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Explorative analysis of thirteen years of radar rainfall data

Thomassen, Emma Dybro; Sørup, Hjalte Jomo Danielsen; Scheibel, Marc; Einfalt, Thomas; Arnbjerg-Nielsen, Karsten

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Danish Water Forum Annual Water Conference,
30 January 2018

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	Session 1. Research and commercialization, Chair Hans-Martin Friis Møller, Kalundborg Forsyning
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Creating spin-outs and doing research in the tension field between the research world, the commercial world, and the funding agencies

Esben Auken and Anders Vest Christiansen**, Department of Geoscience, Aarhus University*

Abstract

In the later years, significant focus has been placed on spin-outs and commercialization of research from the universities. Working in this tension field between high-level research and commercialization can be difficult and to be successful many barriers at the universities and in the commercial world has to be crossed, while balancing expectations from both worlds.

Our background is a large research group working with geophysical methods for high-resolution characterization of the shallow subsurface where most of the human activities take place. Like CRT scanners provide insight into the hidden parts of the human body in the medical world we provide electromagnetic scans of the hidden underground. This information is used in different areas like farming, construction, water exploration etc. We are in many ways very successful and run a research group of about 20 people all driven by various sources of external funding.

In this presentation, we discuss barriers between the research world, the commercial world and the expectations from the funding agencies. This is based on experience from a number of large national as well as international research projects. We have also created several spin-out companies from the research group, a process which is much more difficult than often communicated from the political system.

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How to stimulate entrepreneurship and combine public research with commercialization

Henrik Tækker Madsen[a,b]

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Abstract

Entrepreneurs play an essential role in the modern economy. To the Austrian economist Joseph Schumpeter, they are the heroes of the economy since they drive the wheels of the economy by engaging in cycles of creative destruction; disruption as we call it today. A vital part of stimulating an entrepreneurial environment is the universities as they are a driver for knowledge generation and development. However, there is a big difference between having an interesting idea as a researcher at a university and commercialising it, and the question is how we close this gap.

One example that can be used as a case study, is the company SaltPower, where we design and develop systems that generate electricity based on osmotic gradients. SaltPower is a young company, which was officially founded in 2017, but which we have been working on since late 2014. It began as a good idea that sprang out of a relatively diverse environment where different ideas, thoughts and technologies could meet. This idea was then tested theoretically and experimentally at the university as part of a partially industrial funded post doc and then up scaled to a small mobile pilot unit. Over the last two years this unit has been used to investigate the feasibility of the technology, to verify some of the initial financial estimates as well as take out four patents and now SaltPower is constructing a large-scale demonstration unit that will be the last step before a full commercialization.

SaltPower is still in the early stages and it is too soon to say whether or not it will be a success, but even so the company has come a long way and can be used to make a number of observations on what made this possible. The most important of these is probably the collaboration between SaltPower and Aalborg University. Both have gained and been sufficiently flexible to allow an incremental transition from the good idea at research level, to an almost mature commercial technology. In this way, the gap has been bridged in not one large jump, but in a succession of several small ones.

Session 2. Monitoring, new technologies

	Session 2. Monitoring, new technologies. Chair Esben Auken, Aarhus University
VENUE	**GLASSALEN**
13.30	Stream measurements as a basis for emission based nitrogen regulation - investigating the importance of different sampling strategies for the determination of nitrogen transport in streams / Sofie G. W. van't Veen
13.45	Metagenomic analysis to elucidate the metabolic potential of microbial communities in Danish waterworks / Jane Fowler
14.00	Monitoring Riverscapes with Unmanned Airborne Vehicles / Filippo Bandini
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14.30	Cross-borehole time domain induced polarization used for mapping of flowpaths / Thue Bording
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Stream measurements as a basis for emission based nitrogen regulation - investigating the importance of different sampling strategies for the determination of nitrogen transport in streams

Sofie. G. W. van't Veen, AU*, *J. R. Poulsen*, AU**, *B. Kronvang*, AU***

Abstract

This study investigates the importance of the sampling strategy in streams regarding the determination of the yearly nitrogen (N) transport. Today the N transport in streams is calculated based on the concentration of total N in water samples and discharge measurements, which are found according to a sampling strategy that follows the technical guidelines developed from a GUDP project (Poulsen et al., 2016). The calculation of the annual N transport are among other things used to determine the loading of N to coastal waters and the importance of the emissions of N from diffuse (mainly agriculture) and point sources to surface waters. The guidelines state that the number of water samples per year depends on the hydrological regime of the stream, assuming an uncertainty of less than 10% for the calculated annual N transport. The sampling frequency can in practise be less frequent (monthly) in streams having a stable hydrological regime (groundwater fed streams) and higher frequency (fortnightly) in streams having an unstable hydrological regime (tile drained catchments).

Data used for the study is daily total nitrogen concentrations and daily calculated discharge from two streams in 2015 and 2016: Odder å and Saltø å, located in Jutland (regime 1 – most stable) and Zealand (regime type 4 – most unstable). The water samples were taken with an ISCO sampler as a daily composite sample consisting of sub-samples from every three hours. The daily measurements of N concentrations was used to investigate the difference between the calculated yearly nitrogen transport in the two streams by simulating a 7-, 14-, and 30-day sampling strategy using the normally applied linear interpolation method between days with concentration measurements.

Our results show that the number of water samples per year should be 26 for a stream in an unstable hydrological regime, assuming that the uncertainty associated with the annual N transport should be less than 10%. This corresponds to a water sample every fortnight, which is in accordance with the normal guidelines.

However, the results from the stream in the stable regime type 1 (Odder å), shows that the number of water samples per year should be 26 in order to keep the uncertainty below 10% for the year of 2015, but that 52 samples per year was needed for the year of 2016. This is a higher number of water samples than suggested in the technical guideline developed in the GUDP project, which suggest 12 samples per year. Additionally, the result of this analysis shows surprisingly that the uncertainty of determining the annual N transport in smaller streams is highest in the stream having the most stable hydrological regime as compared to the unstable regime type stream.

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Reference: Poulsen J.R., Tornbjerg H., Windolf J., Larsen S.E., Krongvang B., Højberg A.L. 2016; *Vandløbsmålinger som grundlag for emissionsbasseret kvælstofregulering*, Institut for Bioscience, Aarhus Universitet

Metagenomic analysis to elucidate the metabolic potential of microbial communities in Danish waterworks.

Jane Fowler, Alejandro Palomo S., Arda Gülay and Barth F. Smets, DTU Environment*

Rapid sand filtration is a drinking water technology commonly used across Denmark, Europe and around the world, for the removal of ammonia, reduced manganese and iron, methane, hydrogen sulfide and other compounds from groundwater by a combination of physical, chemical and biological processes. Microbially catalyzed processes dominate the oxidative transformations of most contaminants. In the recent years, several studies have reported the microbial composition of different rapid sand filters (RSF) (Gülay *et al.*, 2016; Albers *et al.*, 2015), however, the link between the microbial composition and the removal of the contaminants in these RSF remains poorly understood.

In the presented study, samples from a RSF in a Danish waterworks were collected and subject to shotgun sequencing. Through a metagenomic analysis and a genome recovery approach, 14 near-complete population genomes were reconstructed and functionally annotated (labelled as CG in figure below). These organisms have the genetic capacity to grow on the typical compounds found in the source water. Hence, we identified population genomes with capabilities to oxidize ammonium, nitrite, methane, hydrogen sulfide, iron and manganese as well as to assimilate organic compounds (Figure 1) (Palomo *et al.*, 2016).
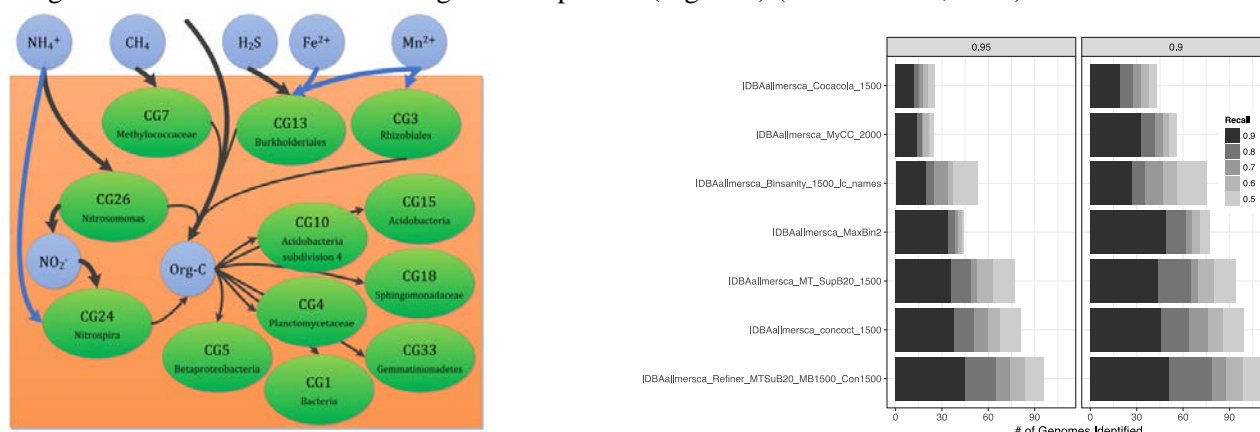
Figure 1. Left) Model of predicted metabolic and geochemical processes facilitating the degradation of groundwater contaminants in rapid gravity sand filters based on metagenomic analysis. Grey arrows denote certain metabolic capability while blue arrows denote putative metabolic capability. Right) Number of recovered genomes with seven different binning methods for a precision of 95% (left panel) and 90% (right panel). Recall denotes the completeness of the recovered genomes.

To obtain a more comprehensive picture of the Danish drinking water treatment microbiome, we collected samples from 12 different waterworks, which were subject to shotgun sequencing. From the metagenomics data set, a 'gene library' catalogue of the Danish drinking water treatment plants was established. In addition, over 100 population genomes were recovered from the metagenomes (Figure 1) and their genetic capabilities were elucidated. With the combination of these analysis, we were able to reconstruct the metabolic networks and identify the potential interactions between the dominant microbial types and the main biotransformation processes occurring in the RSF.

The findings of this study indicate that a better understanding of the ecology of rapid sand filters and could serve as an important resource for an optimal design and operation of these systems.

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Monitoring Riverscapes with Unmanned Airborne Vehicles

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Abstract

To date, hydrometric and ecological monitoring of smaller rivers and streams has relied primarily on in-situ measuring stations and surveys. To a limited extent, aerial surveys from airplanes have been employed and the first UAV-borne solutions are now becoming available.

Riverscapes is a new collaborative project funded by Innovation Fund Denmark under the Grand Solutions scheme. The Riverscapes project aims to develop a new monitoring solution for rivers and streams. The solution will support flood monitoring and management, river maintenance, contaminated sites management and ecological status monitoring as required by the EU Water Framework Directive.

The project will develop a novel payload package for unmanned airborne vehicle platforms delivering the following datasets:

• Water surface elevation in rivers, lakes and floodplains
• Bathymetry (terrain elevation of dry and submerged river bed and surroundings)
• Water surface velocity (full 2D velocity field at the water surface)
• Thermal maps of land and water surfaces
• Narrow-band spectral reflectance of water and land surfaces
• High-resolution digital surface models of the stream environment

This presentation will demonstrate capabilities of the Riverscapes payload package for selected Danish sites and will review monitoring applications and commercial services based on these new data sources.

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A new towed groundbased TEM system for 3D imaging of hydrogeological structures

*Jesper B. Pedersen *, E. Auken, A. V. Christiansen, T. N. Vilhelmsen, and N. Foged, Aarhus University*

Abstract

Most human activities take place in the top 30 meter of the subsurface. Examples are infrastructure development, artificial infiltration and surface water-groundwater interaction. However, hitherto the geophysical methods capable of imaging this zone has limited efficiency when it comes to creating full 3D images.

A new towed geophysical transient electromagnetic system (tTEM) has been developed at Aarhus University. The system is capable of imaging from the surface to a depth of 50 m at a high resolution, both horizontally and depth-wise. In that sense, the tTEM depth resolution bridges the resolution gap from high-resolution, near-surface EM Induction systems and deeper lower resolutions airborne systems. The development has been driven by the fact that geophysical methods capable of imaging this zone has limited efficiency when it comes to creating full 3D images or they do not have sufficient imaging depth. From a hydrological perspective, the data from the tTEM system can reveal structures with high importance for groundwater flow, such as buried valleys, glacial tectonics, local secondary aquifers, hydraulic windows, etc. As the resolution of the geophysical methods increase, it can be recognized that the subsurface is often highly complex (Figure 2). Figure 2 shows 1400 meter profile with a layer sequence including tilting clay layers overlapping sandy sediments, and hydraulic windows connecting the surface to deeper aquifers.

In the presentation we will show a number of case studies recently collected with the tTEM system which focuses on aquifer vulnerability mapping, mapping raw materials, and important hydrogeological structures.
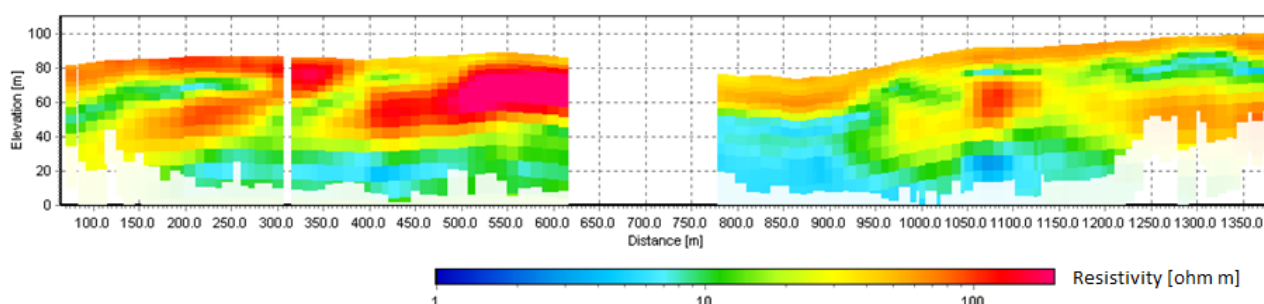
Figure 2: Example of a resistivity profile collected using the newly developed tTEM equipment. Blue and green colors would correspond to clay deposits, and red and orange colors would be sands and gravel. A central part of the data section has been removed due to a road crossing the profile.

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Cross-borehole time domain induced polarization used for mapping of flowpaths

Troels Bording*, A. Christiansen, E. Auken, G. Fiandaca, P.K. Maurya, Aarhus University

Abstract

We present a cross-borehole geophysical technique to accurate imaging of thin, highly permeable layers dominating flow paths in an otherwise low-permeable background.

Contamination spreading through thin permeable layers in the unsaturated zone is a large problem in Denmark and worldwide. In the Capitol Region of Denmark, a large number of smaller and larger sites are contaminated due to various human activities. A large fraction of these sites are in clayey moraines, where the flow of contaminants is predominantly in sand lenses, or thin sandy layers in the unsaturated zone. To determine the flow-paths of contaminants, the geological structures must be described in detail. One approach to achieve this knowledge is by multiple boreholes describing the geology. However, boreholes alone do often not provide the needed resolution to outline the sand lenses accurately.

Cross-borehole time-domain induced polarization (TDIP) is a new tool that allows for mapping not only contrasts in resistivity, but also contrasts in IP parameters, which links to contrasts in hydraulic conductivity/permeability.

