# Abstract proceedings

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A new nitrogen retention map for Denmark


Abstract
The nitrogen load to estuaries have been approximately halved in Denmark since the mid 1980ties, but assessments of the ecological status of marine waterbodies indicates that further reductions in nitrogen loadings are required in some waterbodies to obtain a good ecological status according to the Water Framework Directive. Past and current regulations have primarily relied on a general approach, applying same restrictions for all areas independent on drainage schemes, hydrogeochemical conditions and retention in surface waters. Such a general approach is not cost-effective, as nitrogen retention (primarily as denitrification) varies significantly depending on the physical and biogeochemical conditions. If areas with high and low retention can be identified, regulation can be targeted allowing less strict regulation in some areas and focus stronger regulation and mitigation measures in areas, where nitrate leaching is high and nitrogen retention is low.

As a first step in exploring how a differentiated approach can be integrated in national regulation, a national nitrogen model has been developed for Denmark. The model is constructed by linking existing models describing nitrate leaching from the root zone, groundwater transport and reduction as well as surface water retention models. The models are coupled at sub-catchment scale dividing the country into topographic catchments with a mean size of 15 km², which constitutes the computational units in the national model. Model development, calibration and validation have been performed on measurements of nitrogen transport from 340 streams gauging stations covering approximately half of the total area in Denmark.

The national model is designed to compute the total nitrogen loads to coastal areas and the transport of total nitrogen within sub-catchments, but can similarly be used to compute national maps displaying the estimated nitrogen retention in groundwater, surface water and the total retention from the field to the sea.

Figure 1 Map displaying the total nitrogen retention from the root zone to the marine environment

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New partnership working to reduce water consumption at leading Danish food companies

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Abstract

DRIP - Danish partnership for Resource and water efficient Industrial food Production – is a public-private partnership focused on water efficiency in the food industry – one of the largest water-consuming industries in Denmark and globally.

The partnership’s ambition is to produce more with less water. DRIP will reduce water consumption at leading Danish food companies by developing new sustainable water and production technology solutions and concepts which, without compromising on product quality and food safety are financially worthwhile. The developed technologies and solutions will be tested in pilot or full-scale under production conditions.

The partnership is working to develop new technology that can reduce the industry’s water consumption. The ambition is to use significantly less water of drinking water quality and increasingly use recycled water. The goal is a reduction in water consumption of 15 – 30 %.

Once the technologies are developed, the ambition is to create new export successes for the Danish technology and knowledge providers in the water area while the competitiveness of the food companies will be improved. This is reflected in the partnership vision:

By 2025 the most competitive water consuming industries are those that apply a "water-fit-for-purpose" concept and are heading towards highly efficient use of water, e.g. closed loop solutions, supported by front-runner technology providers, with the required level of food quality and safety and in accordance with environmental regulations.

The partnership consists of a number of food companies and technology providers, three universities and two GTS institutes. The Danish Veterinary and Food Administration, Environmental Protection Agency and Nature Agency are associated partners. The partnership was launched March 1, 2015 under the INNO+ societal partnership framework with an investment of DKK 50m from Innovation Fund Denmark and DKK48m from the partners.

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High resolution CWSI maps for the entire growing season of a cultivated barley field using UAV-collected surface temperatures

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Abstract

With agriculture being among the most water consuming sector of freshwater and an overall increasing pressure on water resources, the development of more efficient irrigation systems is important. Combining the crop water stress index (CWSI) with unmanned aerial vehicles (UAVs) enable detection of specific areas within a cultivated field that requires irrigation to ensure healthy growing plants.

In this study remotely sensed surface temperatures were collected with a thermal camera onboard an UAV. Temperatures were used to calculate spatially distributed CWSI maps over a barley field during growing seasons 2014 and 2015. In the early stages of the growing season, remotely sensed surface temperatures were an ensemble of both soil and canopy temperatures, while later during the season the temperatures increasingly reflected water conditions of the crop. Canopy temperatures were determined using leaf area index and the two source energy balance modelling scheme. This approach enables CWSI calculations for homogeneous and evenly distributed crops (such as barley) during early as well as late stages of a growing season. CWSI maps from the growing seasons of 2014 and 2015 are calculated using both an empirical and an analytical approach, and are compared and validated against modelled canopy conductance and transpiration rates.

