided through technical solutions, due to space limitations. This can prevent contamination of the soil and groundwater systems. Apart from numerous laboratory studies, few scientifically documented experiences in the field exist.

The objective of the research project is to perform independent application oriented research on decentralized stormwater quality treatment devices, which are approved by the Deutsches Institut für Bautechnik (DIBt). For this, three treatment plants (two shaft systems and one filter substratum channel) with different functionalities will be constructed in Munich on a street with heavy traffic under equal conditions. To capture seasonal influences, the study will run for 1.5 years. The emergence of hazardous substances and their detention and remobilization under the influence of deicing salts and long-lasting impounding will be studied. Operational aspects will be recorded and analyzed. Additionally, insufficiently investigated substances, including gasoline additives (MTBE/ETBE), cyanides contained in deicing salts, and fine particles will be monitored.

FUNDING:
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Microbial Systems Research Group

Microorganisms are key factors for the biotransformation of contaminants in natural and engineered systems. For that reason, the Microbial Systems Research Group focuses on the investigation of microbial processes in aquatic and engineered systems, ranging from biological wastewater treatment to the application of biological active filter in drinking water purification. By using state-of-the-art bio-molecular tools, new ways to better understand microbial functional groups and their specific activities, not only on cellular but also on enzymatic levels, open up. One focus is the identification of relevant functional bacterial communities and the detection of their specific activities, e.g. nitrogen conversion (nitrifiers, ANAMMOX bacteria), anaerobic processes (sulfate reducing bacteria, methanogens) and microbial induced corrosion (e.g. sulfide and sulfur oxidizing bacteria). Further research addresses the characterization of taxonomic and functional diversity of microbial communities with special functions, e.g. micro pollutant degrading communities in wastewater treatment and drinking water purification. Therefore, qPCR (Fig. 22) and next generation sequencing (metagenomics and metatranscriptomics) based technologies are applied.

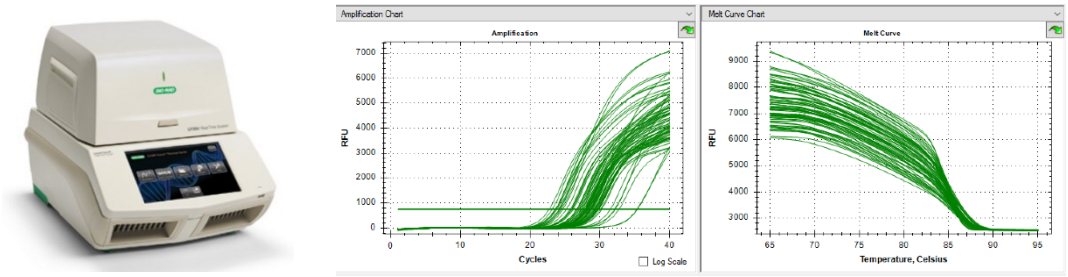

Fig. 22: qPCR analysis in 96 well format targeting different antibiotic resistance genes.

In addition, efficient ways to monitor the inactivation of pathogens and the proliferation and dissemination of antibiotic resistance genes in drinking water and water reclamation systems are evaluated. Detection and quantification of fecal indicator organisms (*E. coli*, total coliform bacteria, and Enterococci, Fig. 23) or specific pathogenic bacteria, e.g. *Pseudomonas* spp. and *Legionella* spp., are established and performed as routine methods.

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COOPERATION:
LFL, FREISING;
LFU, AUGSBURG;
KIT, KARLSRUHE;
CSM, COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, USA

These techniques are used to monitor fecal contamination of surface water, to evaluate disinfection efficiency of advanced treatment processes (UV, ozonation, peroxide), and the elimination capacity of biological active filters that are used, e.g. in wastewater treatment and drinking water purification.
Both classical microbial cultivation techniques (Fig. 24) and molecular biological methods (Fig. 25) are applied to answer current research needs:

- Quantification of pathogens and antibiotic resistance genes in aquatic systems by Polymerase Chain Reaction combined with Denaturing Gradient Gel Electrophoresis (PCR-DGGE), real-time PCR, metagenomics and metatranscriptomics

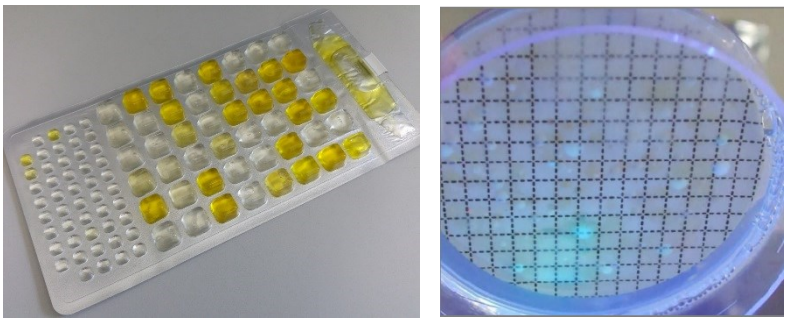

Fig. 23: Colilert-18 analytical system (left) to quickly and reliably detect and quantify E. coli and total coliform bacteria in a given water sample, and the detection of Pseudomonas aeruginosa on specific agar plates by UV radiation.

- Evaluation of activity and biodegradation potential of bacteria and microbial communities in a variety of systems, including porous media systems by Fluorescence in situ Hybridization, FISH applied with Confocal Laser Scanning Microscopy, CLSM

- Monitoring of the dissemination of antibiotic resistant genes in different wastewater treatment systems by (RT)-qPCR

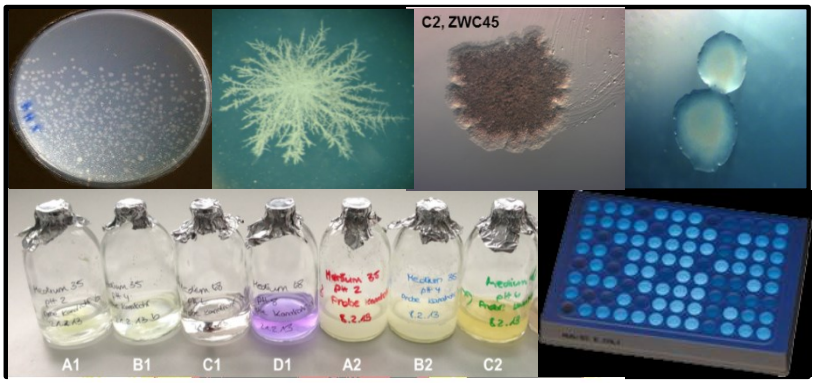

Fig. 24: Classic microbiological cultivation on agar plates and in liquid media (serum bottles and microplates; e.g. detection of E. coli, Most Probable Number counts, MPN) using specific nutrient formulations to detect and quantify a variety of microorganisms.

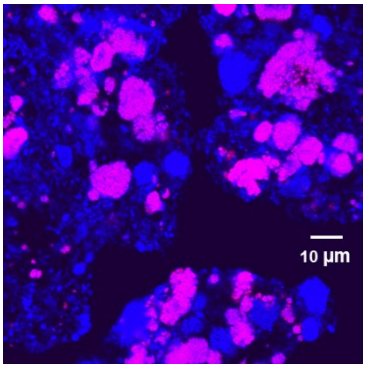

Fig. 25: CLSM image of an activated sludge floc after the application of FISH. Nitrospirae (magenta, nitrite oxidizing bacteria, NOB) and DAPI stained bacteria cells (blue) to show their distribution within a sludge floc.

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Research Group
Engineered Natural Treatment Systems

The removal of emerging trace organic compounds (TrOCs) in ground-, surface and drinking water is of increasing interest to reduce potential adverse effects on aquatic life and human health. Natural treatment processes, such as riverbank filtration, soil aquifer treatment or biologically-active filters, are used in water treatment for many decades. Major objectives of this research group include

- an assessment of key factors for the removal of trace organic chemicals in microbial systems,
- the transitioning of passive natural treatment systems into active processes with predictable water quality,
- the development of new innovative treatment concepts for advanced water treatment and reuse based on biological processes and
- the integration of natural processes into hybrid processes with advanced treatment such as ozonation, advanced oxidation or membrane processes.

In order to actively steer the mitigation of TOrCs, a basic understanding of dominant removal processes is essential. Previous research revealed an optimized compound removal under oxic, carbon limited conditions. The role of refractory organic carbon as primary substrate for co-metabolic degradation, however, is not yet fully understood. Different column systems (Fig. 25) are operated to evaluate the effects of concentration and composition of humic substances on chemical removal in natural treatment processes. In these systems, advanced analytical tools and next generation sequencing are used to quantify trace organic chemicals, characterize bulk organic carbon and to elucidate structure and functions of the microbial community.

Fig. 36: Different setups for soil column experiments.

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Sequential Managed Aquifer Recharge Technology (SMART)

Managed aquifer recharge (MAR) systems, such as riverbank filtration (RBF), soil aquifer treatment and artificial recharge and recovery, have been used for decades to improve the availability of localized water supplies by the utilization of less desirable water sources like storm water, impaired surface water and reclaimed water. During infiltration of water through the vadose and saturated zones, microbial degradation and assimilation is playing a dominant role for the attenuation of organic contaminants.

The innovative sequential managed aquifer recharge technology (SMART) concept actively manipulates subsurface conditions and combines two MAR systems with an intermediate aeration step to provide favorable oxic, carbon limited infiltration in the second system (Fig. 2). This concept has been already successfully tested for treatment of wastewater-impacted surface water at a utility in the United States. In a joint research project with TU Berlin (TUB), the University of Oldenburg (UO) and the Berliner Wasserbetriebe (BWB) the SMART concept was now successfully applied for drinking water treatment in Berlin. Results from laboratory and field scale experiments demonstrated an improved biotransformation of several relevant chemicals in comparison to conventional groundwater recharge.

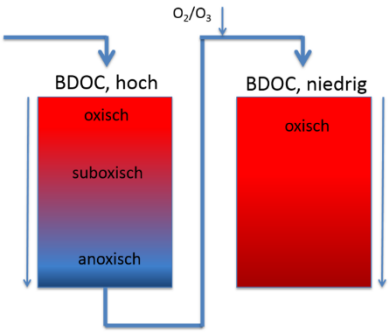

Fig. 27: Principle of sequential MAR technology.

Results from sequencing analyses already demonstrated increased diversity of microbial community under carbon-limited conditions. Together with Prof. Mike Manefield from University of New South Wales, Australia, we aim to identify specific genetic markers characterizing trophic strategies of bacteria. The analyses of these markers from metagenome data or by qPCR methods will enable verification of desired oxic and carbon-limited conditions in sediment samples.

Fig. 28: Infiltration basin on the island Baumwerder, Lake Tegel.

FUNDING:
BERLINER WASSERBETRIEBE

COOPERATION:
TU BERLIN;
UNIVERSITÄT OLDENBURG

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FRAME: A Novel Framework to Assess and Manage Contaminants of Emerging Concern in Indirect Potable Reuse

Within the research project FRAME, which started in January 2015, a cluster of seven European research institutions aims to develop an overall evaluation scheme to comprehensively assess and manage contaminants of emerging concern (CECs) and pathogens in indirect potable reuse (IPR) systems.

Within the project, TUM is responsible for the development of novel treatment combinations to be integrated in IPR schemes. The research group Engineered Natural Treatment Systems conducts pilot-scale studies to evaluate reliable and cost-efficient treatment strategies. Enhanced biofiltration is a promising technology for the mitigation of CECs in wastewater treatment plant effluents. The novel concept aims to combine the benefits of a high microbial diversity in low rate biofilters and the high throughput in rapid media filters. The experimental setup integrates experiences from sequentially operated aquifer recharge systems. By establishing oxic and oligotrophic conditions in the system the formation of a highly diverse microbial community, capable of degrading CECs, is favored. The experimental setup with four independently operating filtration trains allows for a large variety of filtration modes. In addition to that hybrid systems are tested combining biofiltration with other advanced treatment technologies such as adsorption and oxidation. Besides the removal of compounds that are persistent to biodegradation also potential synergies between different individual treatment processes such are investigated.

Fig. 29: Biofilter experimental setup.

Obtained results indicate that the establishment of oxic and oligotrophic conditions during biofiltration leads to an increased removal of various moderately degradable CECs compared to conventional biofiltration. Combining biofiltration with subsequent granular activated carbon filtration resulted in an increased adsorption capacity for CECs due to reduced competitive adsorption of background organic matter. Current studies aim to optimize the system and investigate the potential of combining biofiltration with ozonation.