We present a feasibility study from a gravel pit close to Roskilde with unheard ground-truth verification, as the entire site was dug out after the investigation.
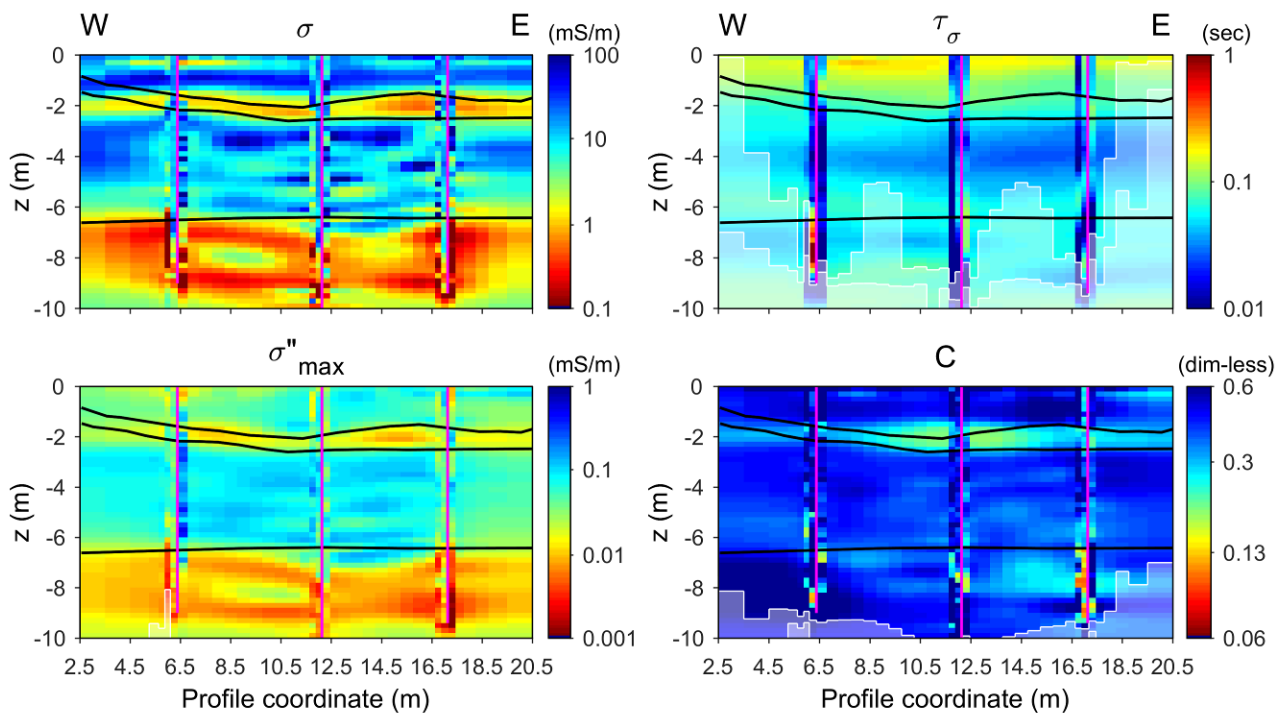
Figure 3: Inversion results from the feasibility study. Black lines show the geological boundaries determined by the

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Diagnostics, Monitoring and Mitigation of N$_2$O Emissions from Wastewater Treatment Operations – Outcomes of the LAGAS project

Malene M. Jensen, *B.F. Smets, DTU*, , DTU, S. Ekström, DTU, A.K. Vansgaard, Krüger, R. Lemaire, VEOLIA, B.G. Plósz, DTU, C. Domingo-Feléz, DTU, Bo Thamdrup, SDU, Chun Ma, SDU, Antonio Delre, DTU, Charlotte Scheutz, DTU, D. Thornberg, BIOFOS*

Abstract

Nitrous oxide (N$_2$O) is a potential ozone depleter and strong greenhouse gas (GHG), with a warming potential ~300 times higher than carbon dioxide (CO$_2$). Anthropogenic N$_2$O emissions - of which 1.2% originate from the wastewater treatment (WWT) sector - is increasing at alarming rates. The goals of the LaGas project were to quantify N$_2$O emissions, and identify and quantify the mechanisms and factors controlling N$_2$O production and emissions from both conventional and recent biological N removal technologies, and to capture this information in novel predictive models with the aim to identify and implement mitigation strategies to control N$_2$O emissions.

With the tracer gas dispersion method, we quantified a plant-integrated GHG emission of five WWT plants (WWTPs), representing different configurations. The emission factors for CH$_4$ ranged between 0.2 to 3.2% of the influent organic carbon, while the N$_2$O emission factor ranged between 0.1 to 5.2% of the total nitrogen, both in the upper range of previous published values. A long-term study of N$_2$O production and emission at reactor-scale was performed at the Lynetten, the largest WWTP in DK. N$_2$O emission factor was 0.8% of the removed nitrogen at the full-scale BioDenipho line at Lynetten. Based on an LCA type evaluation, this corresponds to ~30% of the total carbon footprint of the WWTP. As a result of the intensive measuring campaign at Lynetten, 3 different control strategies to mitigate N$_2$O mitigation were developed and tested. The results were put in LCA context and the most-efficient control strategy reduced the overall CO$_2$ footprint of the plant with 18% compared to normal operation. Incubation-based determination and quantification of N$_2$O production pathways were performed on site with biomass from the BioDenipho reactors at Lynetten, using ^{15}N labelled substrates and ^{18}O-O$_2$. In general, heterotrophic denitrification was insignificant during oxic conditions, while incomplete denitrification became an important N$_2$O contributor under anoxia. Both pathways of ammonia oxidizing bacteria were equally important in oxic incubations with 3 mg/L O$_2$, while low oxygen concentrations favoured N$_2$O production by nitrifier denitrification over hydroxylamine oxidation. The quantitative effect of oxygen as well as other parameters on N$_2$O production pathways was linked to in situ measurements. A mathematical model structure that describes N$_2$O production during biological nitrogen removal was proposed and calibrated. The calibrated model predicts the NO and N$_2$O dynamics at varying ammonium, nitrite and dissolved oxygen levels in two independent systems: (a) an AOB-enriched biomass and (b) activated sludge (AS) mixed liquor biomass. Taken together, the observations and modelling efforts uncover different mitigation strategies to control N$_2$O emissions from biological nitrogen removal processes.

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Session 3. Water treatment

	Session 3. Water treatment / Chair; Hans-Jørgen Albrecthsen, DTU Env.
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15.30	Removal of frequently found pesticides from Danish drinking water using NF/RO membranes. / Mahdi Nikbakht Fini
15.45	Combined membrane and bio-filter purification of pesticide contaminated drinking water / Lea Ellegaard-Jensen
16.00	Methane oxidation and the degradation potential of the herbicide bentazone at Danish waterworks / Mathilde J. Hedegaard
16.15	New biotechnology for pesticide removal at drinking water sand filters / Sanin Musovic
16.30	Removal of persistant ozonation products with moving bed biofilm reactors (MBBR) / Kai Bester
16.45	New innovative Moving Bed Biofilm Reactor (MBBR) concept removes pharmaceutical from municipal wastewater using only biological polishing / Caroline Kragelund Rickers
17.00	The Residuals to Resource project – Water innovation for the Circular Economy from an SME perspective / Maj Munch Andersen

Removal of frequently found pesticides from Danish drinking water using NF/RO membranes

Mahdi Nikbakht Fini[*], *Henrik Tækker Madsen[**], Jens Muff[***], Aalborg University*

The drinking water production in Denmark is almost entirely based on so-called simple treatment (aeration and sand filtration) of groundwater of sufficient quality evaluated by levels of organic and inorganic contaminants such as pesticides, nitrate, and heavy metals. However, the Danish groundwater resources are under pressure and the number of abstraction wells with a concentration of pesticides and their natural transformation products above the 0.1 µg/L threshold value is increasing. Thus, new treatment concepts are required in order to meet the drinking water quality requirements. Membrane filtration using nanofiltration (NF) or reverse osmosis (RO) membranes may play a significant role as a part of a solution ensuring high-quality groundwater based drinking water.

In the present study, two NF membranes (NF99HF (Alfa Laval) and NF270 (DOW FILMTECH)) and two RO membranes (XLE and BW30 (DOW FILMTEC)) were employed for removal of two pesticides frequently found in Danish groundwater: MCPA (2-methyl-4-chlorophenoxyaceticacid, MW: 200.6 g/mol) and MCPP (methylchlorophenoxypropionic acid, MW: 214.7 g/mol) and one pesticide residue BAM (2-6 Dichloro-benzamide, MW: 190 g/mol). Membrane performance was evaluated using Milli-Q water and real groundwater from Varde in Denmark (Hardness: 6.9 °dH, conductivity: 37 mS/m) in order to investigate the influence of the water matrix on the membrane performance in terms of contaminant rejection, adsorption on the membranes and permeate flux.

It was found that only the RO membranes were capable of achieving rejection levels > 90% for all targeted pesticides. Results based on Milli-Q water exhibited that pesticide rejection achieved by the BW30 membrane, ranged approximately from 95% to 97% for BAM, MCPA, and MCPP and XLE ultra low-pressure RO membrane was able to retain 92% to 93% of those pesticides. The NF membranes obtained markedly lower pesticide rejections ranged from 32% to 82%, and within 30% to 79% for NF99HF and NF270, respectively.

The presence of the ionic environment in Varde water led to an increase in all pesticide rejections for all membranes, which could be attributed to membrane pore blocking by the ions, meaning that with regard to a real groundwater matrix, the membrane separation, could be even more effective.

In general, both RO membranes, XLE and BW30, showed promising performance for rejection of the target contaminants. However, regarding the water permeability results (73 l/m2.h for XLE versus 30 l/m2.h for BW30), the XLE membrane was the most suitable membrane for the removal of targeted pesticides from Danish groundwater resources.

This study is an integrated part of a larger project (MEM2BIO) in which a smart combination of membrane separation and biological sand filtration has been proposed to be introduced for drinking water production in Denmark. The residual water stream produced by the membrane process is aimed to be sent to a sand filter hosting specific pesticide-degrading bacteria.

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Combined membrane and bio-filter purification of pesticide contaminated drinking water

Lea Ellegaard-Jensen, *AU-ENVS*, Ole Hylling, AU-ENVS*, Mahdi Nikbakht Fini, AAU**, Jens Muff, AAU**, Henrik Tækker Madsen, AAU***, Jens Aamand, GEUS****, Lars H. Hansen, AU-ENVS**

We here present a novel approach for treatment of pesticide-polluted water. In a two-step system, membrane filtration first separates the water in an ultraclean (80-90% volume) and a residual water stream (10-20% volume), hereby concentrating contaminants, carbon, and minerals in the residual water stream. Secondly, the residual water is fed to a flow-through sand filter inoculated with specific degrader bacteria, who benefit from the concentrated feed.
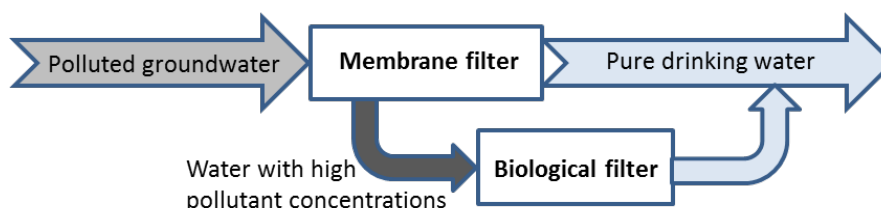
To remove pesticides from contaminated groundwater, the concept of directly adding specific pesticide degrader bacteria to rapid sand filters at waterworks has previously been investigated. However, these tests showed loss of inoculated bacteria and hence degradation activity over time [1, 2]. One of the explanations for this may be the low amount of available organic carbon and other nutrients in the water, which might be insufficient to sustain the bacterial population. We hypothesise that, with our approach, the higher concentration of organic carbon and minerals fed to the bio-filter will prolong the viability of the degrader bacteria in the filter.

We have investigated nanofiltration and reverse osmosis (RO) membranes as potential candidate membranes to perform the concentration and evaluated rejection for three compounds: MCPA (2-methyl-4-chlorophenoxyaceticacid), MCPP (methylchlorophenoxypropionic acid) and BAM (2,6-dichlorobenzamide), using drinking water from three Danish waterworks (Esbjerg, Kolding and Copenhagen). It was found that only the RO membranes were capable of achieving rejection levels > 90% for all targeted pesticides, and the RO membrane XLE was selected for combination with the biofilter.

Performed laboratory experiments with residual water from the membrane filtration showed that degradation of BAM by the degrader bacterium *Aminobacter* sp. MSH1 was enhanced compared to untreated water. The chemical compositions of the membrane-treated water suggest that BAM mineralisation increases with the amount of non-volatile organic carbon and certain micronutrients (e.g. copper) in the water. Research investigating whether membrane residual water enhance degrader population survival and prolong the efficient degradation in flow-through sand filter systems is presently ongoing.

1. Albers, C.N., et al., Degradation of trace concentrations of the persistent groundwater pollutant 2,6-dichlorobenzamide (BAM) in bioaugmented rapid sand filters. Water Research, 2015. 2. Horemans, B., et al., Biocarriers improve bioaugmentation efficiency of a rapid sand filter for the treatment of 2,6-dichlorobenzamide (BAM)-contaminated drinking water. Environmental Science & Technology, 2016.

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Methane oxidation and the degradation potential of the herbicide bentazone at Danish waterworks

Mathilde J. Hedegaard** *, C.O. Lee**, HJ. Albrechtsen, DTU Environment*

In Denmark, pesticides and their metabolites were detected in 49.5% of all groundwater monitoring wells during 1990-2015 (GEUS & Danish Ministry of Energy Utilities and Climate 2016). Pesticides can have adverse impacts on human health, and legal implications. In spite of this, pesticides were detected 87 times above the guideline value in the effluent from Danish waterworks since 2012 (Ministry of Environment and Food of Denmark 2017). It is therefore important to identify sustainable methods to remove pesticides from polluted water sources. Rapid sand filters are used as a widespread technology in drinking water treatment for removal of contaminants such as iron, manganese, methane and ammonium. Even though biological filters are not designed for removal of pesticides, such a biological removal potential has been demonstrated (Hedegaard & Albrechtsen 2014). Since rapid sand filtration is a cheap and sustainable water treatment process, it has been suggested to utilize sand filters for treatment of contaminated groundwater. To take advantage of microbial pesticide degradation in sand filters and to identify associated risks, it is necessary to understand the degradation processes occurring in the filters.

The herbicide bentazone is hard to degrade in aquifers and is thus the second-most frequently detected pesticide in active waterworks wells in Denmark. However, previous studies have demonstrated that bentazone can be degraded by a methanotrophic culture enriched from rapid sand filters at a waterworks receiving methane-rich groundwater (Hedegaard et al. 2018). Methanotrophs are known to perform co-metabolic degradation of some trace contaminants by the key enzyme in the methane oxidation, the methane monooxygenase. In this process the trace contaminant is degraded along with the primary substrate, methane, without being used as carbon or energy source. Thus, the aim of this project was to investigate the microbial bentazone degradation processes in drinking water treatment and the connection with methane oxidation.

Filter sand was collected from waterworks with varying concentration of methane and other water quality parameters, and experiments with ^{14}C-bentazone (approx. 1 µg/L) were carried out in microcosms. Several lines of evidence showed that the biological bentazone removal in filter sand was connected with methane oxidation. For instance, correlated the biological bentazone removal rate in filter sand significantly with the concentration of methane in the raw water of the waterworks. When the methane oxidation in filter sand, was stopped by addition of acetylene, the bentazone removal in filter sand was also halted, which demonstrated a clear connection between the two processes. The bentazone degradation potential was also investigated in microcosms with biomass from the aeration tanks at a waterworks with high concentrations of methane in the groundwater. The biomass degraded bentazone, but only in the presence of methane, showing that methane oxidation was essential for bentazone removal. Additionally, data from the *Jupiter database*, showed that bentazone was detected significantly less frequently in waterworks wells with methane than in wells without methane. This indicated that methanotrophs growing in methane and oxygen counter gradients protected methane-rich groundwater from bentazone contaminations. Thus, using methanotrophs as a treatment technology for bentazone removal, should aim at fitting waterworks without methane in the groundwater.