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Irrigation and sustainable groundwater abstraction

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Abstract

For the second generation WFD River Basin Management Plan (RBMP) in Denmark, new empirical models for three biological quality elements for fish (DVFFa), macrophytes (DVPI) and macroinvertebrates (DVFI), have been developed by DCE based on observed biological quality elements (EQR values) and observed river discharge by use of symbolic regression (EUREKA).

GEUS has implemented these new empirical formulas for biological quality elements by the use of a transient, integrated national water resource model based on MIKE SHE/MIKE 11 (DK-model) for the scale of 3,000 sub-catchments (ID15s, ~ 15 square km in average) for DFFVa and DVFI. The new ecological flow variables consist of six variables: Extremity of low flow (Q90/Q50), Base flow index (BFI), Number of events per year in average above Q50 (Fre1), Q25 (Fre25) and below Q75 (Fre75), and Duration of events above three times Q50 (Dur 3).

For irrigated areas in Denmark, the new status assessment in general shows good status for aquifer sustainability (criteria of max 30 % abstraction of actual groundwater recharge). However, reduction in river low flow due to groundwater abstraction (Qmm) is above screening criteria for many ID15s. Requested by SEGES, GEUS has therefore developed a new baseline model (between high and low scenario) in order to improve the model description of groundwater abstraction for irrigation, and in addition to this made new sensitivity simulations by increasing the irrigation with 25, 50 and 100 % compared to the new baseline. Results of these simulations will be shown, pointing out the needs for additional investigations in order to further consolidate the new indicators, since there are significant uncertainties associated with some of the flow variables when a model, and not observed discharge is used as input (Fre1, Fre25, Fre75 and Dur3).

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Uncertainty assessment of groundwater nitrate reduction maps using multiple geological models – Results from the NiCA project

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Abstract

Nitrate leaching from agriculture is a major environmental problem in the European countries. In Denmark, the young glacial sediments have a high reducing capacity, and a large part of the nitrate leaching is therefore naturally removed by nitrate reduction in the saturated zone. However, heterogeneity in the subsurface leads to large spatial variation in the amount of nitrate reduction within a catchment. A catchment can therefore comprise both areas with a high reduction in the subsurface, as well as areas where nitrate is transported directly to surface waters without significant reduction. Implementing a spatially differentiated regulation on agricultural practice focusing on reducing nitrate leaching on areas with low reduction, would be a more effective approach than the present spatially uniform regulation.

Distributed models can be used to estimate spatially distributed nitrate reduction in groundwater in order to delineate these areas of high and low nitrate reduction. However, due to insufficient and uncertain data, it is difficult to describe the spatial variation of input data and model parameters. The distributed models therefore lack predictive capability at the grid scale, giving rise to uncertainty on the model estimates. Geological uncertainty is believed to be the main contributor to uncertainty on estimated nitrate reduction.

The objectives of this study were to estimate spatially distributed nitrate reduction in groundwater in the Norsminde catchment in Denmark, and to assess the uncertainty on the estimate due to geological uncertainty by using multiple geological models. It was assessed whether the uncertainty could be reduced by using an extensive geophysical dataset in combination with borehole data for constructing the geological models. Finally, an upscaling analysis was performed to analyze how the uncertainty changed with increasing aggregation scale in order to evaluate on the predictive scale of the model.

The study showed a large spatial variation in nitrate reduction in the study area. The uncertainty on the estimated nitrate reduction was large on the original 100 m model scale, but the uncertainty decreased with increasing aggregation scale. The decrease in uncertainty was most apparent the first 500 m, where after the uncertainty started to level off. The results also showed that using geophysical data in combination with borehole data when generating geological models was able to decrease the uncertainty on the estimated nitrate reduction. Finally, the results indicate that predictive capability of distributed models is constrained by the spatial resolution of key data such as geology.