FUNDING:
JPI WATER

COOPERATION:
BFG, GERMANY;
IRSA, ITALY;
ISS, ITALY;
NIVA, NORWAY;
BRGM, FRANCE;
GÉO-HYD,
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Research Group
Advanced Water Treatment and Water Recycling

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The research group Advanced Water Treatment and Water Recycling is led by Professor Helmreich and Dr. Uwe Hübner. The research group deals with advanced treatment methods of nutrient removal (deammonification, advanced P-removal), including oxidative processes for the disinfection and removal of trace organic substances (Advanced Oxidation Processes, ozone, electrochemical processes), membrane processes (ultrafiltration, nanofiltration, reverse osmosis) as well as water recycling.

The research especially focuses on different process options for advanced water treatment, in particular for the removal of nutrients, trace organic substances and pathogenic germs. These hybrid processes include modified biological technical filters, advanced oxidation processes (UV/peroxide, nanomodified diamond electrodes, ozone), granular activated carbon, and membrane processes (ultrafiltration, nanofiltration, reverse osmosis), which can be used in various applications.

A further focus of this research group is on water recycling processes to augment both drinking water and industrial water supplies. One focus is on the development of energy-efficient processes and the integration of energy recovery in water recycling processes. Monitoring of these installations, especially for decentralized applications with new measuring methods, are common overlapping topics of all research fields.

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FÖRDERUNG:
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KOOPERATION:
UBA, BFG, BGS UMWELT, HYTECON, COPLAN AG, BWB, DHI WASY, TUB, UO, TZW

Development of a non-membrane based innovation treatment approach including comprehensive assessment criteria for indirect potable reuse in urban water cycles (TrinkWave)

TrinkWave aims to innovate a multi-barrier treatment concept for indirect potable water reuse based on sequential managed aquifer recharge technology (SMART). Proposed monitoring concepts will consider emerging water quality issues, including detection of viruses, antibiotic resistance, trace organic chemicals and transformation products, in the interest of human health protection.

Major tasks of TUM within this project include the development and testing of novel treatment concept for inactivation of pathogens and removal of antibiotic resistant and health relevant chemicals at pilot-scale, the identification of novel bio-molecular parameters for assessing biofilm-based treatment systems as well as quantitative microbial and chemical risk analysis to assess reuse strategies.

The novel concept SMART*plus* builds upon knowledge and experiences from SMART 1.0, aiming to manipulate sequential redox changes and primary substrate availability to stimulate microbial biodegradation. Important research questions include selection of oxidizing agents (i.e., reactive barriers) for *in-situ* aeration, longevity of system functionality, compatibility with downstream purification processes, and attunement of operational flow rate for optimum removal of target substances at minimal hydraulic retention times. Results from SMART 1.0, as well as the semi-industrial pilot scale model testing at TUM, will inform the design of a full scale SMART*plus* field model (Fig. 30) for implementation in Berlin.

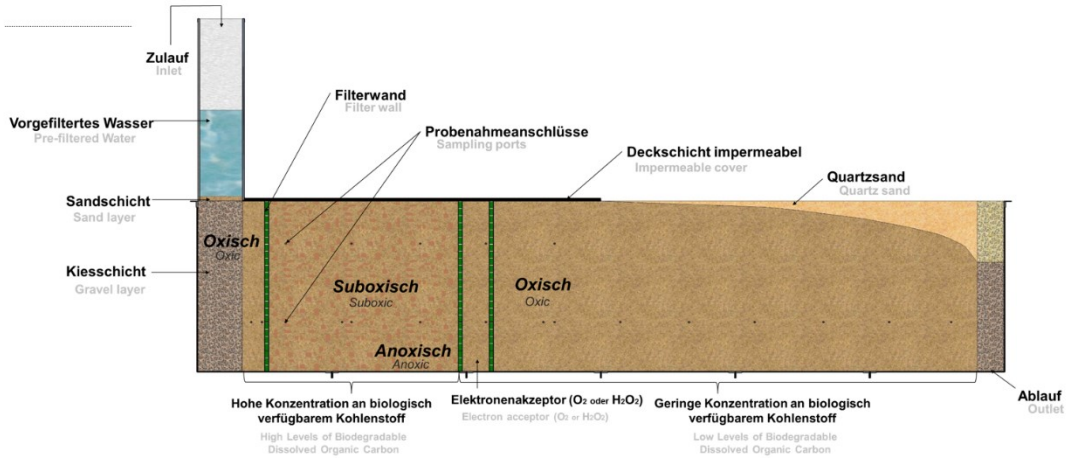

Fig. 30: Schematic of the SMARTplus semi-industrial scale test facility at TUM.

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Status quo of unplanned reuse of treated municipal sewage in Germany (de facto reuse)

In Germany, treated municipal wastewater is generally discharged into surface water, making it part of the natural water cycle (see Fig. 31). If receiving surface waters are extracted, for groundwater recharge, irrigation, or other purposes, downstream of wastewater discharges, such a scenario is considered unplanned (de facto) water reuse. The proportion of treated wastewater in rivers and lakes can vary greatly on a local scale, due to heavy rainfall events and runoff. Currently, national and international multidisciplinary assessment concepts for evaluating risks posed by the influence of dynamic wastewater discharges on surface water quality, especially when this water is used for potable purposes, is lacking. Despite dilution and natural degradation processes in surface water and soil passages (i.e., bank filtration or artificial groundwater recharge), the potential for pathogens and persistent chemical contaminants to reach raw water, then processed into drinking water, persists. This can increase potential risks to human health, and therefore requires appropriate countermeasures.

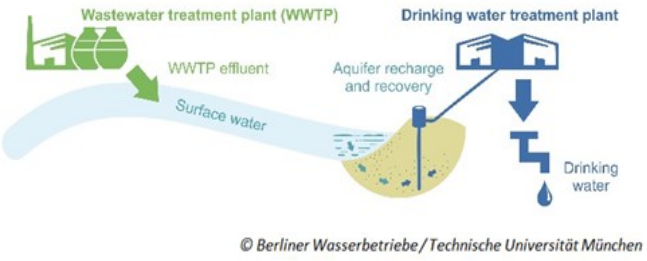

Fig. 31: Unplanned water reuse.

In the case of drinking water production via bank filtration or artificial groundwater recharge, the degree of pollution of surface waters essentially determines the quality of the raw water. Although the proportion of wastewater in surface water resulting in increased risks for drinking water has not been explicitly defined, preliminary studies point out challenges for trace organic substance and pathogen removal during subsequent conventional drinking water treatment, especially where the proportion of wastewater in surface waters exceeds 10%.

This study focuses on de facto reuse in Germany. Relative wastewater content in streams, and their associated effects on raw water quality for direct extraction, as well as for bank filtration and artificial groundwater recharge, are identified and mapped. Based on this data, different load classes will be determined to categorizing impacted water bodies. For select locations and water supply companies, a risk assessment for the drinking water supply will be conducted, taking into account local conditions (flow behavior, well operation, type of treatment).

FUNDING:
UMWELT-BUNDESAMT

COOPERATION:
DHI WASY GMBH

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Energy-efficient Treatment Schemes for Water Reuse - Drinking Water Augmentation

Population growth, demographic changes (urbanization), climate change, lack of conventional freshwater supplies, and more frequent and severe drought conditions are stressing the availability of conventional freshwater resources. Water reuse is one option to close local water cycles and relieve the local water resources. In semi-arid and arid regions, including European regions with water scarcity the utilization of municipality wastewater for water reuse purposes is well established. A significant disadvantage of the used treatment schemes currently in water reuse is the high energy demand and generating objectionable waste streams. Alternative treatment schemes for water reuse are required to overcome these issues and guarantee a sustainable (water supply) development worldwide. Alternative treatment scenarios are developed and will be tested in laboratory- and pilot scale to analyze the optimal operational conditions (Fig. 32). Due to an integrated energy recovery by improved pretreatment and physical separation of organic matter (resulting in higher biogas yield) the overall energy footprint should be decreased. Additionally, integrated energy recovery is realized by the intended production of nitrous oxide from concentrated nitrogen process water streams (see project *PANOWA*). The nitrogen removal from the wastewater can be coupled via the aerobic-anoxic nitrous decomposition operation with the production of nitrous oxide as an additional energy source.

Fig. 32: Ultrafiltration test-skid for municipal wastewater treatment.

Membrane processes will play a major role within the alternative treatment scenarios. In particular fouling and scaling effects will be analyzed and mitigation strategies developed and analyzed. Beside granular activated carbon (Fig. 33), hydrodynamic improvements of the membrane modules by usage of new developed feed spacers and cleaning effects by vibration of the membranes are considered.

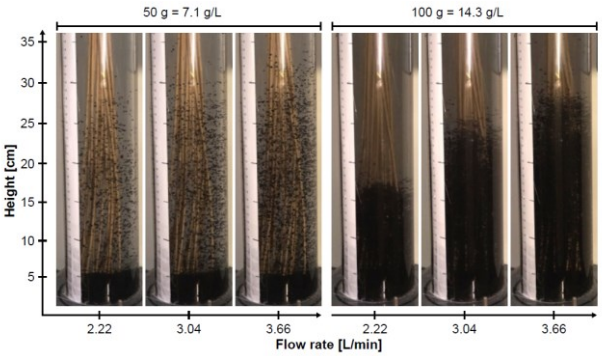

Fig. 33: Investigation of the cleaning effect of ultrafiltration membranes by usage of granular activated carbon.

FUNDING:
TUM;
OSWALD-SCHULZE-FOUNDATION

COOPERATION:
COLORADO SCHOOL OF MINES, USA;
TU DELFT, THE NETHERLANDS;
UNIVERSITÉ DU LUXEMBOURG, LUXEMBURG;
UNIVERSITY OF NEW SOUTH WALES, AUSTRALIA

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Municipal wastewater treatment using reverse osmosis membrane process, biofilter and UV-AOP aiming potable water reuse

Water reuse is a potentially viable alternative for combatting water scarcity. The treatment that water receives should consider the intended final purpose of its use, including direct or indirect potable reuse for human consumption. Reverse osmosis (RO) is an efficient membrane separation process in drinking water production using reclaimed water from wastewater treatment plants. Despite the advances in reverse osmosis, past experiences from operating RO membranes in water and wastewater reclamation plants demonstrated that membrane fouling continues to be one of the most important factors influencing successful application of this technology. Biofouling control is considered a major challenge in operating membrane systems (Fig. 34), as it leads to higher operating pressures, frequent need for chemical cleanings, membrane deterioration, and compromised water quality.

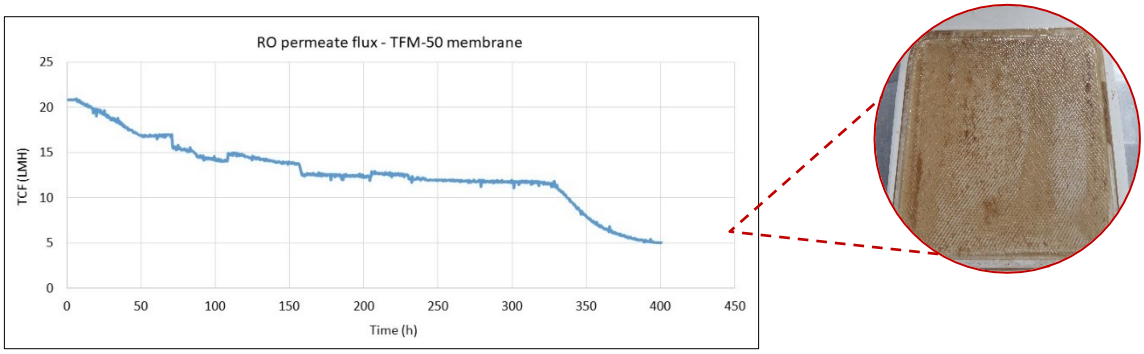

Fig. 34: Monitoring of the RO permeate flux over time during municipal wastewater treatment and membrane surface after biofouling occurrence.

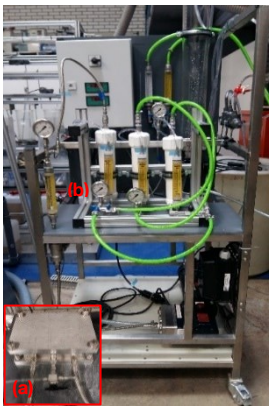

Fig. 35: Bench-scale RO membrane system with a flexible configuration: (a) flat sheet or (b) spiral-wound module.