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New biotechnology for pesticide removal at drinking water sand filters

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Abstract

In Denmark, EU and worldwide, rapid sand filtration is a widespread technology used to produce drinking water from groundwater. A future supply of clean drinking water to consumers is challenged by unfortunate appearance of unnatural substances, pesticides, in groundwater in the majority of EU countries, including Denmark. Natural pesticide-degrading bacteria are revealed in the environment. However, any application of these degraders at the pesticide-polluted sites is challenged due to an extremely low-to-none survival of the introduced bacteria at the application sites.

The aim of current project is to develop an environmentally-friendly biotechnology to deal with the appearance of pesticides in groundwater at RSF sites, which are microbial rich environments. We exploit the existence of pesticide-degrading abilities on mobile genetic elements (MGE[P]), which are ball-like elements frequently exchanged among bacteria in the environment. Introduction of isolated natural pesticide-degrading bacteria with the specific pesticide-degradative gene/s on a ball-like (MGE[P]) element in a sand filter, would ensure transfer of MGE[P] to inherent RSF bacteria and thereby a long-term establishment in RSF, independent of survival or disappearance of introduced bacteria.

The suitability of The Trojan Horse concept was investigated by monitoring the capability of native sand filter bacteria to receive mobile genetic elements. The model MGEs (*IncP* plasmids) were labeled with a green fluorescent gene *(gfp)*, which was only expressed upon transfer to native RSF bacteria, resulting in green fluorescing native bacteria. The model plasmids (MGE) were carried by a laboratory strain *Pseudomonas putida*. The experiments revealed high plasmid-transfer frequencies from *P. putida* to native RSF microbial communities, confirming applicability of the Trojan Horse concept in sand filters. The native bacteria that acquired the introduced model plasmid, sorted by flow cytometry, belonged primarily to the groups of *Alpha-Beta- and Gamma-Proteobacteria.* The selective exposure on native RSF bacteria to single pesticides in long-term enrichment had an evident effect on the structure of microbial communities, increasing the fraction of e.g. *Alpha Proteobacteria* and *Springobacteriia* in the MCPP and glyphosate-containing enrichments, respectively.
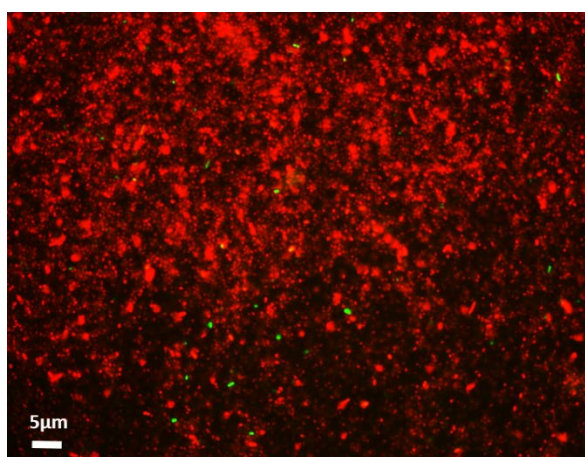
Figure 1. Microscopic visualization of model *IncP* plasmid transfer from a laboratory strain *P. putida* (Red) toward native RSF bacteria (Dark). Upon transfer to native RSF bacteria, the green fluorescent gene *(gfp)* from model plasmid was expressed, allowing visualization of these native RSF bacteria as green fluorescing cells.

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Removal of persistant ozonation products with moving bed biofilm reactors (MBBR)

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Abstract

The major pathway of pharmaceuticals from urban applications to urban surface waters occurs via wastewater treatment plants. Ozonation is able to remove pharmaceutical from wastewater effluents. However, during that reaction ozonation products are formed. Such Macrolide-N-oxodes and hydroxyl diclofenac or other diclofenac ozonation products. Some of these ozonation products were found to be persistent and have adverse effect on the environment. Moving bed bio reactor (MBBRs) were tested for the removal of the ozonation products of macrolide antibiotics and diclofenac at two different concentration levels 1 µg/L and 10 µg/L in laboratory reactors. It was found that the MBBRs are capable of degrading these compounds without back-transformation into the parent compounds. However, reaction rate constants and the degradation kinetics varied for different compounds and different concentrations. Depending on compound and conditions, the degradation reaction kinetics was found to follow either i) zero order ii) first order or iii) lag phase succeeded by first order. Reaction rate constants ranged from 0.07 to 3.7 $*10^{-2}$ h^{-1}. The study has proven that MBBRs have the potential to remove ozonation products as post ozonation polishing treatment.

Erythromycin *N*-oxide
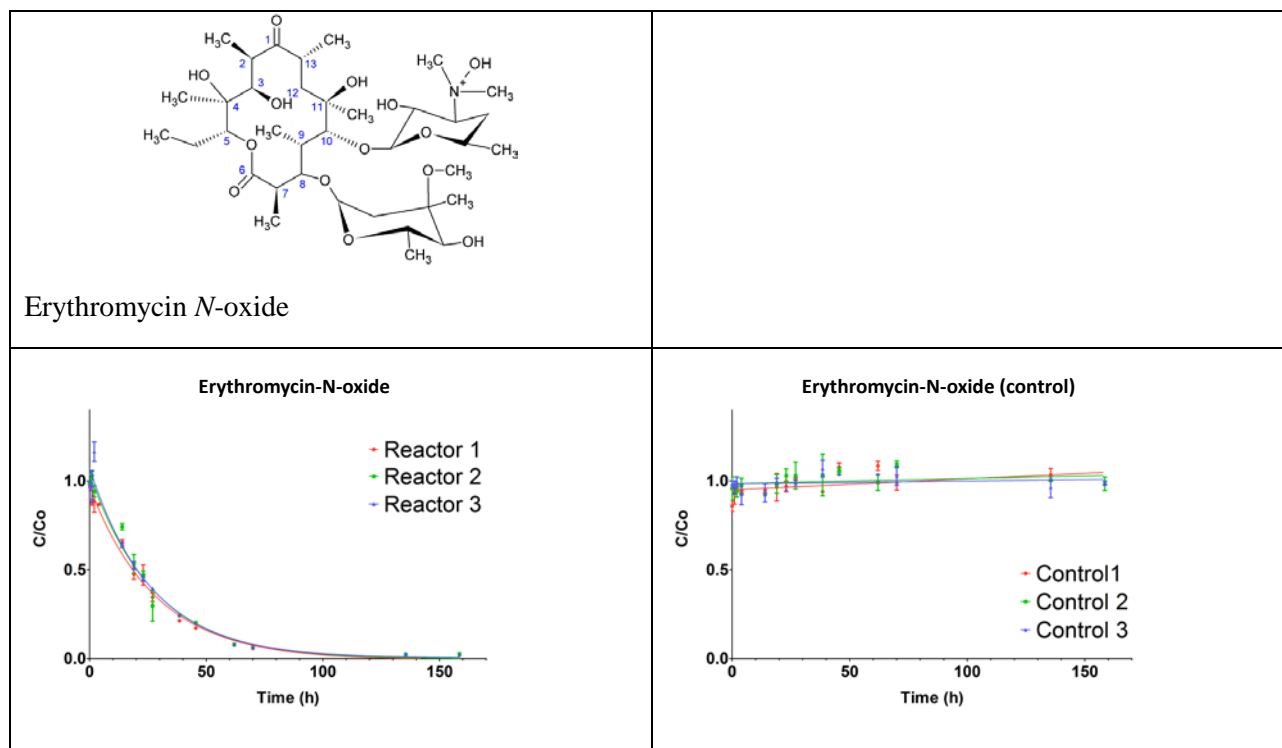
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New innovative Moving Bed Biofilm Reactor (MBBR) concept removes pharmaceutical from municipal wastewater using only biological polishing

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Abstract

As conventional wastewater treatment plants (WWTPs) are not able to remove many refractory organic compounds (i.e. many pharmaceuticals), these compounds are detected in effluents, causing damage to aquatic ecosystems.

Moving bed biofilm reactor (MBBR) is an approach focusing on nitrogen removal. MBBR consists of a tank filled with freely moving plastic carriers with an attached biofilm. These carriers enable the presence of slow-growing bacteria, which would otherwise be washed out with the effluent. Previous studies have demonstrated that MBBR is significantly better at removing/reducing pharmaceuticals than activated sludge.

In this study, a two-stage MBBR treatment train was used to treat the WWTP effluent for pharmaceuticals. The biofilm would have little organic matter to sustain growth of attached biofilm. To increase the amount of biomass, the two-stage MBBR treatment train was intermittently being fed with inlet wastewater, which contains more organic matter (Patent 1650321).

In the first MBBR stage and across the entire system, the NH_4-N was removed by 89 % and 99 %, respectively. The overall removal of DOC was only 6% across the entire system, suggesting that the DOC consisted of highly recalcitrant compounds.

The performance of the two-stage MBBR treatment train had an extremely effective biofilm for pharmaceutical degradation. For the majority of pharmaceuticals, removals were enhanced through intermittent feeding to the reactors in the two-stage MBBR treatment train. Pharmaceuticals breakdown rate constants, normalized with respect to biomass, were significantly higher compared to other studies on activated sludge and suspended biofilm, especially for diclofenac, metoprolol and atenolol. The effect of increasing of HRT on removal of pharmaceuticals was compound specific.

The predicted removal was calculated based on obtained rate constants for pharmaceuticals for each position. A comparison of predicted removal and actual removal at HRT=1 and HRT= 4 h, see Fig. 1.
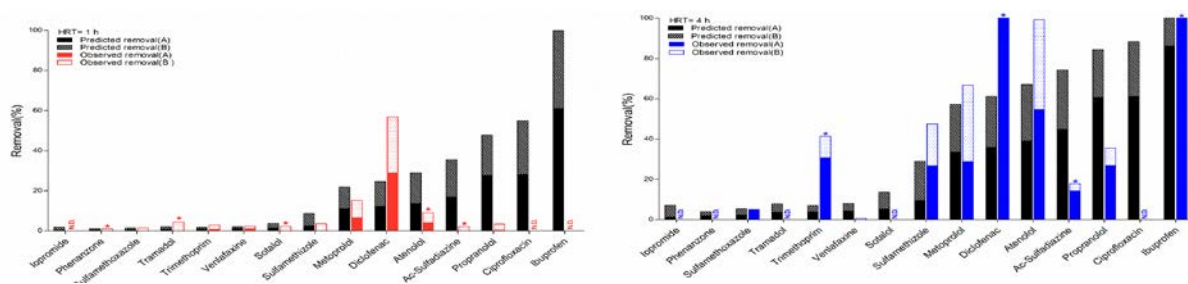
Fig. 1. Predicted and observed removal in the two-stage MBBR treatment train at HRT= 1 h and 4 h.

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The Residuals to Resource project – Water innovation for the Circular Economy from an SME perspective

Maj Munch Andersen*, *DTU Management*

The EU Regional fund project Residual to Resource (Rest til resource) runs from 2016-2018 and is nearing its end. The project has investigated and promoted green and circular business development in Danish SMEs. Project leader is Danish Symbiosis Center with DTU Management as the main analytical partner.
A core aspect of the project has been the development of a circular company screening tool, a task DTU has been responsible for. In considering circular economy potentials we include both water, solid materials, and energy and the trade-off between resource efficiency, internal recycling and symbiotic recycling, see figure 1 below.

Figure 1. The circular screening tool and main project outputs
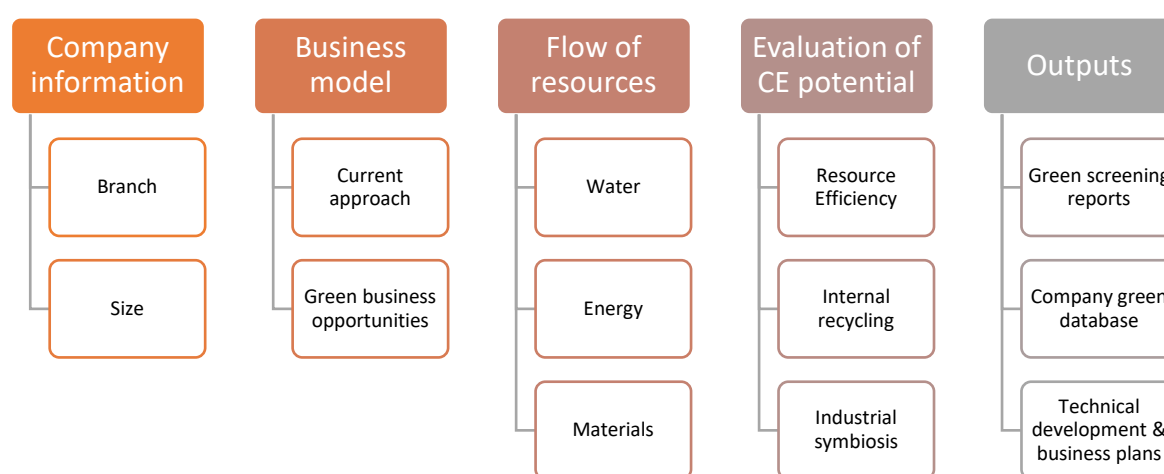
The Circular Economy is also very much about water but this is little recognized among policy makers and generally outside water experts/networks. On the other hand, within water experts/water research circular water innovation is often addressed very narrowly, usually ex-post waste water treatment and usually only looking at water and neglecting related material and energy circular resource flows.

Danish SMEs are not that far in their greening but are, or can easily be motivated into, interested in engaging in green strategizing and innovation. We have identified many potential 'low-hanging fruits' for circular water innovations among the 100 Danish SMEs investigated, particular overlooked in the area of industrial symbiosis.

There is a great need to analyze critically how best to organize circular water innovations (intra-firm, interfirm, firm-utility) and seeing these in relation to related material and energy eco-innovations to achieve the best green business case for the SMEs and hence incentives for continued eco-innovation. Overall, the technical and business potentials for circular water innovations as well as their institutional framework and governance conditions are currently insufficiently analyzed and addressed among Danish companies.