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Significance of hydrological model choice on climate change impact assessments for stream discharge and nitrogen load


Abstract

When water authorities are doing risk assessment or developing management and adaptation strategies for future climate change, information on the future hydrological response to climatic changes are essential information. However, climate change impact studies are affected by a range of uncertainties that influences the final impact signal. The objective of this study was to evaluate the sensitivity of the impact results to the choice of hydrological model compared to the combined effect of land use and climate changes on hydrology and nitrogen load for a 486 km² catchment in Denmark. Three hydrological models, NAM, SWAT and MIKE SHE as well as a root zone model, DAISY, were constructed and calibrated using similar methods. The models are forced with results from four land use scenarios and four climate models.

Results showed that climate model choice was the dominant factor for mean discharge, low and high flows as well as hydraulic head at the end of the century. However, even though the hydrological models showed similar performance during calibration, the mean discharge climate change impact signal varied up to 30% between hydrological models, with even higher variations for extreme discharge events (1th and 99th percentile). For the mean hydrological response changes in land use appeared to cause little effect, while the extremes were shown to differ between the hydrological models when applying different land use scenarios due to dissimilarities in process equations and hydrological model structure. For nitrogen leaching and loads the climate model were found to be the least influencing factor while the dominant factor were the land use scenario, followed by the hydrological model.

Also presented are the plans for the new nitrate transport and reduction project: TReNDS.

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Modelling of water quality and risk of infection during urban flooding
A novel flood risk management tool

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Abstract

Globally, diarrhoea is the fifth leading cause of death. Particularly children are vulnerable, and it has been estimated, that every 10th child dies due to diarrhoea. The diarrhoeal disease burden is highest in developing countries where water supply and sanitation is insufficiently developed. In countries like Denmark, where the water supply and wastewater management is well developed, the risk of water-borne diarrhoea is smaller, and good health care means that the probability of dying due to diarrhoea is very small. This does not mean that diarrhoea does not occur in countries like Denmark. The Danish Health Institute (SSI) estimates, based on telephone interviews, that every Dane is ill with gastrointestinal illness in an average of 1.4 times per year. A part of this is due to water-borne infection, either directly or due to secondary infection from other people who have been infected through water.

The main routes of transmission of waterborne diarrhoea are generally regarded as being through drinking water and via swimming. The flooding in Copenhagen in 2011 showed, however, that there is also a risk of infection associated with floods. A SSI study of professional clean-up workers showed, that 22% (of 257) became ill after clean-up. In addition, another 5 people (non-professionals) were infected with Leptospirosis (Weil’s disease), transmitted through rats. One died. A Dutch study has shown that after a flood, 26% had stomach infections, 29% had influenza like symptoms, 21% had skin problems and 16% visited the general practitioner. This was 3 to 6 times higher than in areas not affected by the flood. There is therefore a need for awareness of the risk of infection associated with floods, both in terms of behaviour by floods and the planning of adaptation to extreme rains.

We have combined our hydraulic models for estimating pathogen concentrations in the floodwater and risk assessment methods and can now determine the risk of becoming infected during floods. The results of the models can tell us when and where the risk of infection is high. With this knowledge, precautions can be taken to keep the risk at a low and acceptable level. In addition, it is possible to analyse the health effects of various adaptations to cloud bursts.

We will show how disease risk is modelled, give an example of flood modelling in Copenhagen, and how the results can be used in the handling of flood water. The results are shown graphically in Figure 1.

![Figure 1](image_url) Right: Modelled fraction of waste water in Nørrebro, Copenhagen. Left: Distribution of health risk in the same area.

The work was funded as a part of DHIs performance contract with the The Danish Agency for Science, Technology and Innovation and the EU FP7 research project Aquavir (NMP4-SL-2013-604069).