A better understanding of biofouling characteristics and mechanisms can help to control biofilm growth, develop mitigation strategies and improve sustainable operation of membrane systems for production of drinking water. A bench-scale membrane system (Fig. 35) with a flexible configuration (flat sheet or spiral-wound module) has been used to evaluate the performance of RO membrane process in drinking water production. Biofilters has been evaluated to observe the degradation of low molecular weight organic compounds. The final permeate quality for purposes of potable reuse will be assessed by UV/AOP.

FUNDING:
DAAD-GERMAN ACADEMIC EXCHANGE SERVICE, GERMANY

COOPERATION:
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Development of a Decision Making Framework for Upgrading and Operation of Wastewater Treatment Plants for Trace Organic Chemical Removal

The focus of this study is on the removal of trace organic chemicals and their correlated surrogate parameters. Issues relating to data, model structures, incorporations of variability and uncertainty, calibration, potential surrogate parameters and model validation will be investigated. The contributions of existing systems and parameters determining environmental contaminant concentrations (e.g., source variability, existing treatment, discharge dilution, environmental processing) will be accounted for.

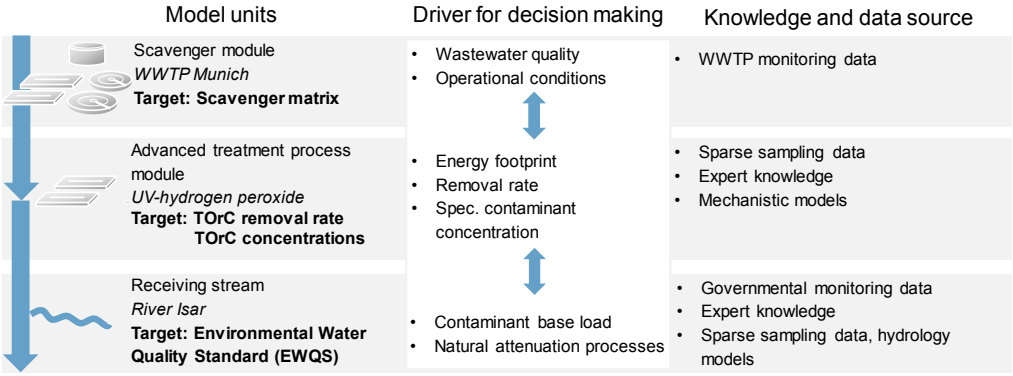

Fig. 36: Model units to achieve machine learning.

The research study focuses on three different model units, where the first two use data driven machine learning strategies to model different target parameters (Fig. 36). The third model unit puts the developed models into an expert knowledge decision making framework, which presents central operational scenarios and individual uncertainties. This approach could result in significant savings in overall energy consumption, thus lowering costs and greenhouse gas emissions. Using state-of-the-art modelling approaches, this research will advance the predictive capacity for diverse contaminant concentrations in wastewater treatment and receiving environmental systems.

In 2017 we have developed a program to pre-process data and further execute advanced multivariate analysis to evaluate the suitability and accuracy of several machine learning (classification) algorithms, respectively. Fig. 37 demonstrates some performance results for different machine learning algorithms used to predict a target variable, in this case total organic carbon. Machine learning can display distinct performance differences.

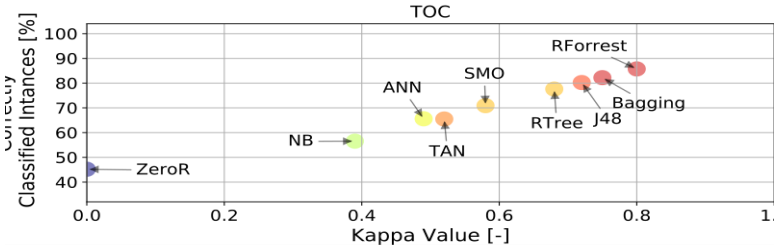

Fig. 37: Machine learning algorithm comparison for classified prediction of total organic carbon (TOC). Algorithms: ZeroR, Naïve Bayes (NB), Tree Augmented Naïve Bayes (TAN), Artificial Neural Network (ANN), Sequential Minimal Optimization (SMO), Random Tree (RTree), J48, Bagging (with J48), Random Forest .

FUNDING:
TUM-IAS
DAAD

COLLABORATION:
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UV-LED based water disinfection: Testing of synergistic and water matrix effects

Recently, sequential managed aquifer recharge technology (SMART) has been proposed as an innovative multi-barrier treatment concept for indirect potable water reuse. This concept utilizes modified engineered natural treatment systems including multiple barriers to deliver a water quality that is suitable for drinking water augmentation, while offering a high degree of groundwater protection. One stage of this multi barrier system is UV-disinfection which is investigated using Ultraviolet light emitting diodes (LEDs). UV-LEDs are an emerging technology for water and wastewater disinfection and have proven effective in inactivating various bacterial, viral and protozoan pathogens. Moreover, UV-C LEDs have shown high potential since they are smaller, lighter, and less fragile than traditional mercury vapor lamps.

Fundamental laboratory-scale investigations are conducted using a triple-wavelength UV-C LED system (HYTECON, Germany) with a PTFE reflector tube emitting at peaks of 265, 275 and 285 nm for inactivation of MS_2 coliphages. UV-irradiance is determined using KI/KIO_3 actinometry and a UV-C broadband radiometer (sglux, Germany). Besides single peak-wavelength effects, the combination of two and three different LEDs is investigated to test the presence of synergistic effects. Furthermore, water matrix effects are investigated using a phosphate buffer solution as a pure reference system and different spiked real water matrices including municipal wastewater treatment plant effluent as well as effluent from a pilot-scale SMART system. Intensive testing of irradiance measurements shows discrepancies in between radiometer and actinometer results due to diffuse reflections of the PTFE tube. Preliminary results from disinfection experiments reveal highest dose response for LED 265 with an inactivation of 5 log followed by LED 275 with 4.2 log and LED 285 with 2.8 log inactivation at 60 mJ/cm², respectively. Combinations of different peak wavelengths LEDs did not result in synergistic effects.

FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COOPERATION:
UBA, HYTECON, TZW

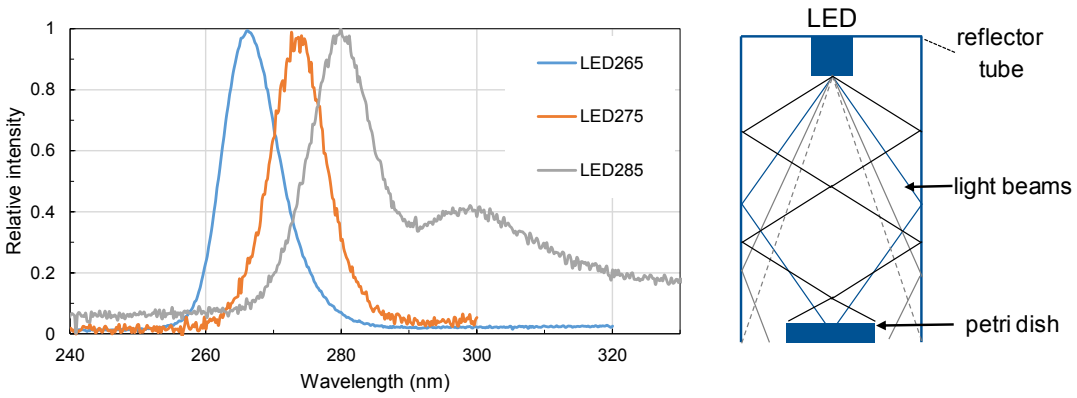

Fig. 38: Relative intensity emission spectra and schematic light beam distribution of LEDs.

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Advanced oxidation processes for the removal of trace organic chemicals

In recent years, trace organic chemicals (TOrC) have been detected in the aquatic environment. Besides urban and agricultural runoff, wastewater treatment plant effluents are the most significant TOrC emitters. Hence, it is likely that environmental quality standards for TOrCs, such as diclofenac, will be implemented at the European Union level in the foreseeable future. To meet future quality standards, advanced treatment options for wastewater effluents cannot be excluded. In the framework of this project, TUM investigated the applicability of UV/H_2O_2 for the oxidation of TOrCs in wastewater effluents as an alternative to ozonation at Bavarian wastewater treatment plants. Research partners were LfU and MSE. The pilot study was conducted using a pilot plant (Wedeco) that was located at the Munich municipal WWTP Gut Marienhof.

The project concluded in March 2017 and revealed that:

- modification of process paramenters in the present UV disinfection system at the wastewater treatment plant Gut Marienhof can result in enhanced removal (about 70%) of photo-susceptible compounds,
- retrofitting the existing UV disinfection system (by e.g. installing more powerful UV lamps) can achieve an additional removal of photo-susceptible compounds (about 82%),
- that oxidation of photo-resistant compounds with UV/H_2O_2 does not provide an economically meaningful alternative to ozonation for advanced treatment of municipal wastewater.

Fig. 39: UV/H_2O_2 pilot plant at WWTP Gut Marienhof (Munich II).

FUNDING:
BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

COOPERATION:
BAVARIAN ENVIRONMENT AGENCY (LFU);
MÜNCHNER STADTENTWÄSSERUNG (MSE)

JÜRGEN EDERER (B.SC.)

Development and validation of a novel and energy efficient system for ozone injection to treat wastewater treatment plant effluents

Ozone is a well established treatment process for advanced wastewater treatment, disinfection of drinking and bathing water as well as the treatment of industrial wastewaters. However, high energy consumption for ozone generation and gas to liquid transfer result in elevated costs for the application of ozone. Within a DBU funded research project, TUM tested a novel concept for ozone injection based on hydrodynamic generation of cavitation. Together with Sewec Ozon GmbH and Cavtec Systems, a pilot ozonation system was designed and constructed to test the novel injector design in comparison to the frequently used venture-injection.

Efficiency of gas injection was visually characterized in a transparent tubing and quantified by determination of system mass transfer coefficients. Both, mass transfer coefficients at two defined operational conditions and visual verification did not show significant improvement of oxygen transfer in the cavitation system. Also an extension to system pressure of 3.0 bar did not result in the formation of expected microbubbles. It can be assumed that higher pressure or increased flow velocities are needed to effectively generate cavitation in the injection system. Since operational pressure of the ozone generator is limited to 0.5-1.0 bar, a simplified system will be used to identify optimum operational parameter. In the meantime, a modified cavitation generator is developed by Cavtec Systems, which will create a vacuum at the point of ozone/oxygen gas injection similar to the venture-injector to avoid the need to overcome system pressure for gas injection.

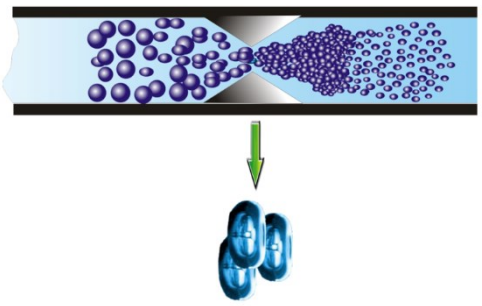

Fig. 40: Principle of hydrodynamically generated cavitation.

FUNDING:
GERMAN ENVIRONMENT FOUNDATION

COOPERATION:
SEWEC OZON GMBH;
CAVTEC SYSTEMS

Assessment of advanced phosphorus elimination in municipal sewage treatment plants

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FUNDING:
BAVARIAN ENVIRONMENT AGENCY

Due to the latest surface water regulation (Oberflächengewässerverordnung), a new benchmark for total phosphorus emissions has recently been introduced. High concentrations of phosphorus can lead to eutrophication of surface waters, therefore negatively affecting the aquatic environment. This has led to a greater emphasis on phosphorus elimination in municipal sewage treatment plants within the last years, since their discharges are defined as point sources for phosphorus. The current technical guideline presents obvious gaps for phosphorus elimination, aiming for threshold concentrations below 0.5 mg/L.

The aim of this research project, funded by the Bavarian Environment Agency (AZ: 67-0270-34797/2016), was to compile an inventory of existing technical measures and implementations of advanced phosphorus elimination in municipal sewage treatment plants, as well as review and analyze the possible courses of action. This encompasses both chemical and biological treatments, as well as process combinations, including mechanical-physical separation processes for precipitation products.