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Session 4. Utilities - processes, emissions and mitigation

	Session 4. Utilities - processes, emissions and mitigation, Chair Ole Mark, DHI
VENUE	**ROOM S01**
10.45	Use of Forward Osmosis to Harvest Methane Oxidizing Bacteria Producing Single Cell Protein / Borja Valverde-Pérez
11.00	Experiences Mitigating Nitrous Oxide Emissions from a Full-Scale Sidestream Deammonification reactor / Nerea Uri Carreño
11.15	Where does N2O from Partial Nitritation-Anammox processes come from? / Jan-Michael Blum
11.30	Model-based optimization of the energy recovery in an industrial wastewater treatment plant / Hannah Feldman
11.45	Evaluating energy recovery potential in Murcia's water supply system / Antonio Vigueras-Rodríguez
12.00	Optimizing the benefits from drinking water softening by better calculating the calcium carbonate precipitation potential - CCPP. / Camilla Tang
12.15	Measuring the effects of central softening of drinking water in households and industries in Brøndby. / Berit Godskesen
12.30	**LUNCH BREAK / Posters**

Use of Forward Osmosis to Harvest Methane Oxidizing Bacteria Producing Single Cell Protein

Borja Valverde-Pérez[1] ?? Mathias L. Pape[1], *, Carina Schneider[1], Astrid F. Kjeldgaard[1], August A. Zachariae[1], Claus Hélix-Nielsen[1,2,] Agata Zarebska[1], Barth F. Smets[1]

Abstract

Upcycling reactive nitrogen from nutrient rich waste streams, like effluents from anaerobic digestion, to single cell protein (SCP) has the potential to reduce the anthropogenic impact on the global nitrogen-cycle as well as provide a much needed alternative source of high-quality protein. Production of SCP would have a significantly lower energy consumption and environmental footprint than traditional protein production. However, harvesting of microbial biomass is usually a cost-intensive process that may compromise the feasibility of the concept. In this study we evaluated the use of forward osmosis filtration for biomass harvesting. Forward osmosis (FO) experiments were carried out using Aquaporin-based biomimetic thin film composite flat sheet membranes to characterize its performance in terms of water flux and rejection of both draw solutes and ammonium from cultivation media. FO experiments were conducted using feed solutions of deionized water and a methanotrophic culture growing in synthetic medium and draw solutions consisting of NaCl, $MgCl_2$, synthetic brine or glycerol at both 30 and 60 atm osmotic pressure. Water fluxes were good at 8-15 L m^{-2} h^{-1}. Ammonium rejection was varied significantly with different draw solutions. Strikingly, NaCl greatly reduced ammonium rejection, potentially due to cation exchange through the membrane. Overall, $MgCl_2$ and glycerol were the best draw solutions – based on both high water flux and high ammonium rejection, without significantly interfering with bacterial growth. However, long term salt accumulation can inhibit bacterial growth (at ca. 8 mg L^{-1} $MgCl_2$ growth was severely inhibited) and affect aggregate formation. Biofouling due to methanotrophic biomass growth did not significantly affect water fluxes. Further research is needed to assess long term operation.
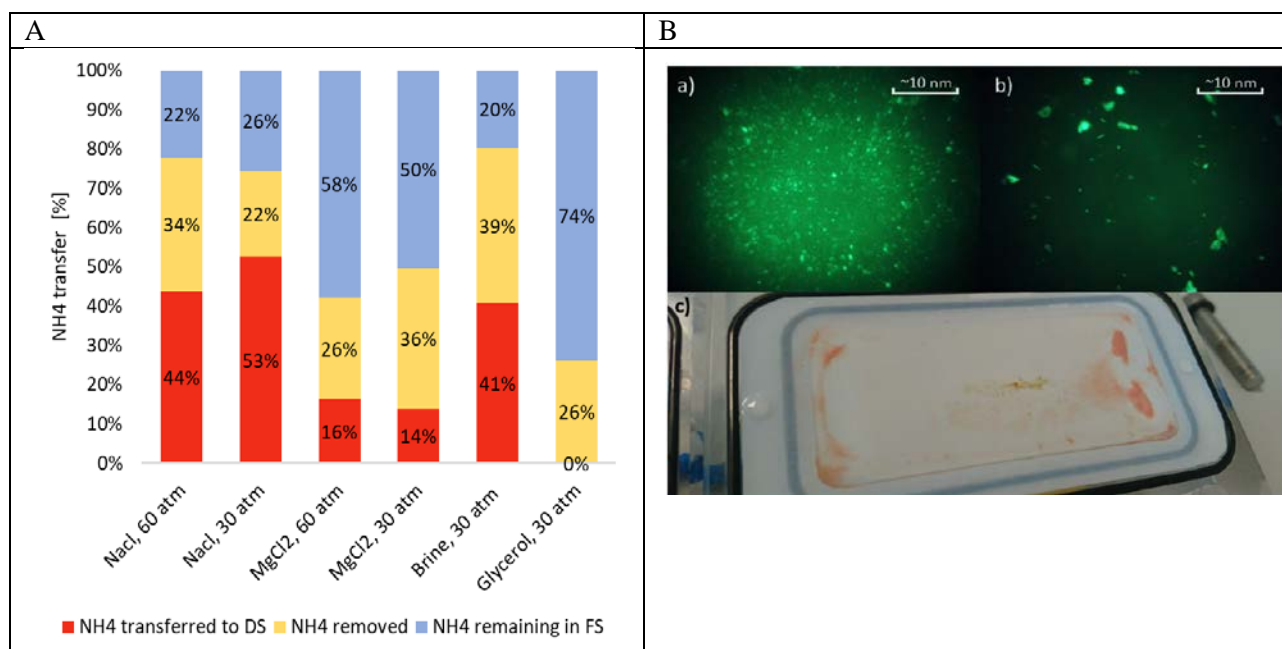
Figure 1. a) Fate of ammonium during the filtration experiments; b) analysis of the biofouling layer on the membrane, showing total bacteria and polysaccharide deposits.

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Experiences Mitigating Nitrous Oxide Emissions from a Full-Scale Sidestream Deammonification reactor

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Abstract

Nitrous oxide emissions from sidestream deammonification reactors can pose a threat to utilities aiming to achieve carbon neutrality. Energy efficient nitrogen removal of digested supernatants using autotrophic process is well established at municipal wastewater treatment plants. Autotrophic processes based on anaerobic anammox granules provide benefits to facilities to the goal of becoming net energy positive as they require less aeration, produce lower amounts of sludge, and require less organic carbon than conventional nitrification-denitrification processes. However, the processes have shown to produce larger amounts of nitrous oxide compared to conventional nitrification-denitrification.

The Ejby Mølle WWTP, in Odense, Denmark, has been monitoring nitrous oxide emissions since the sidestream reactors started operations in 2014 and big efforts have been made in order to better understand the driving forces behind nitrous oxide emissions under different dynamic operational conditions.

Initital monitoring data of nitrous oxide (N_2O) emission showed that +5% of the influent ammonia was released as N_2O to the atmosphere. Based on extensive monitoring data of N_2O emissions under very different operational conditions, an anammox GHG model was calibrated and used for the optimal full-scale implementation of climate neutral partial nitritation-deammonification control strategies. A number of different non-conventional control strategies have been tested with noticeable emission reductions. Changing from an intermittent aeration to continuous aeration has resulted in a drastic drop in nitrous oxide emissions compared to the control reactor.

Table 1. Summary of performance and nitrous oxide emissions data from one of the tests.

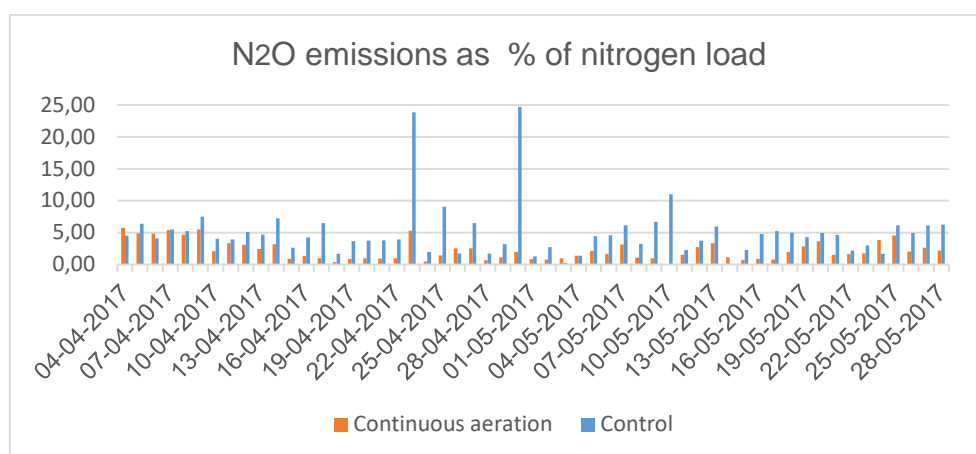|	Load	Ammonia-N removal	Energy use	N_2O emissions
	kg NH_4-N /m^3/day	%	kWh /kg NH_4-N	% -N load
Control reactor	0,5	92,6	1,7	5
Continuous aeration	0,6	91,8	1,4	2,2
	20%	-1%	-18%	**-56%**

Figure 1. Nitrous oxide emissions as percentage of the nitrogen load during the first two months of testing.

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Abstract

The Partial Nitritation-Anammox process has advantages over conventional technologies for the removal of ammonium from wastewater streams. The process convinces particularly due to substantially reduced energy costs for aeration and no need for the addition of external carbon sources. However, its positive footprint is threatened by emission of nitrous oxide (N$_2$O). N$_2$O is a strong greenhouse gas and depletes ozone in the atmosphere. Due to its large global warming potential, low amounts of N$_2$O emitted can already determine the carbon footprint of the process and off-set any environmental benefits.
In the present study, the temporal dynamics of N$_2$O production and emission of a lab-scale Partial Nitritation-Anammox reactor were monitored at high temporal resolution. Due to the application of different aeration regimes and operational conditions, we identified and quantified the main phases of N$_2$O production and emission and were able to correlate N$_2$O production to relevant process parameters.

Essentially all N$_2$O is emitted during aerated phases. However, only approx. 80% of N$_2$O is also produced under oxic conditions. The remaining N$_2$O is produced during phases of anoxia and, subsequently, stripped to the gas phase upon onset of aeration. Oxic N$_2$O production correlates with the ammonia removal rate and points towards aerobic ammonia oxidizing bacteria as main contributors of N$_2$O production in Partial Nitritation-Anammox systems. Notably, the correlation of oxic N$_2$O production and ammonia removal rate displays two distinct linear correlations: at specific ammonia removal rates < 5 mg NH$_4^+$-N*L^{-1}*h^{-1} the specific N$_2$O production rate was 9 times lower, compared to higher ammonia removal rates. Anoxic N$_2$O production correlates with the NO$_2^-$ concentration at the onset of non-aerated phases and points towards the nitrifier denitrification pathway as the main production route of N$_2$O under anoxic conditions.

The findings of the study imply a revision of the concept of high rate ammonium removal processes in wastewater treatment, as high turnover of biological systems may foster non-ideal flux through metabolic pathways. The accumulation of undesired intermediates like N$_2$O may be the consequence, thus offsetting intended environmental benefits. However, in the case of Partial Nitritation-Anammox systems, lower N$_2$O production can be achieved at lower specific ammonia removal rates. Reduced NH$_4^+$ loading and aeration rates or operation at high biomass concentrations and the application of intermittent feeding regimes are promising ways to reduce specific ammonia removal rates, thus lowering specific N$_2$O production rates.
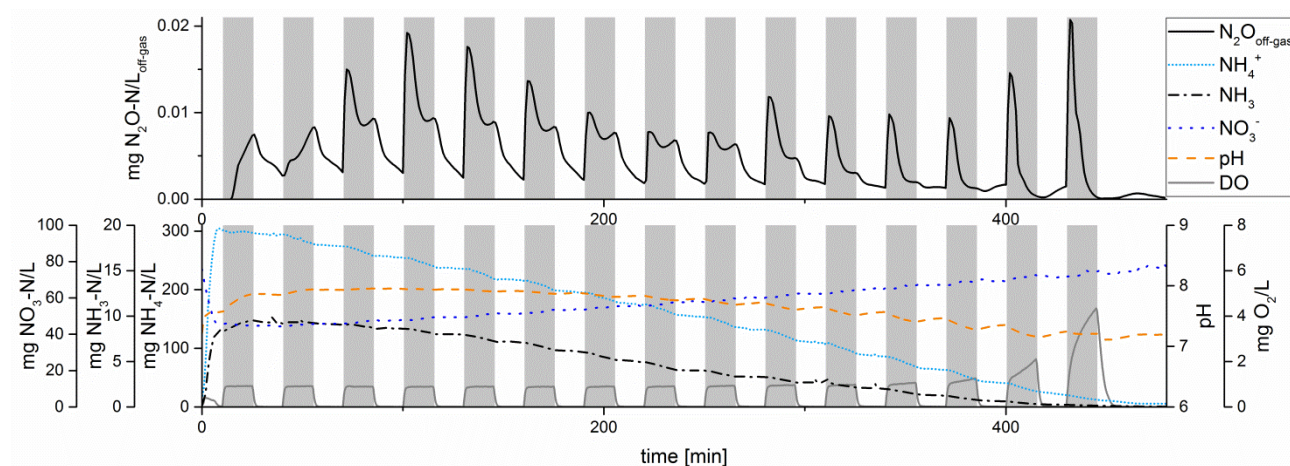
Figure 1 – Reactor performance and N$_2$O emissions during one sequencing batch reactor cycle with intermittent aeration. Concentration profiles of off-gas N$_2$O and bulk NH$_4^+$, NH$_3$, NO$_3^-$, pH and DO (Blum et al., 2018): Blum, J.-M., Jensen, M.M., Smets, B.F., 2018. Nitrous oxide production in intermittently aerated Partial Nitritation-Anammox reactor: oxic N2O production dominates and relates with ammonia removal rate. Chem. Eng. J. 335, 458–466. doi:10.1016/j.cej.2017.10.146

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Model-based optimization of the energy recovery in an industrial wastewater treatment plant

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This study aims to show how mathematical models can be used in (full-scale) industrial wastewater treatment system towards 1) achieving higher reactor conversions, 2) maximizing energy recovery and 3) consequently reducing operation cost and have higher profit. This is done showing two case studies: I) optimization of the reactor conditions (Feldman et al., 2018a) studying the effect reject water in the influent has on the (long-term) reactor performance (Feldman et al., 2018b).

Scenario I: The simulation of pH vs S in the influent. Sulfate and sulfide in the influent to the anaerobic digester is unwanted, due to the competition of sulfate reducing bacteria (SRB) with methanogens (MET), as well as the inhibitory effect of the sulfide already present and produced by SRB. The effect of sulfide inhibition is pH dependent. Simulation results (Figure 1) reveal that the potential S removal (through adsorption and precipitation) in the AD system would not compensate the cost of its treatment (in terms of extra biogas production, Figure 1: point B compared to point A; 3.6 MDKK/year saved vs. a cost of 26.7 MDKK/year). In addition, the model indicates potential reduction in chemicals use (NaOH) without modifying reactor performance when the pH is decreased to 6.8 (point C in Figure 1). The latter will suppose a yearly saving of 6.6 MDKK/year (45 %)

Scenario II: Effect of reject water on reactor performance. The addition of reject water is beneficial on the short term, as the alkaline stream (line is used during sludge stabilization) decreases the need of caustic (83 %) and increases the methane production (~10 %). However, in the long run, the model confirms two potential undesirable aspects. First, the accumulation of precipitates within the granules, decreases MET activity and consequently energy recovery (Figure 2). This is mainly due to the space occupied within the biofilm by inorganic precipitates, which compete with bacteria. As a consequence, VFAs increase and CH_4 decreases. This could lead to granule de-activation and the need to re-fill the reactor with new biomass, supposing a big financial loss. Secondly, $CaCO_3$ precipitation decreases the buffer capacity, which makes the pH controller more unstable (= more use of chemicals).
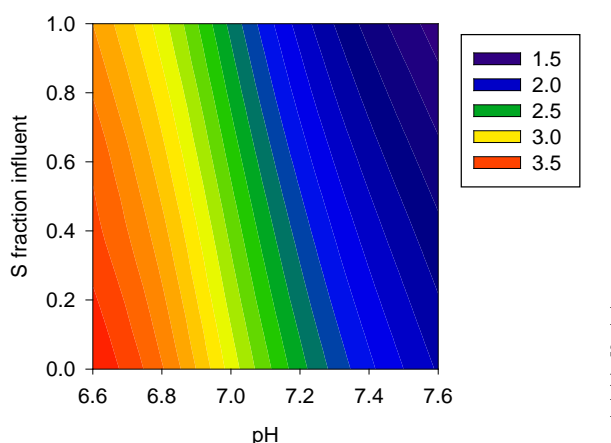
Figure 1: Influence of changing the pH vs. S (sulfate + sulfide) fraction in the influent on the reactor performance index (RPI) in M€/year. Point A = default conditions; point B = influent S is removed; point C = pH decrease to 6.8.
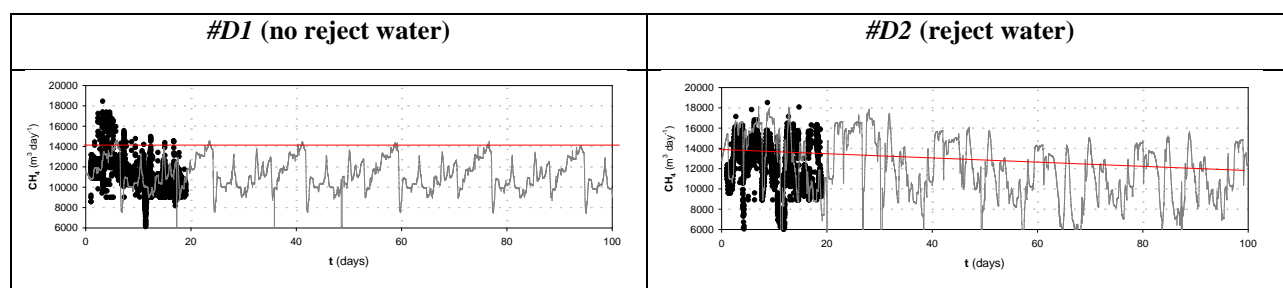
Figure 2: Effect of adding reject water to the influent (right plot) on the methane production on the long-term compared to no reject water addition (left plot)

Feldman H. et al., 2018a. *Biotechnology and Bioengineering*. Submitted.
Feldman H. et al. 2018b. *IWA Biofilms: Granular sludge conference*. Delft, The Netherlands, 18-21 March 2018.