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Environmental life cycle assessment of urban storm water management

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Abstract
The environmental impacts of cloudburst management systems are assessed using Life Cycle Assessment (LCA). A terrestrial LCA approach as introduced by Loiseau et al. (2013) is first used in connection to storm water management (SWM) and tested using two different climate change adaptation strategies for a catchment in Nørrebro, Copenhagen. The catchment area is defined as the reference flow, from which different functions are derived based on the Three Points Approach, which divides rain events in different domains according to frequency (Sørup et al., 2012). This allows defining different safety targets for everyday and rare rain events, which are met by a combination of different elements that differ in the two scenarios. The “green” scenario mainly utilizes green infrastructure, local retention and infiltration, while the second “grey” solution employs underground pipes and retention basins. The environmental impacts resulting from implementing, operating and decommissioning are significantly smaller for the “green” scenario in all eight considered categories (51% down to 13% of the “grey” impacts). The main contributor in both scenarios is the generation of materials, e.g. concrete and steel, which highlights the possibility for system design optimization in order to reduce negative effects. The allocation of impacts shows that different functions of urban SWM systems affect the environment to a different extent, and that a significant share of impacts are caused by processes not directly linked to handling storm water.

![Figure 1](image)

Figure 1 Normalized environmental impacts per year of the two scenarios, for eight selected midpoint categories

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Establishing best practise methods for climate adaptation project design and implementation in urban areas

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Abstract
When implementing climate adaption solutions, the overall goal is to diverge flooding to areas where the potential damages can be reduced or eliminated. However, in dense urban areas green spaces tend to be scarce, and discharging to recipients complicated and expensive.

Typically the available areas underneath roads and parking lots in urban areas are filled with century’s worth of utility piping and their exact location and size can be uncertain. Thus, these existing utilities pose a huge potential risk for the successful implementation of storm water solutions, be it surface or pipe based.

The purpose of this study is to identify a set of best practise methods and investigations to be conducted when implementing climate adaptation solutions in fully developed urban areas. The study identifies risks based on general data from relevant projects in the greater Copenhagen area, focussing on two specific cases, where existing conditions had a large impact on the final design.

The first case is a cloudburst adaptation project in Sankt Annæ Square, in the historic centre of Copenhagen. Here existing utilities caused several changes to the project design late in the detailed design stages and several new solutions were designed during the construction phase which caused significant delays in the project, and added extra expenses to the construction costs.

![Figure 1](image1.png)

Cloudburst pipes barely able to pass between existing utilities.

The second case is a recreational basin located on an old parking lot. During the construction various unknown utility pipes emerged, making a complete redesign during the construction phase necessary. This increased the overall construction cost by 60% compared to the initial contract budget and caused a general delay.

![Figure 2](image2.png)

Lundbeck - Original project, with only one basin (left), and final design, with 3 connected basins (right).

In conclusion the study of the two cases showed that even though most utility companies have their pipes and cables digitally mapped, data can at best be used a guideline. The study also shows that data collection and risk identification of potential complications are a necessity and that project owners have an exaggerated focus on completion date, leaving the projects vulnerable to unforeseen obstacles and challenges.

Therefore it is crucial that project proposals are extended to map potential uncertainty sources and risks, these should then be minimized, primarily by trial excavations if they are utility based, and if not by a risk assessment analysis.

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Dual Porosity Filtration for treatment of stormwater runoff

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Abstract

A promising approach to adaptation of cities to a more dynamic precipitation pattern is to use the urban landscape for detention, infiltration, evaporation and harvesting of the stormwater runoff. In several Danish cities, this approach is prioritized above conventional sewer because of flexibility and contribution to urban greening and liveability (Copenhagen Climate Plan, 2011).