To achieve the benchmark value for the "good ecological status" for surface waters of 0.1 mg Pges/L, municipal sewage treatment plants can make a relevant contribution by further reducing their phosphorus emissions. The evaluation of the current state of all Bavarian wastewater treatment plants showed high reduction potential for total phosphorus emissions at plants larger than 1,000 PE. The detailed balancing of ten wastewater treatment plants in Germany confirmed that the existing processes (chemical phosphate precipitation, possibly with filtration or in combination with biological phosphorus elimination) are suitable for the most extensive elimination. For treatment plants of size class 2, simultaneous effluent concentrations ≤ 0.8 mg Pges/L are operationally stable via simultaneous precipitation. Average effluent concentrations of 0.5 mg Pges/L are generally achievable in the larger wastewater treatment plants, provided that the secondary clarification is measured and operated according to the current recognized rules of technology. The specific investment and operating costs for the implementation of a simultaneous precipitation are approx. 2-5 € / (PE · yr) for treatment plants of size class 2.

The research project ran from July 2016 until July 2017 and was executed in close collaboration with Fa. Dr.-Ing. Steinle Ingenieurgesellschaft für Abwassertechnik mbH, Weyern.

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Urban Water-Energy-Food Nexus

The research project "Urban Water-Energy-Food Nexus," conducted at the chair since April 2017, is financed by the Bavarian State Ministry for Environment and Consumer Protection.

With ongoing economic growth and urbanisation, demand for natural resources such as water, energy and food continue to rise worldwide, especially in cities. The result is serious environmental damage and climate change. Integrated urban planning to leverage on potential synergies of climate change mitigation and adaptation approaches urgently needs to be developed and implemented by 2030 to avert disastrous climatic consequences.

The Water-Energy-Food (WEF) Nexus approach is one way for cities to devise more sustainable development pathways. The approach advocates that supplying water to cities takes much energy, and that much water is also needed to produce energy and food. Planning these three sectors in an integrated manner may enable better water, energy and food security and implementation of the Sustainable Development Goals (SDGs). Water reclamation and reuse is a key synergy opportunity for the operationalization of the WEF Nexus approach.

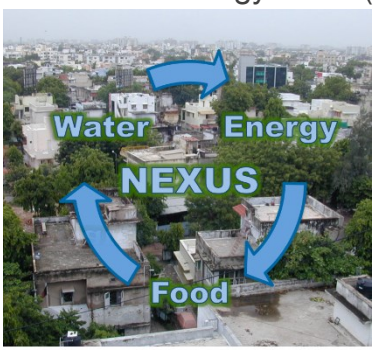


Fig. 41: Water-Energy-Food Nexus scheme.

The aim of the Urban WEF Nexus Project is to study the interaction between the sectors water, energy and food and devise alternative future urban development scenarios to support the development of pilot projects at neighbourhood scale. The project takes Leh Town, the capital of Ladakh, a semi-arid high-altitude region in the Indian Himalayas, as a case study.

FUNDING:
BAVARIAN STATE MINISTRY FOR ENVIRONMENT AND CONSUMER PROTECTION

Fig. 42: Nexus Workshop in Delhi, October 2017.

Further Research Activities

NeXus of Water, Food and Energy

The Chair for Urban Water Systems Engineering is involved in the DAAD-funded project **NeXus of Water, Food and Energy**. The project deals with the interactions of the limited resources water, food, and energy together with academic partners in Ethiopia and Tanzania, and is coordinated by the Chair of Hydraulic and Water Resources Engineering (Prof. Rutschmann).

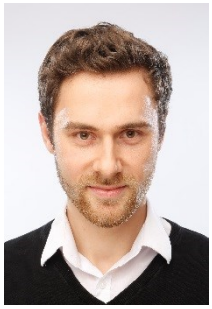
Young Water Reuse Professionals (YWRP)

Staff of the chair, led by Nils Horstmeyer, are actively involved in the Young Water Reuse Professionals (YWRP) group of the IWA Water Reuse Special Group (WRSG), founded in 2015. The goal is to promote international networking of young scientists in the water reuse sector, as well as facilitate exchanges with senior scientists and industry representatives in the field of water recycling. Activities include supporting a communication platform for information exchange (IWA Connect), contributing to WRSG newsletters, as well as assisting in planning the IWA Water Reuse Specialist conferences. At the 11th IWA International Conference on Water Reclamation and Reuse in July 2017 Long Beach, CA, Stevo Lavrnić was also elected a member of the WRSG Management Committee.

Fig. 43: TUM PhD students at the IWA 2017 conference in Long Beach, CA, USA.

Any interested parties can contact Nils Horstmeyer: nils.horstmeyer@tum.de

External PhD Candidates



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Jochen Bandelin is a process engineer developing highly efficient ultrasound systems for the pre-treatment of wastewater sludge at BANDELIN electronic GmbH & Co.KG in Berlin. His PhD thesis is supervised by Professor Jörg Drewes and Dr.-Ing. Konrad Koch.

The doctoral thesis focuses on the systematic investigation of disintegration via ultrasonically induced cavitation in highly viscous media. The ultrasonic energy, produced by piezo-ceramic ultrasonic systems, is intended to rupture the particles in anaerobic processes to increase biodegradability and consequently, increase biogas production. To obtain an undoubtedly positive energy balance, ideal ultrasonic configurations must be determined, to achieve highest sonication efficiency of different viscosities of sludge, by identifying the optimal ratio of amplitude, field size, ultrasonic frequency and power density in the configuration.

For this purpose, the formation and propagation of cavitation fields in highly viscous media is investigated experimentally, then compared to the behavior of cavitation fields in water. This is accomplished via a novel acoustic measuring method to determine the cavitation noise figure. Based on the results of the lab experiments, a new reactor concept enabling the efficient pre-treatment of large amounts of sludge will be constructed. The novel reactor will be tested for its efficiency in pilot-scale, and its cavitation intensity in wastewater treatment sludge and the increase of methane yield will be compared to conventional ultrasound systems. The system will finally be installed at a wastewater treatment plant for full-scale testing. Beside the process engineering considerations of the various ultrasonic concepts, the cost-effectiveness with regard to production costs and life time will also be determined.

VASILIS DANDIKAS (M. SC.)

VASILIS.DANDIKAS @LFL.BAYERN.DE

Vasilis Dandikas is a research associate at the Institute of Agricultural Engineering and Animal Husbandry of the Bavarian State Research Center for Agriculture in Freising, Germany. As part of his doctoral thesis, he deals with the question to what extent the biogas yield and formation rate of any agricultural substrates can be estimated quickly and cost-effectively by means of a mathematical model. For this purpose, substrates of interest are analyzed by means of fodder analysis (Weender analysis with van Soest fraction) and batch fermentation tests (based on VDI 4630) in parallel. By means of a principal component analysis, correlations between biogas yield and formation rate and the chemical composition of the plant substrates are identified.

The statistical analysis showed that the biogas yield can be predicted by three analytical parameters, i.e., lignin (ADL), hemicellulose (HC) and crude protein (XP) with an estimation error of only 5%. In contrast, the parameters non-fiber

carbohydrates (NFC) and XP can serve as regressors for the prediction of the biogas production rate.
Since the change of gas production over time during a batch fermentation test is proportional to the gas production, this can be initially described by first-order kinetics. Thus, the biogas production rate and the yield can be predicted quickly and reliably with known chemical composition of a substrate using the developed models.

SEBASTIAN HIEN (DR.-ING.)

SEBASTIAN.HIEN @UNI.LU

Sebastian Hien is a research associate at the Chair of Urban Water Management and Hydraulic Engineering at the University of Luxembourg. His PhD thesis is supervised by Professor Joachim Hansen and co-supervised by Dr.-Ing. Konrad Koch from the Anaerobic Technologies and Energy Recovery group. In June 2017, he successfully defended his PhD thesis, titled "Approaches for supportive prediction of biogas production rate and control strategies to provide flexible power production".
As part of his work, he investigated various possibilities for predicting biogas or methane production at biogas plants and wastewater treatment plants, in order to integrate them into the concept of virtual power plants. He was able to identify various parameters that have an above-average influence on the prediction of biogas production. For this purpose, data from different treatment plants were collected and used for modeling in dynamic simulations. These simulation results were analyzed based on the identified parameters, such as biogas production from the previous day and the organic loading load. By applying machine learning approaches such as random forests and artificial neural networks, the so-called BioTOOL for short-term prediction of the expected biogas yield was developed. Based on the predictions of BioTOOL, a methodology for the demand-oriented generation of biogas has been established.

CHRISTIAN HILLER (DIPL.ING.)

CHRIS.HILL@ GMX.NET

Christian Hiller is the lead Process Engineer at the Zweckverband Klärwerk Steinhäule in Neu-Ulm, Germany. His PhD thesis is supervised by Professor Jörg Drewes and co-supervised by Dr. Uwe Hübner. The focus of this project is to investigate the removal of antibiotic resistant bacteria (ARBs) and antibiotic resistence genes (ARGs) during membrane filtration as an advanced treatment step for municipal wastewater treatment plants. Membrane processes using different commercially available ultrafiltration membranes are tested with secondary effluent, effluents after powdered activated carbon treatment, and activated carbon treatment with subsequent multi-media filtration. The goal of these studies is to determine optimal operating conditions to maximize ARB and ARG removal. Beside ARBs and ARGs, operational parameters for process control are examined including TOC, UV absorbance, turbidity, particle counts, etc.

KATIE MACINTOSH
(M. SC.)

C.MACINTOSH
@UQ.EDU.AU

Katie Macintosh is a visiting PhD student from the Advanced Water Management Centre, affiliated with The University of Queensland (UQ) in Australia. As part of the UQ-TUM Student Exchange Program she is researching anaerobic co-digestion with the Anaerobic Technologies and Energy Recovery group, supervised by Dr.-Ing. Konrad Koch.

Anaerobic co-digestion (AcoD), the simultaneous digestion of two or more different waste types, can significantly increase the renewable energy production from existing wastewater treatment plants and agri-industrial facilities. There are, however, costs and risks associated with co-digestion. Increased organic loading rates or poorly designed AcoD mixtures may stress the microbial communities causing overload, instability or even process failure. Similarly, AcoD is only one step within a treatment process, the impacts and costs of co-digestion on downstream processes are poorly understood, largely due to a lack of systematic full-scale data.

The doctoral thesis focuses on defining microbial capacity and the impact of process conditions on maximum co-digestion loading. Laboratory experiments have been used to model specific microbial behaviors and the resulting kinetic parameters. The exchange to TUM offers the opportunity to benchmark laboratory experiments against full-scale data to quantify plant-wide impacts.

The collaborative research at TUM is using operational data from full-scale plants to quantify the impact of food waste co-digestion on biogas energy yield and downstream processing costs including biosolids volume and centrate quality. For this purpose, a food-waste product produced at a centralized processing facility in Oberding called ProFermo, is being used as a case-study. ProFermo is distributed as a co-substrate to a number of wastewater treatment plants in the region. This study compares operational data from receiving plants before and after commencing co-digestion to quantify the plant-wide impact of the ProFermo addition. Parameters to be investigated include biogas yield, percentage of self-generated energy, nutrient (N, P) distribution between centrate and biosolids as well as other downstream metrics. Outcomes from this study aim to provide water utilities with a more holistic view of the costs, risks and benefits of anaerobic co-digestion.

Visiting Scientists

MIKE MANEFIELD
(ASSOC. PROF.)

MANEFIELD@
UNSW.EDU.AU

Associate Professor Mike Manefield, University of New South Wales, Sydney, Australia

Prof. Dr. Mike Manefield visited the chair in 2015 as an August-Wilhelm-Scheer visiting professor and continued our collaboration in the field of microbiological structures and functions in modified biofiltration systems during several short-term visits in 2016. Mike Manefield is an associate professor at the School of Biotechnology and Biomolecular Sciences at the University of New South Wales, Sydney, Australia.

STUART KHAN
(PROF.)

S.KHAN@
UNSW.EDU.AU

Professor Dr. Stuart Khan, University of New South Wales, Sydney, Australia

Prof. Dr. Stuart Khan is a Hans-Fischer Fellow of TUM. Stuart Khan is professor at the School of Civil and Environmental Engineering at the University of New South Wales. As a Hans-Fischer Fellow, Prof. Khan receives a three-year grant to carry out his research (2015-2018). Prof. Khan jointly supervises our PhD student Philipp Michel with Prof. Drewes.