Evaluating energy recovery potential in Murcia's water supply system

Antonio Vigueras-Rodríguez , *D. Nowicz, J.T. García, L. Castillo, UPCT* ,*
D. Martínez-Solano, S. Nevado, EMUASA **

Abstract

Murcia is the 7th most populated city in Spain. Its water supply system is extensively monitored through a large number of pressure gauges and flow meters. Murcia's water supply network is fed from distribution reservoirs at enough elevation to avoid needing pumping stations for most of the city districts. Hydraulic resources have been evaluated throughout the water supply system. Besides the pressure reducing valves, where the assessment is quite straight forward [1], District Metered Areas (DMA) inlets have been evaluated. In these areas despite the hydraulic resources are not as great as in pressure reducing valves locations, their location is quite convenient. Actually, these positions are located inside the city, therefore making easy to use the produced energy in municipal self consumption or to provide facilities to the citizens.

In order to perform such evaluation, a detailed model of the water supply network has been implemented in EPANET parting from a GIS model. The first step of the evaluation has consisted in the optimizing and validation of the model. Initially, the model was reviewed by comparing pressure and flow rate measurements in the main pipes. Then, an extensive experimental campaign was designed. In that campaign valves were switched so that each day a set of District Metered Areas (DMA) have just one metered inlet or at the most a very short number of metered inlets, whereas having a set of pressure measurements within the DMA. The obtained data was used to minimize errors in pressure time series, optimising roughness of the main pipes through Levenberg/Marquardt BFGS algorithm using EPANET ToolKit through Epanet-Octave [2]. Important roughness proposed changes tended to be located surrounding particular points, where errors in the GIS were located (mainly wrong diameter assignement). After patching all the errors the algorithm eased to localise, model errors were mostly below measures uncertainty, and therefore, the model was considered validated.

Then, the hydraulic potential at the DMAs inlets has been evaluated by tracking the "instantaneous" minimum pressure and head within each DMA, as well as the flow rate entering the DMA. So that, the maximum head and the range of flow rates is established for the turbine.

At the moment, once that all of these potentials have been assessed, a turbine prototype is being designed.

Figure 4: At the left of the figure the optimal roughness of the main pipes within a DMA corresponding to the first step of validation is shown. At the top on the right of the figure the instantaneous minimal pressure in a DMA is represented showing the ID of the corresponding node, whereas at the bottom the flow rate entering the DMA is shown.

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Optimizing the benefits from drinking water softening by better calculating the calcium carbonate precipitation potential - CCPP

Caroline Tang, DTU* & NIRAS**, L. Lopato, HOFOR***, C.W.A.M. Merks, Witteveen+Bos****, H.-J. Albrechtsen, DTU*

Abstract

Lime scaling e.g. in kettles and on heating elements increases the use of detergents and descaling agents, and shortens the lifespan of household appliances. Centralised drinking water softening is implemented to mitigate these negative effects. However, too much reduction of the water hardness may lead to water that is lime dissolving and corrosive towards piping material. The scaling tendency of water can be evaluated by the water hardness, which is calculated based on the concentrations of calcium and magnesium and expressed in e.g. German hardness degrees (°dH), or the saturation index calculated from the concentrations of calcium and carbonate. Nevertheless, none of these parameters estimate the amount of lime (calcium carbonate) that can precipitate and are hence inadequate when estimating the effects from drinking water softening in terms of lime scaling. The water quality parameter Calcium Carbonate Precipitation Potential (CCPP) has been used in the Netherlands since the 1990's. CCPP is defined as the amount of calcium carbonate that theoretically can precipitate to reach equilibrium (i.e. a saturation index of 0). However, despite its long-term application, several methods for calculating CCPP are applied in practice with only little attention paid to how the different calculation methods affect the final CCPP values and their interpretation. Therefore, this study aimed at settling the current state of the art methods for calculating and interpreting CCPP. We reviewed different calculation methods and compared CCPP values calculated by these methods. The different CCPP calculation methods vary in terms of which ion pairs and saturation constants are included, and for which water temperatures the methods are applicable. Thus, CCPP values calculated with different methods are not directly comparable. The currently most comprehensive method was developed as part of the Stimela modelling environment (de Moel et al., 2013), and includes several ion pairs in addition to the carbonate system and is valid at relevant temperatures up to 100 °C. However, this method cannot be related to current recommended values for CCPP after softening since these are based on another calculation method. Thus, there is a need for establishing new CCPP (limit) guideline values for interpretation. Until then, the current recommendation of reaching a CCPP at 90 °C below 0.6 mmol/L to avoid extensive lime scaling should be used with caution unless CCPP is calculated using the same method. An updated guideline can result in water utilities being able to optimize their softening process by reducing the negative effects from high water hardness as much as possible without the water becoming corrosive, ultimately increasing the socioeconomic and environmental benefits from water softening.

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[1] de Moel, P.J., van der Helm, A.W.C., van Rijn, M., van Dijk, J.C., van der Meer, W.G.J., (2013). Assessment of calculation methods for calcium carbonate saturation in drinking water for DIN 38404-10 compliance. Drink. Water Eng. Sci. 6, 115–124.

Measuring the effects of central softening of drinking water in households and industries in Brøndby

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Abstract

Water softening is expected to markedly reduce environmental impacts and economic costs in parts of Denmark receiving drinking water with hardness levels above 300 mg/L as $CaCO_3$. Danish consumers have expressed a preference for introducing central water softening to avoid removing $CaCO_3$ scaling from household appliances and bathroom surfaces. The effects of water hardness have been quantified in environmental life-cycle assessments and economic cost-benefit analyses that both have shown significant benefits from introducing central water softening in Copenhagen and other hard water areas of Denmark. The studies showed that even though central softening of drinking water entails an increased use of energy, sand, and chemicals at the waterworks, these effects are offset by a decrease in consumption of energy, chemical agents and laundry detergents at the end users as well as a prolonged service life of household appliances heating water. . Based on these findings, Greater Copenhagen Water Utility decided to introduce central softening at their waterworks in Brøndby September 2017. Although the life-cycle (Godskesen et al., 2012) and cost-benefit assessments (Naturstyrelsen, 2011) results are very robust in favor of softening, there is still marked uncertainty related to the actual effects to be achieved in households and industries.

Our project seeks to quantify expected effects through observations and measurements at household and industrial level carried out before *and* after the introduction of softened water in Brøndby, thereby validating the findings of the previous studies.

For two industrial sites we are measuring scaling and heat losses of their water heating systems to quantify the operation and heat transfer efficiency of the systems. In 30 households the consumption of laundry detergent, cleaning and descaling agents, dishwasher salt and scaling in water kettles is observed. All measurements are carried out in identical campaigns of three to six months before and after the introduction of central softening. As expected the measurements completed before the introduction of softening confirms a marked build-up of scaling in the water heaters and heat exchangers that affects the heat transfer efficiency negatively (Fig. 1).

At the conference we would like to present the results from the period with hard water and the preliminary results from the period with softened water.
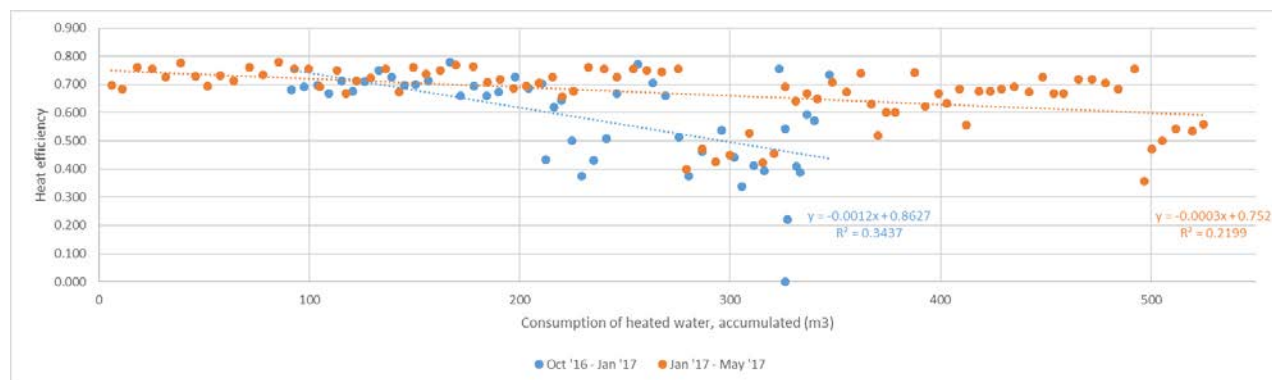
Figure 5. Development of heat efficiency as a function of consumption of heated water in an industry in Brøndby in the period with very hard water.
The project will also cover the experienced convenience when going from hard to soft drinking water.

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Godskesen B., Hauschild M. Z., Rygaard M., Zambrano K. C. & Albrechtsen H. J. (2012). Life cycle assessment of central softening of very hard drinking water. *Journal of environmental management.* **105**, 83-89. Naturstyrelsen, 2011. Central blødgøring af drikkevand. ISBN-nr: 978-87-7279-030-5.

Session 5. Stormwater, flooding, forecasting and climate adaption

	Session 5. Stormwater, flooding, forecasting and climate adaption. Chair Anders Refsgaard, COWI
VENUE	**ROOM S01**
13.30	Script based groundwater modelling for increased model flexibility and improved analysis / Troels.N. Vilhelmsen
13.45	A Typology for Climate Change Adaptation: Event Magnitudes, Spatial Scale and Goals. / Herle M. Madsen
14.00	Explorative analysis of thirteen years of radar rainfall data. / Emma D. Thomassen
14.15	Assessing spatial correlations of sea surges around Copenhagen / Stylianos Georgiadis
14.30	Combining seasonal forecasting of meteorology and hydrology – case studies / Mike Butts
14.45	Safe recreational lake water / Michelle L. Rebsdorf
15.00	**Coffee break / Posters**

Script based groundwater modelling for increased model flexibility and improved analysis

Troels N. Vilhelmsen[1], S. Christensen[2], R.R. Frederiksen[3], M. Fienen[4], A.T. Leaf[5], E. Auken[6]

Recently, script-based methods to setup, run and post-process groundwater models have been developed to support MODFLOW and related USGS modelling programs (Bakker et al., 2016). Script-based modeling can improve efficiency, quality and repeatability in the development and analysis of hydrological models. In the rOpen project we seek to expand and modify the framework developed by Bakker et al. (2016), such that it can be used for high-resolution analysis of nitrate leaching from agricultural areas in Denmark. However, to make such analyses cost efficient on large (e.g. national) scale requires development of new modeling methods.

In this presentation we will show how Danish data sources such as Jupiter and Gerda databases (Møller et al., 2009), high resolution digital elevation models (DEM), DMI climate, data and GIS information on land use, streams, and catchment areas can be used in this framework to develop groundwater models. The geophysical and lithological data will mainly be utilized for setting up the subsurface structures. These structures will be defined based on the newly developed tTEM system, which produces high-resolution resistivity models of the subsurface. The DEM will be used to define layer elevations, flow directions, and streamflow networks. Recharge estimates will be determined using the Daisy root-zone model (Abrahamsen and Hansen, 2000). Existing GIS data will be used to define the model outline, location of additional boundary conditions and specifications of practices and land use on the surface. All of the data sources going into the modeling environment will be independent of the finite difference grid used in the numerical model, to facilitate subsequent modifications to the horizontal numerical resolution or the number of layers in the model. This is simply done by resampling the data sources to a new finite difference grid with a different resolution.

Based on this methodology, general frameworks can be generated for setting up models. Site dependent modifications can then be made to these frameworks to make the setups applicable in other areas. This will allow for faster model development, which can be updated more easily with new data collection.

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A Typology for Climate Change Adaptation: Event Magnitudes, Spatial Scale and Goals

_Herle. M. Madsen__, DTU Environment*, M. M. Andersen, DTU Management**, M. Rygaard, DTU Environment***, P. S. Mikkelsen, DTU Environment****_

In this study, we examine different professional actors' conceptualizations of climate change adaption. The result of our study are an analytical frame that characterizes climate change adaptation according to three features: event magnitude (everyday, design, and extreme), spatial scale (local, urban, and national-international), and (a wide range of) goals. With this study, there is for the first time outlined a broad definition of how climate change adaptation is applied in practice; supported by our empirical work exemplifying for the case of Copenhagen where pluvial flooding is a central climate change problem.

We formulated this analytical framework through a qualitative research design with two interconnected research rounds resulting in a total of 32 semi-structured interviews. Our research design with interconnected rounds strengthens the interpretation and analysis of the qualitative data. Our empirical work show that climate change adaptation in Copenhagen currently are ambiguously defined. The different actors do not agree on what climate adaptation are and their choices of different characterizing features result in different choices of technologies. The actors do not agree on how different event magnitude domains can be defined; however, there is a tendency to prioritizing the extreme domain. The actors focus on strongly on the medium and small scale (urban and local), with only few actors bringing up the larger spatial scale (national/international). The actors apply an impressively varying range of goals. It should however be noted that no goals stand alone, they are always to be considered in the context of other goals, spatial scale and event magnitude. The most frequently goal are cost reduction referencing cost-benefit analyses. The actors apply a large range of technologies, that can be categorized as above- or below-ground solutions; however the technologies are not just focused on stormwater management, rather the encompasses the entire urban water system. Again, with a reference to cost-benefit analyses are above-ground solutions often prioritized. Our data shows a new cognitive paradigm developing, where cost-benefit analysis argue for economic goals and multifunctionality goals in adapting to extreme rain while optimizing on a water catchment scale. However, the new cognitive paradigm is not matched by the current regulation, showing that system change has not happened.

Because of the ambiguous and diffuse definition of climate change adaptation we recommend that discussions of the definition of climate change adaptation are incorporated into all implementation and innovation projects. This is relevant for municipalities and utilities in implementation projects, and in innovation projects it is relevant for knowledge institutions and private companies. We additionally recommend a clear and inclusive definition of climate change adaptation including the attributes event magnitude, spatial scale and goals as important factors are developed in the near future.

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Explorative analysis of thirteen years of radar rainfall data

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T. Einfalt, hydro & meteo***, K. Arnbjerg-Nielsen, DTU Environment*

Abstract

Rainfall is one of the most influential input parameters in urban hydrology, and still it is often modelled with a simple design storm with the same intensity even over large catchments. In this study we examine the rainfall characteristics of convective and front extreme events using radar data (5 minutes, 1x1 km resolution) over an area of 1824 km^2 covering the catchment of the river Wupper, North Rhine-Westphalia, Germany. The focus of the analysis is on describing the complexity of hourly and daily extreme rainfall with the further purpose of identifying suitable characteristics that can later be used in a spatial weather generator suitable for urban hydrology.

Extreme events are sampled by a Peak Over Threshold Method with an average of three events per year of data. Two samples of extremes are analysed: hourly and daily extremes. Four different sampling strategies for sampling extreme events from spatial data are examined; these consider different spatial sampling ranges between 1 grid cell to the entire case area. The sampling strategies are compared with regard to the total number of events, average event length and seasonal distribution of events. The radar data is initially analysed based on the seasonal variation and spatial correlation of extreme events at grid cell level.

The spatiotemporal properties of the extreme events are explained by means of principal component analysis, cluster analysis, and linear models. For each method a set of 16 descriptive variables are used. These describe the properties of each event, e.g. duration, maximum volumes, spatial coverage and heterogeneity, and movement of cells. A simple identification- and tracking algorithm for rain cells based on intensity threshold and fitting of ellipsoids, is developed for the study.