In addition to the challenges of finding space for the water in the dense urban environment, this approach is challenged by the quality of the stormwater runoff. The key question is how to ensure an adequate quality of stormwater runoff, before infiltrating to drinking water aquifers, discharging to biologically sensitive surface waters, or harvesting as a secondary water supply. On one hand we need to find ways to adapt existing cities to future climates, on the other hand we need to save the quantity and quality of our freshwater reserves for future generations.

Dual Porosity Filtration (DPF) is a technology designed treat stormwater runoff and be fitted in to the dense urban environment, since it is placed below ground. It removes suspended fines (colloidal – 100 µm size) and dissolved contaminants from using sedimentation, adsorption and bio-degradation as unit operating processes.

At the moment three pilot facilities with DPF (one in Ørestad Copenhagen, one in Vanløse Copenhagen and one in Maarslet, Aarhus) has been monitored during both normal rain events and by adding synthetic stormwater runoff. The results are promising showing high removal rates of suspended solids and the pollutants attached to these, but also dissolved metals and phosphorus are retained, so that concentrations in the effluent water can comply with the demands from the Waterframe Directive. The retention of organic micropollutants such as pesticides and PAH’s could be improved, by e.g. incorporating another filter material in the DPF.

The presentation will focus on the documentation, ways to improve and further uses of DPF.

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MiDAS Field Guide – a Comprehensive Online Source of Information about the Microbes of Activated Sludge


Abstract

Treatment of wastewater is important for protection of receiving waters and resource recovery. In most treatment systems, microbial communities carry out the processes and a detailed understanding of their diversity and function is essential for process optimization. Microbial composition can be described using high throughput 16S rRNA amplicon sequencing, and putative function of microorganisms can be proposed by classifying sequences to a genus for which the function is known. Environmental sequences are classified using public databases (e.g. SILVA). However, genus names for many organisms present in wastewater treatment systems are missing therein.

To improve classification for process-important organisms, we have developed MiDAS taxonomy, for which the SILVA taxonomy has been manually curated with annotations for all the abundant and important genera in full-scale activated sludge. Based on a survey of 25 full-scale Danish wastewater treatment plants over 6 years and using MiDAS taxonomy, we have collected more than 150 key organisms in activated sludge wastewater treatment systems, linked their identity with available information on their function and distribution and included this information in MiDAS field guide (www.midasfieldguide.org).

MiDAS taxonomy gives a solid foundation for the study of microbial ecology of the wastewater treatment processes. The online MiDAS field guide links the identity of genera that are important for the wastewater treatment process to details about their morphology, diversity, physiology and distribution. It has proven very useful for studies of key processes such as nitrification/denitrification, biological phosphorus removal as well as investigations of poor flocculation and settling (bulking). Currently we are continuing our efforts to establish universal guide to the microbes of activated sludge by comparing microbial community composition in 32 WWTPs located worldwide. This will facilitate a better understanding of the ecology of the ecosystem of activated sludge.


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Dealing with decentralized wastewater treatments using innovative wetland technology (iWetTec)

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Abstract
Decentralized and innovative wastewater treatment technology that meets the increasing stringent discharge standards is a research responsibility and different new and improved technologies are currently being tested. Decentralized wastewater treatment alternatives may include technology using passive systems that require relatively large surfaces to engineered treatment systems with smaller footprint but requiring some energy input. The Department of Bioscience of Aarhus University has a long tradition of research in the development of the optimizations of decentralized and plant based systems for the treatment of polluted waters. The research is still investing efforts and resources in the development and optimization of treatment systems as well as determining the processes occurring in the different components of treatment plants.

Research and development in the past years at the Department includes the optimization of high rate constructed wetlands for the treatment of industrial wastewater effluents (HIGHWET project), the development and establishment of green and sustainable technology to safeguard water resources in India while generating reuse of treated wastewaters (SWINGS Project) and the use of innovative microbial electrochemical constructed wetlands for wastewater treatment (IMETLAND project). Additionally to the treatment systems, the Department is also working in the determination of processes and pathways for the depletion of nutrients and pollutants in wastewaters. Special attention is being placed in the removal and transformation of emerging micro-pollutants.