KARL LINDEN
(PROF.)

KARL.LINDEN
@COLORADO.EDU

Professor Dr. Karl Linden, University of Colorado-Boulder, Boulder, Colorado, USA

Prof. Dr. Karl Linden visited the chair from August 2016 until January 2017 as an August-Wilhelm-Scheer visiting professor. Karl Linden is the Helen and Hubercroft Professor of Environmental Engineering at the University of Colorado-Boulder, USA. As the world's leading expert in the field of UV processes, Prof. Linden supported ongoing research in the field of UV-based advanced oxidation processes at TUM.

JENNIFER BECKER
(ASSOC. PROF.)
JGBECKER
@MTU.EDU

Associate Professor Dr. Jennifer Becker, Michigan Technological University, Michigan, USA

Prof. Dr. Jennifer Becker was a TUM Visiting Professor at the chair. From August 2016 – June 2017, she supported ongoing research on the removal of biological trace substances at the chair. Prof. Dr. Becker is Associate Professor of Civil and Environmental Engineering at Michigan Tech University, USA.

ERIC SEAGREN
(PROF.)
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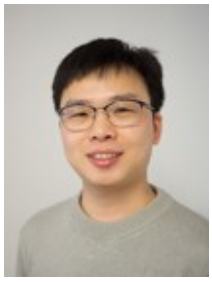
@MTU.EDU

Professor Dr. Eric Seagren, Michigan Technological University, Michigan, USA

Prof. Dr. Eric Seagren was a TUM Visiting Professor. From August 2016 – June 2017, he worked together with Prof. Drewes to set up a mentoring program for female scientists at TUM and MTU (PhD candidates, post-docs) who have an interest in pursuing an academic career. Prof. Dr. Seagren is a professor of Civil and Environmental Engineering at Michigan Tech University, USA.



WENLONG WANG
(M.SC.)
GA48TAQ@TUM.DE

Wenlong Wang, M.Sc. Tsinghua University, China

Wenlong Wang visited TUM from October 2016 – September 2017 as a visiting researcher. Wenlong is a PhD candidate at the School of Environment at Tsinghua University in China, where he is supervised by Prof. Dr. Hong-Ying Hu. Wenlong works on the topic "Use of UV-LED for the disinfection and oxidation of organic trace elements." He works closely with Dr. Uwe Hübner and the research group Advanced Wastewater Treatment and Water Recycling.

SOŇA FAJNOROVÁ
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Soňa Fajnorová, M.Sc. University of Chemistry and Technology, Prague

A PhD student from the University of Chemistry and Technology in Prague, Czech Republic, under the supervision of Prof. Jiri Wanner, **Soňa Fajnorová** has been visiting TUM since August 2016. Funded by Bayerisch-Tschechische Hochschulagentur, she is investigating the inactivation of antibiotic resistant bacteria and removal of antibiotic resistant genes in advanced wastewater treatment processes and water recycling.

International Cooperation Partners

Last year, we further expanded our international partner network! (Fig. 44)

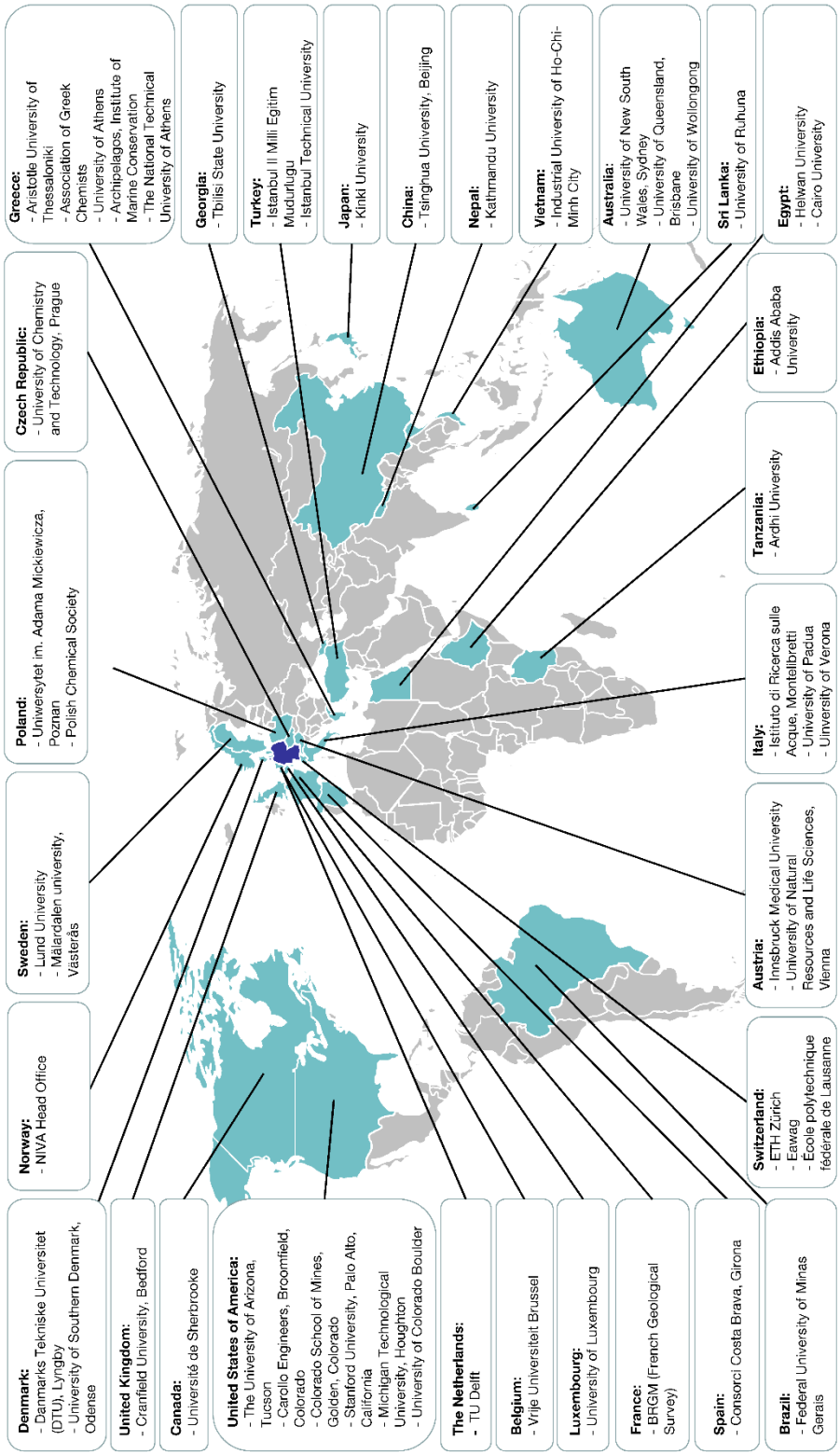

Fig. 44: Overview of international collaboration partners.

National/International Committee

Water Reuse Specialist Group (IWA)

Since autumn 2013, **Jörg E. Drewes** is serving as chair of the **Water Reuse Specialist Group (WRSG)** of the **International Water Association (IWA)**. With over 3,400 members, WRSG is the largest specialist group within the IWA with experts in the field of water recycling from more than 110 countries. In 2017, the 11th IWA International Water Reuse Conference was held in Long Beach, California, from July 24-27. With more than 650 attendees, an exciting technical program, excursions to various water reuse treatment plants, and conversations with international scientists in the field of water reuse, the conference was a huge success (Fig. 45). A large delegation from our chair attended (Fig. 46).

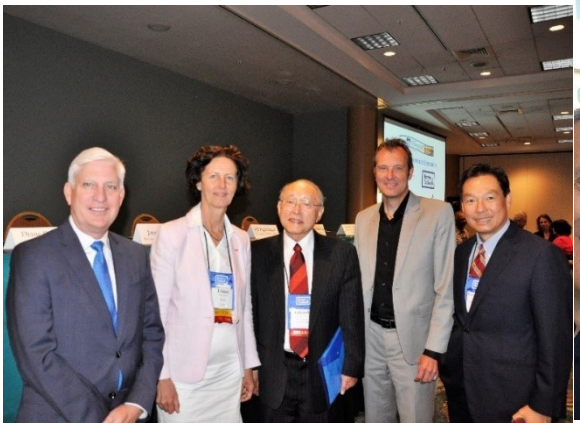

Fig. 45: Keynote Speakers of the opening of the 11th IWA International Conference on Water Reuse in Long Beach, CA, USA.

Fig. 46: Conference attendees from the Chair aboard the ship Queen Mary I.

The host of the 12th International Conference on Water Reclamation in June 2019 will be Berlin, which won hosting rights over Amsterdam. Preparations for this meeting are already under way.

DWA-Working Groups

Prof. Dr. Helmreich is currently actively involved in the **DWA-A 138** working group "*Planning, construction and operation of rainwater infiltration systems*" and the new leaflet DWA-M 179 "*Decentralized rainwater treatment plants*".

Jörg E. Drewes is involved in the **DWA Committee KA-8** "*Advanced Wastewater Treatment*", in the **DWA-Working Groups Biz 11.4** "*Water Recycling*" and in the **KA-8.1** "*Anthropogenic Substances in the Water Cycle*".

German Water Chemistry Society

Uwe Hübner is involved in the specialist group "*Transformation Processes of Biological Wastewater Treatment and Wastewater Recycling*", a sub-committee of the **German Water Chemistry Society**. The group is currently developing a status paper that summarizes the current state of knowledge on biological degradation processes.

Journal International Journal of Environmental Research and Public Health – Guest Editor

Prof. Dr. Helmreich was guest editor of the journal *""International Journal of Environmental Research and Public Health"* for a special issue *"Urban stormwater management".*

Journal of Water Reuse and Desalination – Editor

Jörg E. Drewes is editor of the new journal "*Journal of Water Reuse and Desalination*" (JWRD) since 2015. JWRD is an international journal that publishes contributions regarding water reuse and water desalination. For further information, please visit: http://jwrd.iwaponline.com

Journal Water Solutions – Editor

Since 2016, **Jörg E. Drewes** is editor of the new journal "*Water Solutions*" . Water Solutions is published quarterly. The journal reports highlights of the latest developments in the water and wastewater sector in Germany for an international audience. For more information, please visit: https://www.gwf-wasser.de/en/

Promotion of Young Talent/ Workshops/ Other Activities

Institute Outing – Summer 2017

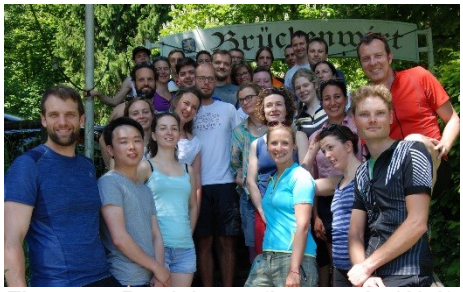

Fig. 47: Betriebsausflug nach Wolfratshausen

This year we went on a bike tour from Munich to Wolfratshausen on May 29, 2017. Starting from the Munich Zoo, over 30 kilometers were biked or hiked by our staff. We stopped for a short break at Gaststätte Brückenwirt, then continued the tour until Wirtshaus Flößerei in Wolfratshausen, where we shared a well deserved and delicious lunch.

45th Sewage Handing Workshop (ATS)

The 45th Abwassertechnische Seminar (ATS) or Sewage Handling workshop, focused on the limits of and opportunities for enhanced phosphorous elimination in municipal wastewater treatment plants, was held at the Oskar von Miller Forum on June 28th, 2017. The seminar compared the relevance and legal foundations for widespread phosphorus elimination. An inventory of existing technical possibilities for the most extensive phosphorus elimination options, as well as a critical analysis of the options for action were presented. Chemical and biological processes, process combinations, as well as mechanical-physical separation processes for precipitated products were considered. Examples of municipal sewage treatment plants were used to discuss the results and operational experiences from various processes.

Research Symposium with UCT Prague

A joint research symposium for PhD students and group leaders Prof. Jiri Wanner's group at the University of Chemistry and Technology, Prague and TUM was held at the chair on July 12, 2017. The symposium was funded by the Bavarian-Czech University Agency.

Fig. 48: PhD students and staff from TUM and UCT Prague before the summer party.