Between 5 and 9 dimensions can be found in data. This somehow gives a rough indication of how many independent variables a weather generator at this scale should employ. Both the principal component analysis and cluster analysis show patterns that can be explained by the physical properties of rainfall. In particular, it seems that the observed differences between hourly and daily extremes can well be described by relatively simple scaling across the set of variables, i.e. only the level of each variable varies significantly, but not the overall structure of the spatial precipitation.

The explorative analysis show that there is ambient potential for making a spatial weather generator for precipitation extremes for urban application.

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Assessing spatial correlations of sea surges around Copenhagen

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Abstract

The location and land morphology of the metropolitan area of Copenhagen makes the city extremely vulnerable for flooding stemming from sea surges. In the period where reliable observation data is available, the latest remarkable and devastating sea surge was recorded in November 1872, with several casualties. Nowadays, a flood similar to the one of November 1872 would have much higher economical, societal and environmental impacts than at that time. From that time on, sea level values causing critical floods have not been exceeded.

Based on historical records, reliable estimates of the frequency and intensity of sea surges have to be established even for the most infrequent and in practice un-observed events. Furthermore, the current protection standards will be insufficient in the near- or long-term future due to expected changes in the mean sea level induced by climate change. In order to provide reliable estimates for the past, a deeper understanding of the sea surges and the risk of flooding they induce to Copenhagen are studied. In our analysis, data from four meteorological stations around Copenhagen (namely Copenhagen Harbour, Drogden Fyr, Hornbæk and Gedser) are treated. The observations for Copenhagen Harbour and Drogden Fyr cover a total period from 1974 to 2015, with sub-hourly data resolution. For Hornbæk and Gedser, hourly data from 1891-2012 are provided.

The cyclical sea-level patterns and the hydrological processes that cause extreme sea levels are investigated. The contribution of tidal cycles and seasonal variations to the sea-level oscillations are validated. Sea surges in the zone around Copenhagen are generated by two fundamentally different and mutually exclusive processes; surges originating from the North and the Baltic Seas respectively. Due to the location of Copenhagen, only parts of the city will be exposed to any one sea surge. The Southern parts of Copenhagen are exposed to storms from the Baltic Sea, while the Northern parts of the city are at risk from sea surges from the North Sea. Furthermore, high sea levels observed in Hornbæk and then in Copenhagen are correlated to low levels in Gedser and Drogden Fyr. These physical characteristics are revealed by the correlations among the various meteorological stations and can be used to give more reliable estimates for the actual flood risk in Copenhagen through use of the longer sea level records from Hornbæk and Gedser. The exposure of Copenhagen to extreme sea level is therefore assessed aiming at a well-founded estimation of the risk of urban flooding due to sea surges.

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Combining seasonal forecasting of meteorology and hydrology – case studies

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Abstract

Seasonal forecasting can affect decision making in many water-related sectors including water supply, hydropower and agriculture as well as flooding. Examples range from long-term contingency planning for floods and droughts, water demands and allocation for irrigation or domestic/industrial water use, energy production forecasting, environmental monitoring and climate adaptation. Hydrological seasonal forecasts over periods of weeks to months are particularly useful for water resources management where future flows depend on storages such as snow accumulation or man-made reservoirs. Typically, these would include reservoir operations for hydropower, irrigation and water supply or natural accumulation of water as snow, ice or groundwater.

While the potential of seasonal forecasting, both in terms of economic benefits and climate change adaptation, is widely recognised, seasonal forecasting has yet to be fully exploited. One reason is the coarse spatial resolution at which seasonal meteorological forecasts are available, while water resources managers or reservoir operators are interested in much finer resolutions. This means effective downscaling procedures are needed for operational forecasting. The second reason is the perception that these forecasts are highly uncertain. This requires methods to quantify the uncertainties in these forecasts and evaluate decisions against this uncertainty. These challenges were addressed as part of the European FP7 project EUPORIAS, (http://www.euporias.eu/). Within EUPORIAS, we have developed a decision support tool for seasonal hydrological forecasting.

In this paper, we use a case study in Spain to illustrate the design and development of this seasonal forecasting tool exploiting the latest generation of climate model-based seasonal forecasts for hydrological forecasting. This first study area, the Urumea catchment, in northern Spain is vulnerable to floods, droughts and water scarcity and the Añarbe reservoir must be operated to fulfil the different requirements for hydropower production and water supply as well as environmental and flood protection. The rainfall exhibits a strong seasonal pattern and large variation in amount from year to year. Previous studies have shown that the North Atlantic Oscillation provides some seasonal predictability in the precipitation over the Iberian Peninsula.

The second case study is located in the Upper Maule Basin in Chile. The Colbun hydropower plant in the Maule Basin in central Chile is one of the country's largest hydropower schemes. The reservoir inflows are affected by both runoff generated directly from precipitation and indirectly through snow accumulation and snowmelt. Some previous studies suggest that ENSO phenomena influence the precipitation patterns. We examine, in this case study, the uncertainty of seasonal forecasts derived by combining seasonal forecasts of both climate and hydrology. Our initial results suggest that while the precipitation forecasts exhibit considerable uncertainty, snow storage, reservoir storage and operation strongly affect the hydrological response and improve the reliability of the seasonal hydrological simulations.

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Safe recreational lake waters

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Abstract

When heavy rain events overload the combined sewer systems, diluted raw sewage potentially overflows to nearby lakes, rivers and seas, and compromise the bathing water quality. In Denmark, traditional solutions to reduce storm water discharges include separation of rainwater and sewage or the establishment of detention ponds. However, this requires large investments and takes a long time to implement, which challenges the increasing demand for fast implementable climate adapting solutions.

Using Lake Skanderborg as a model, this project introduces a novel approach for monitoring, early warning and treatment of storm water discharged from the sewerage system to the lake waters. This unique concept combines several strategies, disciplines and data types:

- A hydraulic drainage model for the catchment area around Lake Skanderborg calibrated by the use of data from local rain gauges and loggers installed in the overflow constructions,
- A complex flow model simulating the distribution of the overflow waters let into the lake, thereby predicting if the bathing water quality at the beaches will be affected. The model is calibrated by the use of GPS trackers in the lake and simulations are based on weather data and input from the drainage model,
- Microbiological source tracking determining the levels of E. Coli and Enterococus in streams and over flow constructions leading to the lake,
- A drone boat developed for efficient and flexible collection of water samples in specific sampling points in the lake.
- Efficient and economical feasible solutions for storm water treatment challenging the traditional solutions used today. Two treatment concepts have been developed, installed and tested as pilot plants at an overflow construction site at Lake Skanderborg: an efficient gravel and plant-based filter solution suitable for near-natural areas and a compact modular treatment plant based on mechanical and chemical treatment steps suitable for overflow constructions with limited space available.

Altogether these activities have led to the development of an efficient multidisciplinary early warning system, which provides a unique service to the bathing guests of Lake Skanderborg: Weather data and output from the drainage model delivers input to the flow model. Furthermore, the microbial data is implemented in the flow model to simulate the potential bacterial contamination at the beaches. Based on these inputs an automatic warning sign by the lake informs the bathing guests about the current bathing water quality and warn if the model predicts that the bathing water quality will potentially be compromised. Also, the operation of the storm water treatment solutions will interact with the warning system.

In total the project provides a state-of-the-art interactive early warning system evaluating upcoming overflow events and their effect on the bathing water quality and at the same time ensuring treatment of the storm water before it enters the recipient.

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Session 6. Water efficiency /Industrial water

	Session 6. Water efficiency /Industrial water. Chair Jørn Rasmussen, DHI
VENUE	**ROOM S01**
15.30	Introduction to the DRIP project; Chair; Jørn Rasmussen, DHI
15.45	Opportunities for increased water efficiency in Danish food processing industry / Martin Andersen
16.00	Industrial cleaning-in-place processes in brewery – a systematic mapping study / Jifang Yang
16.15	Reuse of water in Danish pork slaughterhouses / Karen Sørensen
16.30	Eco-efficiency of introducing water efficiency at the chicken feet processing line at the chicken slaughtering house HK Scan in Vinderup Denmark / Berit Godskesen
16.45	Risk Assessment of natural carcinogenic compounds from Bracken fern plants in surface waters with LC/MS / Vaidotas Kisielius
17.00	Stone wool based filter technology for treatment of rainwater in densely populated urban areas / Dorthe Lybye

Opportunities for increased water efficiency in Danish food processing industry

Martin Andersen and *G.H. Kristensen, IN-Water ApS*

Abstract

The Danish societal partnership DRIP (Danish Partnership for Resource and Water Efficient Industrial Food Production) has now been in operation for more than two years and the first results have started to emerge with activities being developed and solutions demonstrated among leading Danish manufacturers within brewery and beverages, slaughterhouses and meat processing, fish proteins and dairy ingredients.

One of the first activities of the partnership was to carry out a pre-assessment phase to define the baseline of current water management practices and level of water efficiency at the end-users and to formulate ambitious but realistic water efficiency targets for each of the participating end-users through development of preliminary specific scenarios and a catalogue of projects and activities to be pursued throughout the partnership.

The pre-assessment phase has revealed that despite the participating food manufacturers being among the best-in-class with respect to water efficiency practices, still significant opportunities are present to further improve the degree of water efficiency with several opportunities to save not only water but develop integrated solution that will capture water as well as energy and increase the yield of the production.

A total of 8 productions sites among above branches have been undergoing pre-assessment activities - activities that have developed 114 ideas for improved water efficiency. The ideas have since been matured – some have been immediately implemented among the end users, others have been considered not attractive to pursue further. But a significant portfolio of further studies and projects has developed where a match has existed between the interests of the individual end-users and one or more of the participating technology suppliers with the support from knowledge institutions and regulators.

The presentation will cover an overview of the elements in a pre-assessment activity – and give examples across the different branches of the different ideas ranging from simple improvements of existing practices and technologies, over integrated water reuse solutions to large wastewater reclamation and reuse opportunities including management of brines and other reject streams generated.

Industrial cleaning-in-place processes in brewery – a systematic mapping study

Jifang Yang, *K.V. Gernaey, U. Krühne, DTU Chemical Engineering*, P. Rasmussen, A. Kokholm, Carlsberg**,*
M. Nordkvist, Alfa Laval***

Abstract

Cleaning-in-place (CIP) is a common practice in food and pharmaceutical industries for the cleaning of equipment and transfer lines without opening or dismantling the facilities. Most of current CIP operations are based on time, meaning the circulation of detergent and the water rinses are executed for a pre-defined period. Only ionic measurements are taken for assessing the complete removal of detergent compounds, whereas measurement is generally not used to evaluate the removal of soil deposits. Thus, the consumptions in CIP operations are commonly higher than needed to ensure clean equipment. A main concern for industrial customers is therefore how to minimize the cleaning costs without compromising the hygienic quality.

This study presents a mapping of CIP at a leading Danish brewery, Carlsberg Fredericia Brewery. The purpose was to document the overall processes, CIP recipes & equipment, water and energy consumption, cleaning frequency, cleaning costs, and the use of measurements. A series of suggestions are provided based on best practice guidelines to improve the current cleaning regime from an economic point of view. Furthermore, a cost model is built to analyse the contributions of different operation factors to the overall cost, which clearly presents the potential benefits to optimize the CIP procedures.

This research results from the Danish partnership for Resource and water efficient Industrial food Production (DRIP) project. Subsequent projects are proposed to improve the current CIP systems as a result of the pre-study. The general conclusions of the mapping study can also help to reduce cleaning costs in other food industries.
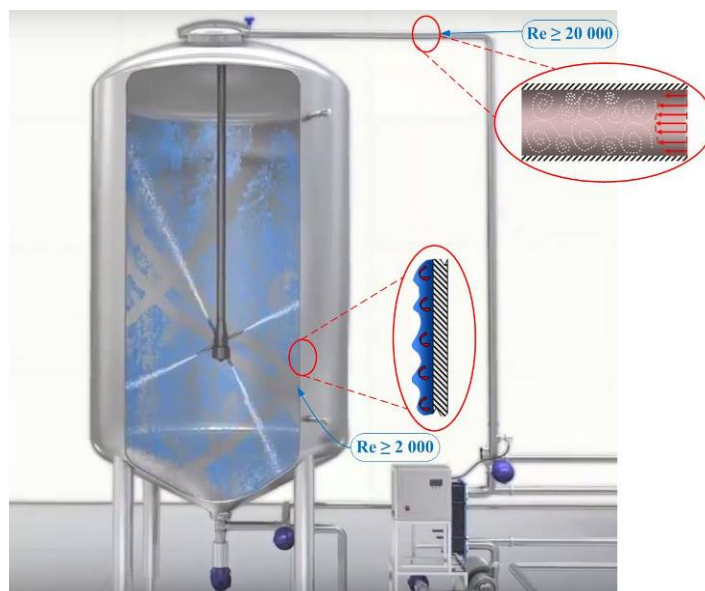
Figure: Example of tank cleaning using a rotary jet head

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Reuse of water in Danish pork slaughterhouses

Karen Sørensen, A. G. Koch, Danish Meat Research Institute*, T.F. Chemnitz & L. Niss, Danish Crown**

Abstract

Danish slaughterhouses have focused on the use of water since the 1990's, resulting in a reduction of the use of tap water per carcass produced with more than 60 %. At the same time, an increase in automated processes, minimizing lifts and monotonous workloads for employees, has created an increased use of water for cleaning mechanical tools and equipment. If the curve of water used per unit produced is to be broken, new methods and initiatives must be applied in an industry very sensitive to risks of food safety.

Slaughterhouse processes are performed in different zones with regards to hygiene, all relating to food safety. Overall, processes take place in either the unclean or the clean area. In the unclean area, the animals are euthanized and put down, followed by a series of processes cleaning the surface of the carcasses. Hereafter the carcasses enter the clean slaughter area, where they are opened, organs are removed, and the carcass is split, before being cooled and sorted for further processing.

In the clean slaughter area, water is used for cleaning and disinfecting tools and equipment after handling individual carcasses, to prevent the transfer of disease between carcasses. This individuality is sustained until each carcass has been veterinary approved for consumption, due to food safety regulations. Water used for cleaning tools and equipment in the clean slaughter area during production hours, is relatively low in COD, but reddish in colour due to the presence of haemoglobin, and with higher bacterial counts (CFU/ml) than tap water. Water treatment technology aiming at preparing the water to a quality "fit for purpose" in the unclean slaughter area, therefore must aim at removing the red colour as well as reducing the microbial counts.

At the Danish Crown slaughterhouse in Horsens, a project is aiming at producing water fit for purpose from process waste water. Water is collected at the equipment in the clean slaughter area; sieved, treated, and used for the de-hairing process at the unclean slaughter area. The treatment technologies employed are UV light for disinfection of water, whereas various technologies are tested to find the most suitable technique for de-colouring of the haemoglobin content. The preliminary results show, that UV is highly capable of reducing bacterial counts to the levels of tap water, and it has been found that de-colouring can be obtained with O_3, however, further tests must be performed to optimise dosing of O_3 for efficient de-colouring, to produce a quality of water for producing water satisfying both microbial as well as aesthetic quality parameters.
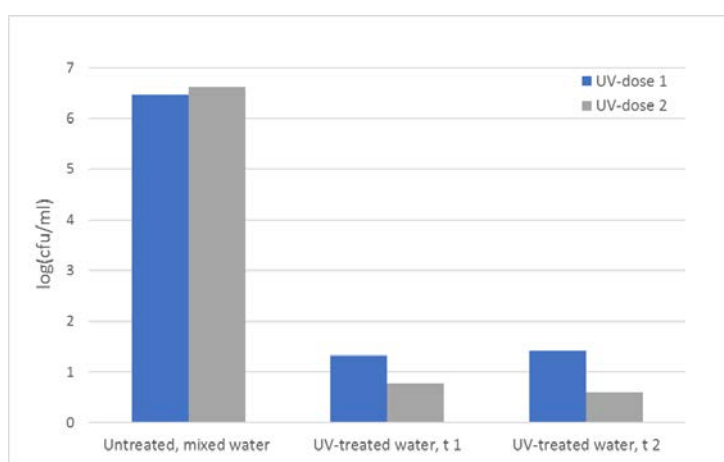
Figure 1: Microbiological quality of water before and after UV-treatment (aerobic total counts, PCA, 20°C, 5 d)

Technical tests of potential solutions are done hand in hand with preliminary risk assessments as well as and economical evaluations, ensuring viable solutions that can be implemented full scale in the future.