Scienclisten

In 2017, we collectively biked over 35,000 kilometers to and from the chair! This equates to 5.2 tons of CO_2 saved in comparison to an average car, and 13.7 tons CO_2 in comparison to an economy flight. Well done!

Annual Meeting of PhD Candidates of Water Institutes

PhD students from German speaking water research institutes come together once a year to present research findings, exchange ideas, and network. The 38th "Assistententreffen" took place from September 20-23rd 2017 in Kaiserslautern.

Fig. 49: Lara Stadlmair, Carmen Leix, Johann Müller, Thomas Lippert and Florian Ebertseder at the Assitreffen.

Visiting the University of New South Wales in Sydney, Australia

From September to November Karin Hellauer visited Prof. Mike Manefield and his team at the UNSW in Sydney, Australia, which was funded by the DAAD. The aim of this stay was to identify genomic markers for different trophic strategies of microbial communities in engineered filtration systems, in addition to learning several bioinformatics tools, and receiving training in cell counting using epifluorescence microscopy. Karin met several scientists in this research field and present research at JAMS (Joint Academic Microbiology Seminars).

Many thanks to Mike and his colleagues, especially Sophie Holland, Sabrina Beckmann and Federico Lauro, for their support! It was a great experience to work with Mike's group and to spend several weeks abroad.

Fig. 50: Mike Manefield, Karin Hellauer, Sabrina Beckmann in Australia.

Fig. 51: Karin Hellauer & Sophie Holland in Australia.

Published Books

Brigitte Helmreich and **Jörg Drewes** contributed book chapters to *‚Innovative Wastewater Treatment and Resource Recovery Technologies: Impacts on Energy, Economy and Environment'* in 2017. Brigitte wrote *‚Post-treatment for micropollutants'* and Jörg wrote *‚Producing high-quality recycled water'*.

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TUM Water Cluster

The TUM Water Cluster is a priority program for water research between many faculties at the TUM. Its goals are to coordinate water research and teaching, coordinate exchange of information on water-related topics, and present external research.

Research Projects

In 2017, two major research projects on micro- and submicroplastics began, under the direction of the chairs of Aquatic Systems Biology and Urban Water Systems Engineering.

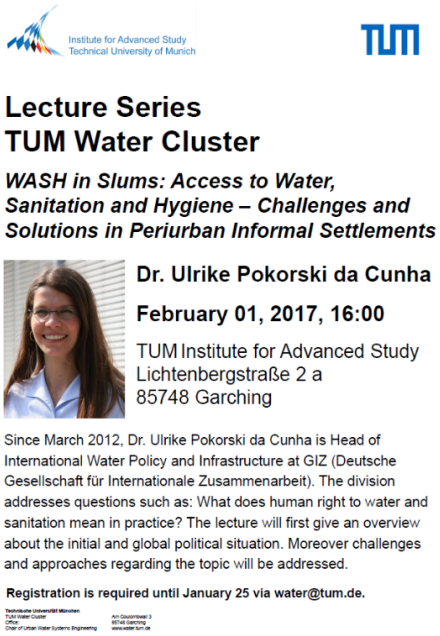
The research project "Innovative Methods of Analysis for Submicroplastics" (Sub-µTrack), funded by the Federal Ministry of Education and Research (BMBF), aims to develop innovative analysis and assessment methods to quantify plastic particles in different water samples, assess their toxicity, and address the related societal impacts. The project is distinguished by focusing on particles smaller than 1 µm. Due to their possible cell permeability and larger specific surface area, such particles have potentially higher (eco) toxicological relevance. In addition to the coordinating Chair of Urban Water Systems Engineering (Prof. J. Drewes, PD Dr. J. Graßmann), the Chair of Analytical Chemistry and Water Chemistry (Prof. M. Elsner, Dr. NP Ivleva) and the Chair of Aquatics Systems Biology (Prof. J. Geist, Dr. S. Beggel) of the TUM Water Cluster are involved. Furthermore, the Chair of Animal Physiology and Immunology (Prof. M. Pfaffl) and the Chair of Science and Technology Policy (Prof. R. Müller) of TUM, as well as six other partners from industry and various authorities are involved in the project.

The goal of the interdisciplinary research project "Microparticles in the aquatic environment and in food - are biodegradable polymers a conceivable solution to the 'microplastic problem?' (MiPAq), is to characterize particles from non-degradable petroleum-based plastic materials (as opposed to biodegradable materials), and to compare them with natural sediment particles. In particular, biopolymers as conceivable a substitute for conventional plastics should be emphasized. In addition, this project is characterized by a holistic view of biopolymer application, from the environment to food.
The project is led by Prof. Jürgen Geist (Chair of Aquatic Systems Biology) and Prof. Jörg Drewes (Chair of Urban Water Systems Engineering) as co-investigator. Other members of the TUM Water Cluster involved are the Chair of Analytical Chemistry and Water Chemistry (Prof. M. Elsner, Dr. NP Ivleva, IWC), the Chair of Food Packaging Technology (Prof. H.-C. Langowski) and the Chair of Food Chemistry and Molecular Sensor Technology (AG Water Technology, Dr. med.

K. Glas) as well as over 10 industrial partners. The project is supported by the Bavarian Research Foundation.

Lecture Series of the TUM Water Cluster

2017 also featured two guest lectures from Dr. Ulrike Pokorski da Cunha (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)) as well as Prof. Torsten Schmidt (Universität Duisburg-Essen).



Institute for Advanced Study
Technical University of Munich

Lecture Series
TUM Water Cluster

WASH in Slums: Access to Water, Sanitation and Hygiene – Challenges and Solutions in Periurban Informal Settlements

Dr. Ulrike Pokorski da Cunha

February 01, 2017, 16:00

TUM Institute for Advanced Study
Lichtenbergstraße 2 a
85748 Garching

Since March 2012, Dr. Ulrike Pokorski da Cunha is Head of International Water Policy and Infrastructure at GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit). The division addresses questions such as: What does human right to water and sanitation mean in practice? The lecture will first give an overview about the initial and global political situation. Moreover challenges and approaches regarding the topic will be addressed.

Registration is required until January 25 via water@tum.de.

Institute for Advanced Study
Technical University of Munich

Lecture Series
TUM Water Cluster

What shall we measure tomorrow? Needs and trends in future water analysis

Prof. Torsten C. Schmidt
University of Duisburg-Essen

June 07, 2017, 16:00 h

TUM Institute for Advanced Study
Lichtenbergstraße 2 a
85748 Garching

Water analysis nowadays has achieved a remarkably mature status that safeguards quality of water for anthropogenic purposes and ecosystem health. However, there is still a broad range of challenges that should be addressed in the further development of analytical methods. These will be in the focus of the presentation and include widening of the scope of the analytical window and taking into account the evaluation of chemical stressor effects.

Registration is requested by May 31 via water@tum.de.

Exhibition „Engineers in Construction: Inventors, Entrepreneurs, Designers & Problem Solvers“ at the Oskar von Miller Forum

The TUM Water Cluster supported an exhibition "Engineers in Construction: Inventors, Entrepreneurs, Designers & Problem Solvers," which ran from November 9, 2017 to January 7, 2018 at the Oskar von Miller Forum. The exhibition focused on the complex profession of civil engineering, aiming to convey the cultural and technological relevance of the field. The conditions under which engineers were and are active, and how their work should be valued. In this context, the TUM Water Cluster presented the steadily changing tasks of engineers dealing with water in residental areas, their work in social, political and economic context, and focused on past, present and future challenges of adequate water supply and sanitation in urban areas.

Designed as a traveling exhibition, it will move to the M: AI, the Museum of Architecture and Engineering in North Rhine-Westphalia in spring 2018. The exhibition is accompanied by a summary publication in German.

Publications

Books and Book Chapters

- Drewes, J.E.: Wasserwandel in Städten und der Zukunft. In: Lang, W.; Hellstern, C.; (Hrsg.): Visionäre und Alltagshelden. Ingenieure - Bauen - Zukunft.. DETAIL Business Information, 2017
- Drewes, J.E., Horstmeyer, N., Michel, P., Khan, S.: Producing high-quality recycled water – Producing high-quality recycled water. In: Innovative Wastewater Treatment & Resource Recovery Technologies: Impacts on Energy, Economy and Environment. IWA-Publishing, 2017, 285-295
- Helmreich, B., Metzger, S.: Post-treatment for micropollutants removal – Post-treatment for micropollutants removal. In: Innovative Wastewater Treatment & Resource Recovery Technologies: Impacts on Energy, Economy and Environment. IWA-Publishing, 2017, 214-229
- Huber, M., Muntau, M.: Technische Möglichkeiten zur weitestgehenden Phosphorelimination auf kommunalen Kläranlagen. In: 45. Abwassertechnisches Seminar: Weitestgehende Phosphorelimination auf kommunalen Kläranlagen – Möglichkeiten und Grenzen. Technische Universität München, 2017, 55-69
- Huber, M., Welker, A., Drewes, J.E., Helmreich, B.: Auftausalze im Straßenwinterdienst – Aufkommen und Bedeutung für dezentrale Behandlungsanlagen von Verkehrsflächenabflüssen zur Versickerung. In: Runge, H. (Hrsg.): Herausforderung Regenwasser. DIV Vulkan Verlag (1. Aufl.), 2017, 84-99
- Huber, M.; Welker, A.; Hilbig, H.; Wulff, M.; Helmreich, B.;: Vergleich zweier Filtermaterialien zur Entfernung von Phosphat und Schwermetallen aus Verkehrsflächenabflüssen. In: Runge, H. (Hrsg.): Herausforderung Regenwasser. DIV Vulkan Verlag, 2017, 71-83
- Khan SJ, Walker T, Stanford BD and Drewes JE: Advanced Treatment for Potable Water Reuse – Advanced Treatment for Potable Water Reuse. In: Advanced Oxidation Processes for Water Treatment: Fundamentals and Applications. IWA Publishing, 2017

Peer-reviewed Journal Articles

- Bieber, S.; Letzel, T.;: RPLC-HILIC und SFC - Polaritätserweiterte und orthogonale Trenntechniken für den Nachweis von organischen Spurenstoffen. Wasserforum-Sonderpublikation, 2017
- Ansari, A., Hai, F., Drewes, J.E., Price, W. Nghiem, L. (2017). Forward osmosis as a platform for resource recovery from municipal wastewater. *Journal Membrane Science* **529**, 195-206.
- Drewes, J.E.: Die Spurenstoffstrategie des Bundes – Einschätzung eines Beobachters. GWF Wasser Abwasser **158** (9), 2017, 30-34
- Hellauer, Karin; Mergel, Dorothea; Ruhl, Aki S.; Filter, Josefine; Hübner, Uwe; Jekel, Martin; Drewes, Jörg E.: Advancing Sequential Managed Aquifer Recharge Technology (SMART) Using Different Intermediate Oxidation Processes. Water **9** (3), 2017
- Herzog, Bastian; Dötsch, Andreas; Lemmer, Hilde; Horn, Harald; Müller, Elisabeth: Profiling 5-tolyltriazole biodegrading sludge communities using next-generation sequencing and denaturing gradient gel electrophoresis. Systematic and Applied Microbiology **40** (8), 2017, 508-515
- Huber, Bettina; Hilbig, Harald; Drewes, Jörg E.; Müller, Elisabeth: Evaluation of concrete corrosion after short- and long-term exposure to chemically and microbially generated sulfuric acid. Cement and Concrete Research **94**, 2017, 36 - 48
- Huber, M.: Bewertungsverfahren für dezentrale Anlagen zur Niederschlagswasserbehandlung von Verkehrsflächenabflüssen. KA Korrespondenz Abwasser, Abfall **64** (9), 2017
- Huber, M.: Bewertungsverfahren für dezentrale Anlagen zur Niederschlagswasserbehandlung von Verkehrsflächenabflüssen. Vom Wasser **115** (2), 2017, 70-71
- Huber, M., Welker, A., Hilbig, H., Wulff, M., Helmreich, B.: Vergleich zweier Filtermaterialien zur Entfernung von Phosphat und Schwermetallen aus Verkehrsflächenabflüssen. Wasser/Abwasser (158 (3)), 2017, 74-87
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- Koch, Konrad; Lippert, Thomas; Drewes, Jörg E.: The role of inoculum's origin on the methane yield of different substrates in biochemical methane potential (BMP) tests. Bioresource Technology **243**, 2017, 457 - 463

- Koch, Konrad; Lippert, Thomas; Sabadini, Natalia Hauck; Drewes, Jörg E.: Tube reactors as a novel ultrasonication system for trouble-free treatment of sludges. Ultrasonics Sonochemistry **37**, 2017, 464 - 470
- Leix, Carmen; Drewes, Jörg E.; Ye, Liu; Koch, Konrad: Strategies for enhanced deammonification performance and reduced nitrous oxide emissions. Bioresource Technology **236**, 2017, 174 - 185
- Letzel, T.; Drewes, J.;: Neue Bücher. TUM Campus (3), 2017
- Muntau, Meriam; Schulz, Manoj; Jewell, Kevin S.; Hermes, Nina; Hübner, Uwe; Ternes, Thomas; Drewes, Jörg E.: Evaluation of the short-term fate and transport of chemicals of emerging concern during soil-aquifer treatment using select transformation products as intrinsic redox-sensitive tracers. Science of The Total Environment **583**, 2017, 10 - 18
- Müller, J.; Drewes, J.E.; Hübner, U.;: Sequentielle Biofiltration zur Entfernung anthropogener Spurenstoffe aus dem Ablauf kommunaler Kläranlagen. Mitt. Umweltchem Ökotox **23** (3), 2017, 77-79
- Nghiem, Long D.; Koch, Konrad; Bolzonella, David; Drewes, Jörg E.: Full scale co-digestion of wastewater sludge and food waste: Bottlenecks and possibilities. Renewable and Sustainable Energy Reviews **72**, 2017, 354 - 362
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Conference Proceedings

Oral presentations

- Drewes, J.E. and Bieber, S.: Strategien im Umgang mit Spurenstoffen. 50. Essener Tagung, 2017
- Drewes, J.E., Gondhalekar, D.: Urban Water-Energy-Food Nexus Workshop. Workshop TUM-Indian Institute of Technology Madras, 2017
- Drewes, J.E., Hellauer, K., Karakurt, S., Zhiteneva, V., Regnery, J., Hübner, U.: Sequential Managed Aquifer Recharge Technology (SMART) For Enhanced Micropollutant Removal from Laboratory Studies to Full-scale Applications. IWA 10th Micropol & Ecohazard Conference, 2017
- Drewes, J.E., Koch, K. Hübner, U.: Opportunities to tackle the full potential of wastewater. Blue Planet Berlin Water Dialogues, 2017
- Drewes. J.E.: Opportunities and Challenges for Water Reuse in Europe – Lessons learned from international Experience. Circular Economy Stakeholder Conference, 2017
- Hellauer, K., Mergel, D., Ruhl, A.S., Filter, J., Hübner, U., Jekel, M., Drewes, J.E.: Sequential Managed Aquifer Recharge Technology (SMART) – Principles, Performance and Optimization Strategies. IWA 11th International Conference on Water Reclamation and Reuse, 2017
- Helmreich, B.: Erfahrungen zur stofflichen Belastung von Versickerungsmulden an Zinkdachabflüssen. 16. Regenwassertage, 2017
- Helmreich, B., Huber, M., Rempe, L.M., Drewes, J.E.: Development of a two-step decentralized stormwater treatment system with a low-cost filter material for space-limited ultra-urban traffic areas. 14th IWA/IAHR International Conference on Urban Drainage (ICUD), 2017, 1016-1018
- Helmreich, B., Huber, M., Rempe, L.M., Drewes, J.E.: Entwicklung einer zweistufigen Behandlungsanlage für Verkehrsflächenabflüsse unter Berücksichtigung urbaner und kommunaler Anforderungen. Aqua Urbanica, 2017
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- Huber, M.: Entwicklung und Anwendung eines Bewertungsverfahrens für dezentrale Anlagen zur Niederschlagswasserbehandlung von Verkehrsflächenabflüssen. Wasser 2017, 2017, 25-32
- Huber, M.; Muntau, M.;: Technische Möglichkeiten zur weitestgehenden Phosphorelimination auf kommunalen Kläranlagen. 45. Abwassertechnisches Seminar: Weitestgehende Phosphorelimination auf kommunalen Kläranlagen – Möglichkeiten und Grenzen (Berichte aus der Siedlungswasserwirtschaft *215*), 2017, 55-69
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- Hübner, U., Miklos, D., Müller, J., Fajnarova, S., Herzog, B., Drewes, J.E.: Evaluation of alternative concepts for removal of trace organic chemicals from secondary effluents. IWA 10th Micropol & Ecohazard Conference, 2017
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- Karakurt, S., Sperlich, A., Hellauer, K., Hübner, U., Jekel, M., Drewes, J.E.: Großtechnische Validierung der sequentiellen Grundwasseranreicherung. Jahrestagung der Wasserchemischen Gesellschaft, 2017
- Koch, K.; Drewes, J.: Impact of inoculum's origin on the methane yield in biochemical methane potential (BMP) tests. International Conference "Progress in Biogas IV, 2017
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- Murgolo, S., Hübner, U. Helmreich, B., Drewes J.E., Mascolo, G.: Investigation of Electrochemical Process For Removal of emerging organic pollutants in Wastewater Treatment Plant Effluents by a Boron-doped Diamond Electrode. 5th European Conference on Environmental Applications of Advanced Oxidation Processes - EAAOP5, 2017
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- Wang, W., Hübner, U., Miklos, D., Linden, K.G., Hu, H., Drewes, J.E.: Degradation of trace organic chemicals by LED-UV/chlorine for reclaimed water treatment: synergistic effects. IUVA 2017 World Congress & Exhibition, 2017

- Welker, A., Dierkes, C., Dierschke, M., Huber, M.: Evaluation of novel sorption media filter materials for the advanced treatment of stormwater runoff from highways. 14th IWA/IAHR International Conference on Urban Drainage (ICUD), 2017

Poster Presentations

- Dandikas, V.; Heuwinkel, H.; Lichti, F.; Drewes, J.; Koch, K.: Comparing a global and a local modeling approach for the prediction of the biogas yield of energy crops. International Conference “Progress in Biogas IV”, 2017

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- Bieber, S.; Letzel, T.;: SFC und RPLC-HILIC mit MS-Detektion - Polaritätserweitertes Spurenstoffscreening in Gewässerproben. APPLICA 2017, 2017
- Drewes, J.E., Koch, K. Hübner, U.: Opportunities to tackle the full potential of wastewater. Blue Planet Berlin Water Dialogues, 2017 (Wasser Berlin)
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Theses

Doctoral Dissertations

- Bieber, Stefan: International management strategies for trace organic compounds in waterbodies and supporting advanced analytical techniques
- Leix, Carmen: Innovative strategies for enhanced deammonification performance and reduced nitrous oxide emissions.

Master’s Theses

- Aniol, Jonas: Investigation of Membrane Fouling Mitigation with Fluidized Granular Activated Carbon in Ultrafiltration Membrane Treatment of Municipal Wastewater
- Arias Rodriguez, Leonardo Francisco: Performance Comparison of UV sources for disinfection of E. faecium and E. coli.
- Aron, Helen: Evaluation of a pilot plant for the treatment of municipal wastewater for irrigation of acricultural-economic areas in West Africa through the use of Biochar
- Berger, Elvira: Variantenuntersuchung beim Neubau der Kläranlage in Grafenwiesen
- Bo, Jin: Investigation of biological degradation for industrial wastewater (Master Sustainable Resource Management)
- Brkjaca, Florian: Improving the removal of trace organic compounds during sequential biofiltration by varying different key parameters
- Cao, Yannan: UV/Chlorine for TOrCs removal: Pilot scale studies and influence factors
- Charoensiri, Jinjuta: Feasibility of oxygen releasing compounds (ORC) as an electron acceptor in SMART 2.0 application
- Dery, Alicia: Urban Water-Energy-Food Nexus: Case Study of Thiruvanmiyur Neighborhood, Chennai, India
- Dollinger, Florian: Aufbau der Entschiedungsmatrix und Variantenberechnung und –auswertung als Vorstufe für eine strategische Planung
- Eckl, Veronika: Dichtheitsprüfung nach der EÜV, Möglichkeiten der Umsetzung am Beispiel des Kanalnetztes der MSE
- Euba, Olivia: Domestic rainwater harvesting: Opportunities and Challenges
- Fettback, Tim: Methodology development to assess success and failure of decentralized small-scale sanitation systems in India
- Gessner, Verena: Characterization of solids in traffic area runoff: Continuous measurements and correlation with settling velocity
- Habel, Fabian: Pilotversuch zum Vergleich der Denitrifikationsqualität hinsichtlich der Nitritbildung während der nachgeschalteten Denitrifikation im Sandfilter bei voll- und unterstöchiometrischer Methanolzugabe

- Häring, Dominik: Phsophate recovery from secondary wastewater effluent with microalgae
- Hartl, Rebecca: UV-based advanced oxidation processes - Pilot process validation and process stability evaluation of UV/H2O2 for trace organic chemical removal from WWTP effluents
- Högl, Lukas: Optimization and adaption planning of water supply networks
- Jakobi, Kristin: Alternative Rücknahmenetze für Altfahrzeuge der BMW Group mit dem Ziel der Rohstoffsicherung dargestellt am Beispiel von Deutschland
- Lindström, Sara: Development of a 2D BDD electrode reactor model in COMSOL Multiphysics to predict electrochemical oxidation of organic pollutants
- Luginger, Pascal: Entwicklung und Etablierung eines alternativen Probenaufgabensystems für SFC-Analysen
- Mayerlen, Sara: BDOC character and concentration and ist influence on TOrCs transformation
- Mayr, Rupert: Scientific assessment and evaluation of approaches to phosphorus recovery in ist practical application
- Padel, Barbara: How many bacteria live in Bavarian groundwaters - first attempts for the definition of microbial natural background range
- Reichel, Julia: Immobilization of oxidative enzymes selected by Mass Spectrometric screening
- Rivas, Maria: Performance Assessment of Powdered Activated Carbon for the Removal of Benzene from Surface Waters
- Rosenwirth, Bianca: Deutsche Studie zum globalen Schutz gegen Plastikverschmutzung der Weltmeere - Eine monetäre und funktionale Gegenüberstellung zweier maritimer Abfallwirtschaftskonzepte
- Rupp, Marius: Untersuchung zur Optimierung der Aufbereitung von Gärrest zur Reduktion von Ablagerung
- Schmid, Felix: Chemical phosphorus removal - mass balance of the phosphorus removal of selected municipal wastewater treatment plants using operating data
- Schmid, Ludwig: Assessing competitive adsorption of dissolved organic matter during the removal of trace organic chemicals using activated carbon in different water matrices
- Schmidt, Florian: Entwicklung eines Verfahrens zur Kostenschätzung bei der Sanierung von Trinkwasserbehältern auf Grundlage der Zustandserfassung und Sanierungskonzeption
- Schmitz, Jan: Investigation of membrane fouling of NF/RO membrane applications to enhance efficiency of an integrated membrane system for potable water reuse
- Schneider, Roland: Historische Recherche zu Altlasten am Betriebsgrundstück der MAN Truck & Bus AG am Standort Nürnberg
- Schön, David: Impact of Feed Spacer Accuracy on Hydrodynamic Modeling of Pure Water Flow in Membrane Modules – A Modeling Approach by Using COMSOL Multiphysics™ and Geomagic Design™ X
- Schweiger, Daniela: Development of in-situ oxidation step for a pilot scale sequential managed aquifer recharged technology (SMART) system for indirect potable water reuse
- Sharmin, Rasna: Development of computational fluid dynamics (CFD) models for simulating foulant reduction by patterned RO and NF membranes
- Thalmann, Christian: Immisionsbetrachtungen am Beispiel der eines Flusses
- Thiel, Paul: Application of Mechanically Pretreated Municipal Wastewater as Organic Reducing Equivalents for the Biological Production of Nitrous Oxide from Ammonia-rich Digester Centrate
- Thies, Cornelius: Investigation of the Effect of Air Supported Cleaning for Ultrafiltration Membranes
- Ziemendorf, Eric: Rapid Small-Scale Column Test to Enable Differentiation between Sorption and Biodegradation Rates of Trace Organic Chemicals in a Biological Activated Carbon Filter