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Eco-efficiency of introducing water efficiency at the chicken feet processing line at the chicken slaughtering house HK Scan in Vinderup Denmark.

Berit Godskesen, DTU Environment, X. Zhan**, DTU Environment & M. Rygaard***, DTU Environment*

Abstract
Water efficiency in food and beverage industry is becoming an increasingly urgent issue, as the industry is facing growing pressure to reduce their water use e.g. from local water shortage, public concern, political regulation, and market competition. Water reuse is considered promising as it not only upgrades production in a sense that less freshwater is required to produce same amount of food products, but also influence freshwater uptake on both upstream water supply and downstream wastewater treatment processes. However, water reuse may lead to rebound effects, which may counteract the anticipated reductions in freshwater use and associated environmental impact. Therefore, it is necessary to shift the focus from water-efficiency alone towards absolute assessment of entire water system's performance to support a move towards sustainable industrial practice.

This case study from the DRIP project evaluates a poultry slaughterhouse owned by HK Scan in Vinderup, Denmark, which is facing challenges from freshwater uptake and wastewater treatment. In response to those challenges, DRIP proposed a solution of reusing rinsing water in the chicken feet processing line. The objective is to carry out an absolute assessment of the environmental and economic consequences for the water system in after implementing the reuse practice in the chicken feet processing line. The entire water system is considered from groundwater abstraction, freshwater supply, water use in the chicken feet processing line, wastewater treatment, to finally disposal.

Three scenarios are developed: a baseline describing the current situation; a reuse scenario representing the reuse practice proposed by DRIP; and a scenario based on the reuse practice with the addition of indirect rebound effect of using the saved freshwater for optimizing one clean-in-place (CIP) process. The three scenarios have one common functional unit, which is the annual available freshwater of 73,600 m^3 supplied to the chicken feet processing line in HK Scan Vinderup, who can achieve a production of 4,980 ton chicken feet under normal operation conditions for one year (baseline year is 2017).

Life-cycle assessment (LCA) is used to evaluate the scenarios environmentally. The economically performance of the scenarios is carried out by conventional life cycle costing (CLCC). In the end, environmental and economic assessment results are combined in an eco-efficiency matrix, in order to provide a decision support covering both dimensions.
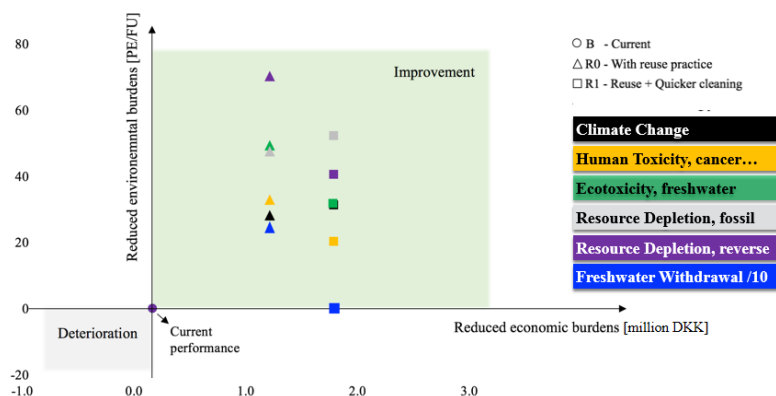

Figure 6. Eco-efficiency matrix of water reuse in the chicken feet processing line at HK Scan.
This study concludes that implementing reuse practice in the chicken feet processing line is positive as it optimizes freshwater use in the chicken feet processing line and reduces wastewater generation. Based on current capacity of the chicken feet processing line, annual water saving is expected to be 38,000 m^3, and potential cost saving is expected to be 1,050,000 DKK. Since this reuse practice is simple to implement, and there is a great amount of similar processes in meat processing industry, it is expected that this reuse practice can be adopted by others gaining same positive and eco-efficient effects.

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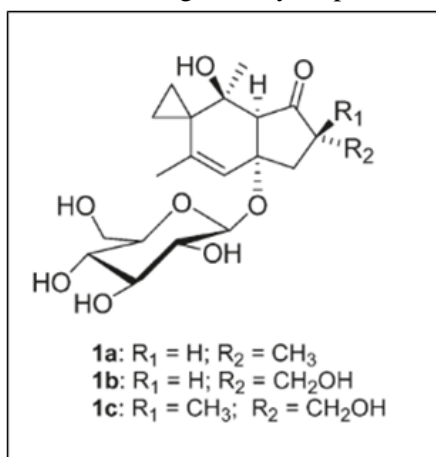# Risk assessment of natural carcinogenic compounds from Bracken fern plants in surface waters with LC/MS

Vaidotas Kisielius, Metropolitan University College*., H.C.B. Hansen, KU-PLEN., M. Rodamer, Agilent Technologies***, L.H. Rasmussen, Metropolitan University College****

Abstract

Many species of plants and fungi produce wide range of natural toxins. Ones of the most common plant-produced toxic secondary metabolites are glycosidic compounds. The molecular structures of glycosides make them highly water soluble and mobile in soils and sediments. However, the environmental distribution and fate of these toxins are largely unknown. The purpose of this project is to develop feasible analytical methods and identify environmental risk factors that predetermine release of the toxic glycosidic natural molecules from non-agricultural lands to environment. A special attention is payed to the risk to aqueous environments adjacent to water bodies.

Bracken ferns (*Pteridium aquilinum*) – one of the five most abundant plant species in the world – are reported to produce up to 6 kg/ha of carcinogen ptaquiloside. Previous studies demonstrated leaching of ptaquiloside from Brackens to soils and upper ground water bodies. Particular environmental factors like heavy rain events have been shown to vastly facilitate leaching of the carcinogen from the plants to their surrounding environments. Recently, similar compounds to Ptaquiloside have been discovered that are most likely to express carcinogenic properties and that have not been taken into account in the abovementioned previous studies. This implies that the overall carcinogenicity of the Bracken released compounds may have been underestimated.

A novel liquid chromatography – mass spectrometry (LC/MS) analytical method for simultaneous detection and quantification of ptaquiloside, ptaquiloside-like compounds (see the picture) and their immediate degradation products is being developed. The method aims for optimal analysis, capable for fast quantification of at least 6 molecular structures applying a short chromatographic column. The analytical method is being developed towards particularly low limits of detection for measuring water bodies or water supplies, where natural carcinogens may be present in trace concentrations. When the analytical techniques will be verified, a spatial and temporal variation of these compounds in several surface water ecosystems in Denmark will be monitored throughout the vegetation and decomposition cycle of the Bracken fern plants in 2018. The monitoring study will determine particular environmental precursors responsible of leaching of the toxins to aqueous environments. The analytical method will be passed for a partner project aiming for monitoring of natural toxic compounds in ground water bodies.

Structures of norsesquiterpenoid glycosides:
1a: Ptaquiloside; 1b: Ptesculentoside; 1c: Caudatoside.
(Modified from Fletcher, M.T., et al. 2011)

1a: R_1 = H; R_2 = CH$_3$
1b: R_1 = H; R_2 = CH$_2$OH
1c: R_1 = CH$_3$; R_2 = CH$_2$OH

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Stone wool based filter technology for treatment of rainwater in densely populated urban areas

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Abstract

Climate changes have caused increased or heavier rainfalls. This has created the need to separate rain water and waste water in Danish cities to decrease the load on the wastewater treatment plants to avoid that capacity is exceeded and subsequent release of untreated waste water to nearby recipients.

Even though rain water is not as heavily polluted as waste water; rain water has been shown to contain several both organic and inorganic pollutants, which should be removed prior to discharge to recipient. The best available technology today is rain water basins; the use of rain water basins is however not feasible in densely populated urban areas where sufficient space is not available.

ROCKWOOL has developed a small stone wool unit based on our technology for horticultural substrates that can be used to build modular underground storage and delay and cleaning of rain water. The fibrous material adds strength to the cavity and provides a substrate for biologic activity.

This technology has been tested in collaboration with Aarhus Water and Danish Technological Institute with support from MUDP. First in small scale at Strandvejen in Aarhus, where the stone wool units received run-off water from the heavily trafficked road, replacing the sewer pipes between two sewer grates. Water was collected before and after passage of the stone wool unit and a reduction in especially organic pollutants was observed.

In October 2017, a large unit (6 m x 12 m x 1.2 m) has been installed at Risvang Allé in Aarhus as part of a larger project by Aarhus Water. The design criteria from Aarhus Water are: 1) Compact, 2) Cheap and easy installation, and 3) Scalable to fit different needs and water volume requirements. The solution is at present designed to treat only the first flush of a heavy rainfall as this has the highest concentration of pollutants.

We are now awaiting results from the new unit at Risvangs Allé.

Left: Construction of a pilot-scale filter at Strandvejen
Bottom: Construction of the unit at Risvangs Allé

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POSTERS

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Biofouling of membranes: filamentous yeasts - an overlooked factor?

Erini Vitzilaiou, *, S. D. Aunsbjerg, **, I. Stoica, ***, S. Knøchel, Copenhagen University****

Reverse Osmosis (RO) membranes are increasingly being used in the food industry for water treatment and re-use within the industrial facilities. Spiral wound membrane structure, usually used for this purpose, offers high surface area per volume unit, but it is susceptible to fouling and biofilm creation. Biofilm structures may survive the Cleaning-In-Place system (CIP). This can lead to flux reduction and may present a challenge for the quality and safety of the final product. We therefore investigated the microbiota on RO membranes, used for water sanitation in the food industry, and its response to cleaning and disinfection. Biofilm communities were visualized with light microscopy and Confocal Laser Scanning Microscopy (CLSM) while 16S and 26S rRNA sequencing, physiological, biochemical, macro-and microscopic observation were used for identification of bacteria and yeast isolates. Tolerance of the filamentous isolates to different time-temperature assays and CIP solutions was tested.

A dense network of filamentous yeast covering a great area together with budding yeast cells and bacteria was observed before CIP, while after CIP only yeast species were detected and isolated. The dominant species in the biofilm after CIP were identified as closely related filamentous yeast genera of similar physiology and cell morphology. Isolates exhibited high tolerance to heat and CIP treatment.

Filamentous yeast species are rarely described as part of RO membranes biofilms. We believe that they can be easily overlooked due to their slow growth and low numbers relative to the many fast growing bacteria. However, their hyphae structure may facilitate attachment and survival. More research is needed on their role in microbial adhesion, and flux changes and product quality, as well as removal strategies.
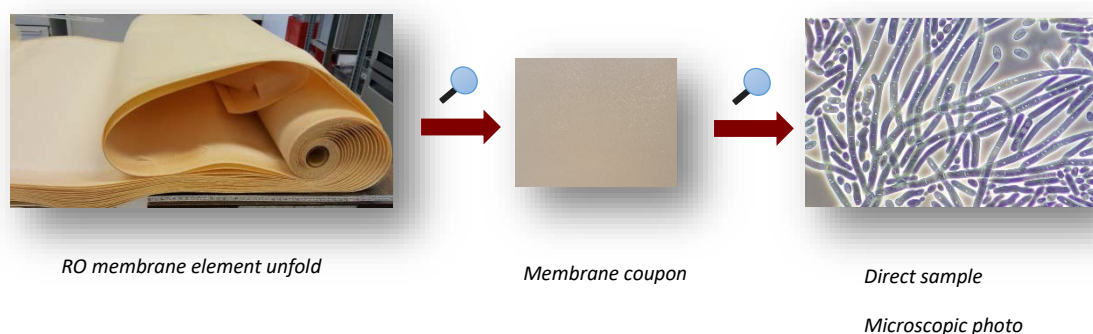
RO membrane element unfold   Membrane coupon   Direct sample

Microscopic photo

Figure 7: Scheme of membrane sampling.

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Commercialization of the pellet method softening. Bringing radical changes to waterworks and society.

***Krzysztof. P. Kowalski,*** *Danwatec**

Abstract

Decrease in water hardness would result in a significant social and environmental benefits. Therefore, many waterworks have been searching for solution that could be applied and bring a new water quality to their clients.

For medium size and large waterworks the best match seemed to be a pellet method, that is based on a precipitation of calcium carbonate as consequence of increasing pH with help of dosed natrium hydroxide in fluidized bed reactor. The process has been vastly used in Netherlands, where it was developed and applied for the last 30 years. Danwatec, in cooperation with Dutch consulting company Royal HaskoningDHV, started pilot investigations in summer 2015 at the Store Heddinge waterworks, to evaluate and adapt technology to Danish drinking water production. The project succeed in commissioning the full-scale softening plant that has been in use since 1st June 2017.

Before it was possible some investigations were made with focus on finding the tools to understand, control and optimize process in reactor and ensure produced water quality. For example, application of a geochemical modelling with help of PHREEQC software was applied to evaluate scaling and corrosion potential for different scenarios.

The presentation will also introduce customers awareness and hesitation regarding application of advanced water treatment and compare it with their feedback after receiving soft water for 6 months now.
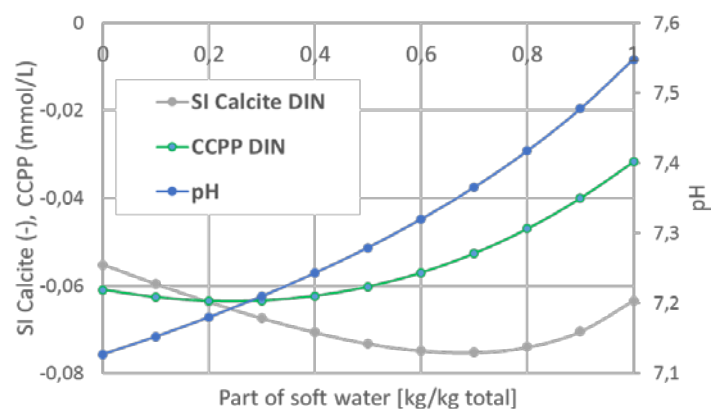
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Turning floods into resources: on-site water treatment and storage with treatment trench

Kenneth Kristensen*, A. Perry-Moore**, M. Trento***

Abstract

Cities around the world, especially in developing countries, are experiencing both flooding due to urbanization and climate change as well as shortages of water supply resulting from a variety of reasons, such as drought, over-extraction of groundwater or pollution of surface water resources. The Treatment Trench is a nature-based technology that addresses both problems in a simple way. Using simple materials that can be adapted to local conditions, the Treatment Trench combines knowledge of detention and infiltration that are used in other parts of the world to manage stormwater for flood prevention, with a filter soil system that purifies and stores water locally, providing clean water as a resource for locals where water supply is unreliable in poor, underserved areas in developing countries.

The Treatment Trench requires minimal maintenance while it provides a cheap supply of clean water to locals, using a small-scale, decentralized, passive water treatment solution which also offers management of stormwater. The trench is a modified French drainage system and consists of three layers: 1) a vegetated top layer of local, water resistant plants for storm-water overflows; 2) A middle layer of filter soil, which can effectively remove suspended solids, xenobiotic organic compounds, heavy metals, and pathogens (Kadam et. al. 2008); 3) and a bottom layer for water storage, composed of gravel (this layer can include large PVC pipes with holes drilled into the sides to increase water storage capacity). Furthermore, a geotextile filter between the filter soil and the bottom layer prevents clogging between the gravel. A manual pump connected to the bottom of the third layer makes the treated water accessible to the locals. If the filter soil is maintained with good vegetation, no maintenance is necessary, but the long-term water cleaning properties of the filter soil requires more monitoring over time. Furthermore, trash in streets, open defecation, erosion and sedimentation might be a threat to the composition and effectiveness of filter soil and must be evaluated by laboratory analysis.
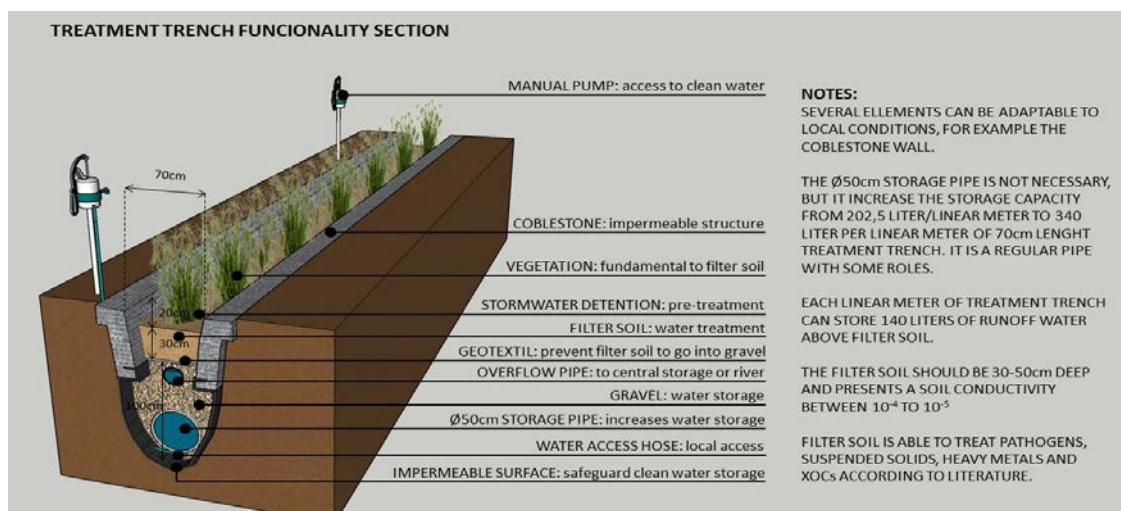
The figure illustrates one possible design of the Treatment Trench and its different components.

This is a scalable technology that makes use of local materials and utilizes readily available man-power for simple construction. The design is flexible and can be fitted to local conditions, needs and resources, while implementation can span from yards - providing clean water for households - to a district-wide scale. The overflow water can be directed into nearby rivers to increase the overall water quality or to a central storage reservoir to be used during dry periods.

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From wastewater to fertilizing water- pilot scale operation

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Abstract

The fundament for agricultural production is the availability of fresh water resources and at islands, this is a scarce resource, which is also the case for the island of Samsø. To maintain the production of fruit and vegetables, there is an increasing need to control the water circuits of the island and utilizing the resources it contains directly. The Island of Samsø, Denmark is in the forefront and aims to be a model island for a circular bio economy. To accomplish this, there is a need to rethink wastewater treatment so it is aligned with the seasonal variation of the agricultural production. In the summer period, only reduction of COD and micropollutants should take place so nutrients are kept in the water used for irrigation. However, in the winter period the removal should also include the nutrients when the effluent water is released to the Sea.

Proof-of-concept was accomplished in laboratory scale experiments and pilot scale equipment was installed in two 40'' containers. Biological treatment technologies included a membrane bioreactor and a sequence biofilm batch reactor and the chemical polishing was conducted by ozonation.

Results supported the findings in lab scale; efficient COD removal, while the nutrients N and P were still available in the treated water. Experiments have also documented reduction of micropollutants and heavy metals following a water sample through the system. Remarkable biological activity was observed for removal of the organic micropollutants, and any residual concentrations, were efficiently removed by ozonation. Inlet concentrations of Hg, Cd and Cr were rather low and the treatment reduced them to below the detection limit.
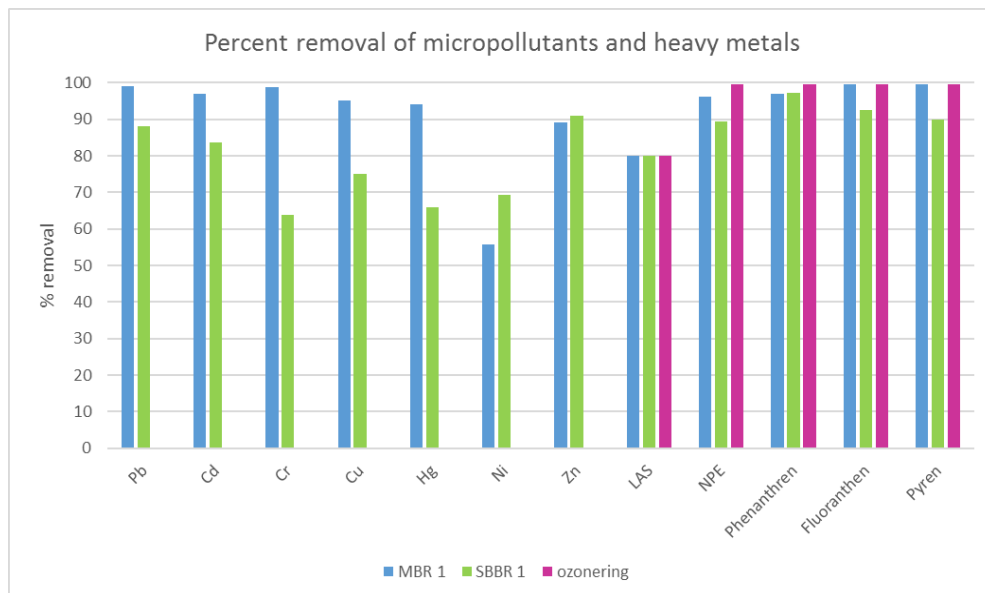
Therefore, it can be concluded based on experimental data, that the water produced has the properties required for use as fertilizing irrigation water for the major agricultural production on the island. Thus, N and P are maintained in the water while heavy metals and micropollutants are removed.

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Proposal of a procedure to asses Pollutographs. Application to Murcia's Combined Sewer Overflows (CSOs).

Antonio Vigueras-Rodríguez, J.T. García, , L. Castillo, UPCT* ,
P. Espín, D. Martínez-Solano, S. Nevado, EMUASA **

Abstract

Directives 91/271/EEC and 93/481/EEC set norms regarding the management of Combined Sewer Overflows. European Commission monitors the implementation status and implementation programmes. In fact, during the year 2019 all the utilities should be able to quantify the pollution spilled during storm events. And afterwards, plans have to be developed in order to reduce the impact of such events. In this paper, we proposed a method to estimate the transported pollution during events as well as to serve as a tool for developing plans to lessen the corresponding pollution.

The procedure is divided into three steps:

A. Periodical measurements of all relevant pollutants, e.g. total suspended solids and chemical oxygen demand, in wet and dry weather. Such pollutant "concentrations" are correlated with the turbidity, updating the relation among them [1].

B. Continuous measures of the turbidity. Turbidity is continuously register in the sewer areas near overflow spillways. Turbidimeters are a very convenient equipment for this purpose [2]. Actually, it is reliable, its measures are highly correlated with the total suspended solid concentration, and its maintenance is easy. In this way, combining A. and B. turbidity measures provide us a real-time estimation of the pollutant concentration. on real time.

C. Assessment of each catchment hydrograph. Depending on the available data, this step could be based on a design, a measured or a simulated hydrograph. In order to apply this methodology to Murcia's Combined Sewer System, we have used simulated hydrographs based on real measured rainfall. Murcia's utility has developed a calibrated SWMM model, and therefore, using the rainfall data, it is possible to estimate hydrographs for all the relevant points of the system.

D. Estimation of each catchment pollutograph. Combining the pollutant concentration, estimated in the previous steps, with the hydrographs, we can assess how the mass of pollutants are transported. This information allows us to comply with EU Directives, but it will also be useful to design Murcia's strategy to minimize environmental impacts.
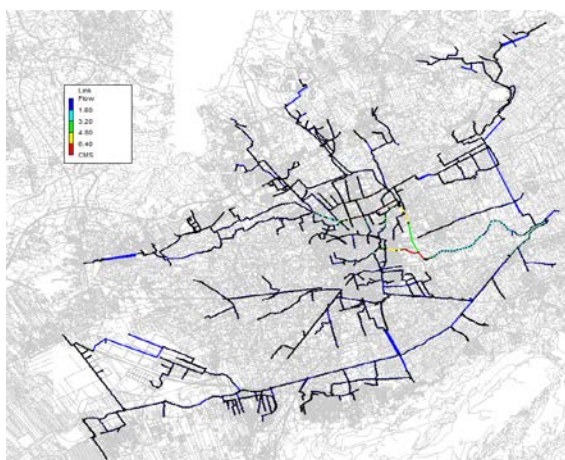
Figure 8: Example of one time step of the storm simulations carried out using Storm Water Management Model (SWMM).

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Impacts of design configuration on the functionality of the microbial community and ibuprofen removal of constructed wetlands

Pedro Carvalho, AU-ENVS*, Liang Zhang, AU-BIOS**, Carlos A. Arias, AU-BIOS **, Kela P. Weber, RMC***, Kai Bester, AU-ENVS*, Hans Brix, AU-BIOS **

Abstract

Constructed wetlands (CWs) are one of the best examples of an engineered eco-technology making use of phytoremediation to treat contaminated water. CWs are nowadays spread across the globe providing primary to tertiary wastewater treatment, as well as agricultural and industrial dedicated solutions. In spite of its low-cost/tech setup, CWs are also a promising technology to reduce trace organic micropollutants, also known as contaminants of emerging concern (CECs). Research being developed at Aarhus University with international partners aims at understanding the removal pathways of organic micropollutants in CW systems, with the ultimate goal of designing dedicated CWs to address these contaminants.

One of our past studies aimed to investigate the effects of constructed wetland design (unsaturated, saturated and aerated saturated) and plant species (Juncus, Typha, Berula, Phragmites and Iris) on the mass removal, and removal kinetics of the pharmaceutical ibuprofen, as well as to try and link removal to microbial community function. Planted systems had higher ibuprofen removal (29% – 99%) than the corresponding unplanted ones (15%–85%) in all designs. The use of forced aeration improved ibuprofen removal only in the unplanted mesocosms. In general, ibuprofen removal followed a first-order removal kinetics model with removal rate coefficients (k_A) varying between 3 and 35 cm/d. The ibuprofen mass balance revealed that its removal was mainly attributed to microbial degradation by the fixed bed biofilm, but plant uptake and degradation within plant tissues also occurred. The ibuprofen removal was positively correlated with the oxygen concentration in the water and the removal of nutrients, indicating that degradation was possibly due to co-metabolisation processes. Data from the microbial community metabolic function, studied via community-level physiological profiling analysis, revealed that the microbial activity and metabolic richness found in the interstitial water and biofilm of the unsaturated designs were lower than those of the saturated and aerated designs. In all three designs, biofilm metabolic richness was significantly higher ($p<0.05$) than that of interstitial water. Both the interstitial water and biofilm microbial community metabolic function were influenced by CW design, plant presence and species, but design had a greater influence than plants. Moreover, a canonical correlation analysis indicated that biofilm microbial communities in the three designs played a key role in ibuprofen degradation. In fact, the enzymes associated with co-metabolism of L-arginine, L-phenyloalanine and putrescine may be linked to ibuprofen transformation.
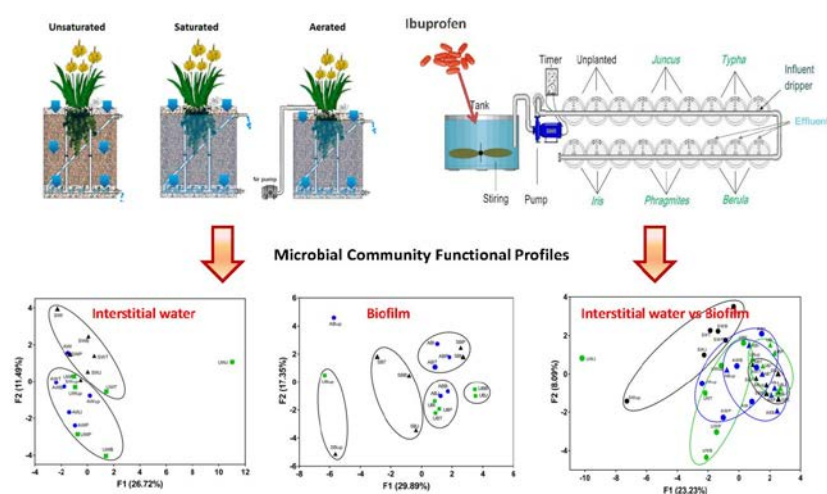
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Monitoring and removal of natural toxins in groundwater from catchment scale to tap water

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Abstract

Natural toxins comprise a large and chemically very diverse group of emerging contaminants, but their fate in the environment is still not fully understood. They are released continuously to the environment and their behavior can be compared to xenobiotics. Although pesticides are usually more stable, a number of natural toxins are more water soluble which makes them rather mobile, with possibility of leaching to surface and groundwater from terrestrial source. Hence, there are concerns whether some groups of natural toxins might pose a risk to drinking water quality.

The focus of this study is on a natural toxin ptaquiloside (PTA), a norsesquiterpene glycoside produced by one of the five most common plants on the planet, Bracken fern (*Pteridium aquilinum*). Ptaquiloside is highly water-soluble carcinogenic compound with almost no sorption to soil and sediment, which is readily released from Bracken and leached to the aqueous environment. The PTA characteristics suggest a high potential for its presence in groundwater if the right conditions are met. Fast leaching of PTA beyond microbially active layers during intense rainfall events at low subsurface temperatures may be of key importance. In addition, clay-containing aquifers and/or acid groundwaters in aquifers could make PTA hydrolysis very slow. Leaching of PTA to soil, surface and upper groundwater have been already empirically confirmed in Denmark, Ireland and England. However, there has been no research effort devoted to the potential presence of PTA and its degradation product pterosin B (PTB) in groundwater used as drinking water source. Aim of this research project is to fill this gap, and investigate presence of both PTA and PTB in groundwater aquifers, a commonly used drinking water source in Denmark. This part of the study is conducted on selected locations of interests for Greater Copenhagen Utility – HOFOR. In addition, it is of particular interest for this project to investigate PTA and PTB presence in private shallow drinking water wells. A range of different groundwater types, geology and climate conditions will be investigated. In order to achieve these objectives, several key subprojects are conceived: (1) identification of bracken rich locations in vicinity of the drinking water wells, (2) method development for PTA and PTB preservation in ground-water samples, and (3) monitoring of PTA and PTB in water-plant nexus. Furthermore, another goal of the project is to explore the fate of natural toxins through the drinking water treatment. There is a lack of measured data quantifying the efficacy of common treatment processes, for both private and public water supplies, with respect to natural toxins. For that reason, this project aims to understand fate of natural toxins through the different drinking water treatment steps and test potential technologies for their removal.

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EU Partnership Instrument for the China Europe Water Platform focus area on Rural Water and Food Security

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A European consortium led by GEUS has received a grant of 1M €as support for a 4-year program on implementation of the China Europe Water Platform Focus Area on Rural Water and Food Security. Key partners in the EU are the Finnish Environment Institute, University of Cordoba and Aarhus University while key partners in China are the Ministry of Water Resources and the Water Research Institute of Shandong Province. As associated partners, The Danish Environmental Agency, the Italian Ministry of Environment and The Water Supply and Sanitation Technology Platform are also involved in the program.

The program centers on groundwater management, use and protection, and spans policy development, applied research and technology demonstration, and business cooperation. The Danish model(s) for groundwater-based rural water supply and village-based wastewater treatment will be marketed as platforms to test new advanced water treatment technologies, which can cope with the principal types of groundwater pollution in China. If marketing is successful, EU companies will be invited to use the platform to test, adapt and market their technologies in China. Other topics to be addressed within the programme are groundwater dependent ecosystems, groundwater monitoring and assessment with focus on diffuse pollution, water saving irrigation and managed aquifer recharge.

The presentation will give an overview of the foreseen activities and how interested Danish and European stakeholders can take part in the activities.