Study Projects

- Arias Rodriguez, Leonardo Francisco: Performance Comparison of UV sources for disinfection of E. faecium and E. coli.
- Aron, Helen: The state of wastewater management in Global South Countries at the example of Ethiopia – a review.
- Bickert, Nadine: Assessment of water losses at house connections at the example of Stadtwerke München (SWM) (UI)
- Burger, Sandra: Evaluation of a stormwater management with regard to sustainability and development of water resources within the framework of technical posibilities.
- Dollinger, Florian: Sanierungskonzept für die Schmutzwasser-Kanalisation Olching
- Ganthaler, Sofia: Determination of the biodegradability of Terbuthylazine, Metolachlor, Nicosulfuron and Prosulfuron in a maize field: a case study
- Herb, Frank: Optimized implementation of a Power-to-Methane plant into a wastewater treatment plant in Germany - Recommendation for core elements and cost target analysis
- Lahmouri, Mounia: Microbial methanation in a thermophilic anaerobic trickle bed reactor - process performance after extended standby periods
- Larasser, Martin: Design, Construction and Commissioning of a Partially Automated Multi-Optional Membrane Test-Skid (NF/RO)

- Little, Emiliy: Examining the economic potential of renewable energies through optimization for the Northeast region of the United States
- Rehlen, Laura: Determination of a reliable method to identify the irradiance of LED array systems for water disinfection
- Rizou, Zoi: Impact of ultrasonic treatment on the dewaterability and viscosity of waste activated and digested sludge
- Schmid, Felix: Chemical-phosphorus removal – mass balance oft he phosphorus removal of selected municipal wastewater treatment plants using operating data
- Schwaller, Christoph: Installation and testing of a laboratory unit for conducting Biochemical Methane Potential tests at the Addis Ababa Institute of Technology, Ethiopia
- Stapelfeldt, Oliver: Technical feasibility study of Trace Organic Chemical removal in consideration of the existing UV System at the Wastewater Treatment Plant Gut Marienhof
- Sharmin, Rasna: Rapid Small Scale Column Tests to Observe the Breakthrough Behavior of Trace Organic Compounds in Granular Activated Carbon Filters
- Weiß, Franz: Druckregulierung durch Druckreduzierventile und Pumpen als Turbinen in Trinkwasserversorgungssystemen
- Wiese, Felix: Set up and start-up of a trickle bed reactor for microbial methanation

Bachelor's Theses

- Bieling, Nicolas: Literaturrecherche von Transformationsprodukten in der aquatischen Umwelt für das BMBF Verbundprojekt FOR-IDENT
- Bonas, Felix: Treatment Plant Design for Small-Scale Cosmetics Industry Effluent
- Eliasson, Ageir Björn: Application fields for stationary phases in supercritical fluid chromatography
- Erpf, Jakob: Einführung in die dezentrale Niederschlagswasserbehandlung für Verkehrsflächen- und Metalldachabflüsse
- Gilger, Julia: Optimierung und Betreuung eines Feldversuchs zur Aufbereitung von Abwasser in Tamale, Ghana zur Bewässerung
- Heck, David: Vergleich der Anaerobstufen von Kläranlagen in Bayern
- Huber, Vincent: Relining-Verfahren von nicht begehbaren Kanälen und Rohrleitungen in der kommunalen Abwasserentsorgung
- Isildak, Eda: The combination of ozonation and biological post-treatment to improve the removal of trace organic chemicals during wastewater treatment
- Kührt, Annika: Optimierung der Entwässerung auf der Kläranlage Tegernseer Tal
- Noceti, Luca: Schadstoffe aus Dachabflüssen von Nicht-Metalldächern – Eine Literaturstudie
- Salvermoser, Kukas: Transformationsprodukte von Spurenstoffen in der wässrigen Umwelt - Datenakquise für das BMBF Verbundprojekt FOR-IDENT
- Stoiber, Alexander: Hydraulische Kanalnetzberechnung und Überstauberechnung anhand eines Beispieles
- Schmidt, Nicolas: Belastung der regenabflüsse von Kupfer- und Zinkdächern – Eine Literaturstudie
- Schott, Sebastian: Vergleichende Bewertung von erprobten Steuer- und Regelstrategien sowie neuen Möglichkeiten zur bedarfsgerechten Ozondosierung zur Spurenstoffelimination
- Stoll, Clara: Vergleichende Bewertung von Ozoneintragssystemen zur Elimination von Spurenstoffen auf kommunalen Kläranlagen
- Uchaikina, Anna: Literature study on water relevant biogenic molecules
- Walzik, Christine: Untersuchungen zum Anfahrbetrieb der Deammonifikation

Dissertations and Awards

Fig. 52: PhD committee of Dr.-Ing. Carmen Leix.

Congratulations to **Dr.-Ing. Carmen Leix** for successfully defending her dissertation, titled „Innovative strategies for enhanced deammonification performance and reduced nitrous oxide emissions“. Her committee members included Prof. Dr. Lackner (TU Darmstadt), Prof. Dr. Morgenroth (ETH Zurich) und Prof. Dr. Drewes (TUM).

Congratulations to **Dr. rer. nat. Stefan Bieber** for successfully defending his dissertation, titled ‘International management strategies for trace organic compounds in waterbodies and supporting advanced analytical techniques’ on December 18th. His committee members included Prof. Dr. Torsten Schmidt (Uni. Duisburg-Essen), PD Dr. Thomas Letzel, and Prof. Dr. Drewes (TUM).

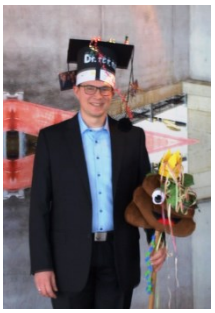

Fig. 53: Dr. rer. nat. Stefan Bieber.

Dr.-Ing. Maximilian Josef Huber received the **Willy-Hager-Preis** for his outstanding dissertation in the field of process engineering for (industrial) water and wastewater treatment. The title of his thesis was „Development and Evaluation of an Assessment Method for Decentralized Treatment Systems for Runoff from Traffic Areas“. He defended his Dissertation on June 15th and received the honourable 'summa cum laude'.

Fig. 54: Willy-Hager-Preis awarded to Dr.-Ing M. Huber (Foto: Wasserchemische Gesellschaft)

Meriam Muntau, M.Sc., was awarded the **Max-von-Pettenkofer-Preis** of the DWA Bavarian National Association (Landesverbandes Bayern) for her master thesis, titled “Assessment and management of emerging contaminants in indirect reuse systems: Surface spreading in Braunschweig”, which she completed in 2016 at our chair. She received it on October 18th, 2017 at the DWA meeting in Hof.

Lukas Högel, M.Sc., received this year's **H.P. Scholz-Preis** for exceptional study achievements and his master thesis, titled "Evaluation and Optimization of Water Distribution Networks Based on Computational Network Models". Lukas finished his masters studies in environmental engineering in April 2017, and graduated top of the class. He was jointly supervised by Apl.-Prof. Brigitte Helmreich from our chair, and Apl.- Prof. Steffen Krause and Salomé Parra, M.Sc., from the chair of Urban Water Management and Waste Engineering of the Universität der Bundeswehr München.

Fig. 15: Lukas Högel (links) mit dem Dekan Prof. Dr. Christoph Gehlen (rechts) am Tag der Fakultät bei der Preisverleihung (Foto: Andreas Herddergott)

Rofida Wahman, M.Sc., received the third place prize for her poster at the Langenauer Wasserforum 2017, held on 13th-14th November in Langenau. The topic was "Novel Analytical Strategies for Anthropogenic Compounds in Plants: Vegetable Biomonitors for Water Contaminations".

David Miklos, M.Sc., and **Wenlong Wang**, M.Sc., successfully presented their research at the IUVA World Congress in Croatia, held on September 17-20, 2017. Congratulations to David Miklos (1st) and Wen-Long (tie-2nd) on winning the student presentation awards!

Fig. 56: Wenlong Wang, David Miklos, Prof. Dr. Karl Linden, and Natalie Hull in Croatia.

The **Roland Mall Foundation** presented three gifted students from the field of water and environment each with a scholarship of €500/month for the entire standard period of study of the Master's program. The selected students (from left: Mario Gramm, Marlies Prahtel and Mohammed Al-Azzawi) were selected based on their previous accomplishments. The scholarships were personally presented by Mr. Michael Mall, Chairman of the Foundation Board (left) at the day of the faculty on July 7th.

Fig. 57: Foto: von links: Mario Gramm, Marlies Prahtel, Mohammed Al-Azzawi und Michael Mall am Tag der Fakultät bei der Stipendienverleihung (Foto: Andreas Herddergott)

Teaching

The Chair of Urban Water Systems Engineering offers a wide range of different courses for the Bachelor study program *Umweltingenieurwesen* and *Bauingenieurwesen* as well as for the Master programs *Environmental Engineering*, *Civil Engineering*, *Environmental Planning and Engineering* and *Sustainable Resource Management*. The emphasis of these courses is placed on water chemistry, advanced water treatment, energy recovery from wastewater, water recycling as well as conceptual design for sustainable water supply and wastewater disposal systems for urban areas. In 2016, the following lectures have been offered:

Summer Term

- Advanced Water Treatment Engineering and Reuse: Drewes, Jörg
- Anaerobtechnik und Energierückgewinnung: Koch, Konrad
- Brauchwasser: Glas, Karl
- Exkursion Kanalisation: Weißbach, Maximilian; Helmreich, Brigitte
- Hydrochemistry Laboratory: Helmreich, Brigitte; ; Heim, Carolin; Hübner, Uwe
- Industrial Wastewater Treatment and Reuse: Helmreich, Brigitte
- Modelling of aquatic systems: Koch, Konrad
- PhD Seminar SiWaWi: Drewes, Jörg, Koch, Konrad
- Projektkurs Siedlungswasserwirtschaft: Drewes, Jörg
- Process Simulation and Design of Wastewater Treatment Plants: Becker, Jennifer
- Thermodynamik und Energietechnik Übung: Hübner, Uwe
- Thermodynamik und Energietechnik: Hübner, Uwe
- Umweltanalytik: Letzel, Thomas
- Umweltrecht: Spieler, Martin
- Urban Climate - Anwendungen: Katzschner, Lutz
- Waste Water Treatment: Koch, Konrad

Winter Term

- Engineered Natural Treatment Systems: Hübner, Uwe
- Fundamentals of Urban Climate: Katzschner Lutz
- Gewässerschutz: Gschlößl, Tanja
- Ökologie und Mikrobiologie: Herzog, Bastian
- Grundlagen Verfahrenstechnik: Böhm, Bernhard; Koch, Konrad
- Hydrochemistry: Helmreich, Brigitte
- Hydrochemistry Laboratory: Heim, Carolin; Helmreich, Brigitte; Hübner, Uwe
- PhD Seminar Siedlungswasserwirtschaft: Koch, Konrad; Drewes, Jörg
- Planung und Betrieb von Kläranlagen: Böhm, Bernhard; Steger, Martin
- Planungs- und Genehmigungsverfahren nach deutschem und europäischem Wasserrecht: Spieler, Martin
- Practical Aspects of Engineered Natural Treatment Systems: Hübner, Uwe
- Siedlungswasserwirtschaft Grundmodul: Helmreich, Brigitte; Koch, Konrad
- Technical Communication Skills in Water and Wastewater Treatment: Drewes, Jörg; Koch, Konrad
- Water and Wastewater Treatment Engineering: Drewes, Jörg

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Friends of the Chair

The Development Fund of the Chair of Urban Water Systems Engineering e.V. at TUM is a non-profit organization to support research and teaching at the chair.

Membership is open to anyone who supports the goals of the foundation. Funds of the foundation are used to:

- Provide seed grants for research efforts
- Supplement to cover printing costs of scientific reports/publications
- Publish the book series “Reports of Urban Water Systems Engineering”
- Support teaching funds
- Support travel fellowships for doctoral candidates and graduate students
- Partially support of research infrastructure
- Facilitate scientific meetings and workshops in the area of water treatment and wastewater treatment and reclamation

We publish our annual report **forum** to keep our members informed regarding activities at the Chair of Urban Water Systems Engineering.

In order to fulfill these tasks, we depend on donations. Thus, we welcome financial and in-kind contributions. We do not charge a membership fee.

Donations can be transferred electronically to the following account at the Postbank München (IBAN: DE04 7001 0080 0034 9498 02, BIC: PBNKDEFF). All donations are tax deductible.

The office of the Development Fund is led by Raphaela Hoffmann.

Employees

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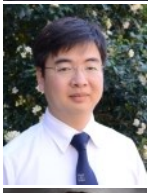

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