The HIGHWET project started two years ago with an innovative combination of a hydrolytic upflow sludge bed (HUSB) and Engineered Constructed Wetlands that were modified by fitting aeration devices so higher oxygen transfer rates are achieved. Furthermore, the treatment plant is also fitted with reactive media to test P removal capacity. The system was established to treat wastewaters originated from a food producing factory with COD discharges as high as 6000 mg/L, TN of ca. 500 mg/L and TP of ca. 30 mg/L. The overall removal for COD, TN and TP in the system is always higher than 95%.

The SWINGS project aims at developing environmentally friendly technology to treat water and wastewater and to produce water suitable for human consumption as well as for reuse for irrigation in India. The project established 5 treatment plants in 4 different sites, using different technology; including constructed wetlands, river bank filtration, gravel filters, combined with solar powered disinfection units by means of natural solar disinfection, UV reactors and anodic oxidation.

The IMETLAND project is a development of Microbial Electrochemical Technologies (MET) applied to constructed wetlands that combine electroactive bacteria with electroconductive material to improve the performance of the classical constructed wetlands. The biological processes are improved by the generation of electricity by bacteria that is transported through the water column and increases wastewater treatment capacity.

Emerging organic contaminants (EOCs) such as pharmaceuticals, plasticizers or surfactants is a new and challenging issue when dealing with water pollution. Treatment wetlands systems are promising technology to mitigate the effect, but currently there is lack of information on the processes and performance. In this respect, extensive research is being done by the group in order to determine the pathways and transformations of pharmaceuticals, fungicides and pesticides that will increase the knowledge that can help to improve the designs of phytodegradation technologies.

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Resource efficient treatment and reuse of wastewater from a feather laundry

K. Litty, C.H. Fischer & L.B. Friis-Holm, all Danish Technological Institute*

Abstract
Most industrial laundries use enormous amounts water, which represents a significant cost for the laundries. Consequently, the laundry industry is becoming increasingly interested in water recycling. Over the past 5-10 years, several R&D projects have shown that there are substantial environmental and economic benefits associated with the treatment and reuse of water from conventional laundries. However, reuse of water from conventional laundries is only applied to a limited extend in Denmark.

The Danish R&D project “The resource efficient laundry” headed by The Danish Technological Institute, focused on the development of a cost efficient concept to minimize the total resource usage from laundries with highly polluted wastewater. For this, the wastewater from a leading manufacturer of down and feather duvets and pillow (Dykon) was used. The overall target was to identify the optimal process solution that leads to the lowest environmental impact and costs.

In lab scale, the effect on the final product quality of different water qualities and soap dosage used for washing and rinsing was determined using relevant international quality parameters. This included carrying capacity, fat content of feathers and turbidity of drain water. The lab-scale experiments clearly illustrated, that it was possible to use water of a lower quality while retaining the final product quality.

To verify the results, three full-scale tests were carried out using four water qualities of water for washing and rinsing: A) wastewater from the washing process treated with polymer supported fine screening (Hjortkær); B) wastewater from the washing process treated with (a) plus MBR (Biobooster); C) wastewater from the washing process treated with (b) plus RO (Silhorko) and D) tap water. In all three large-scale tests, the quality requirements of the washed feathers were met.

An environmental and financial evaluation showed that fine screening of all wastewater and reuse of 50% of the fine-screened wastewater currently is the most interesting option for Dykon among the investigated alternatives. By implementing that solution, Dykon will be able to half their expenses during a 5-year period. However, a MBR-solution could potentially be profitable if the production increases.

Based on these encouraging results, a new R&D-project has been initiated aiming at developing a cost efficient treatment and reuse concept of wastewater at a laundry specialized on hospital textiles. Data from the large-scale trial will be included in the presentation as well as an overall assessment of the water purification system with regard to efficiency and environmental impact.

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New and intelligent way of treating problematic wastewater

Z. Cai & A.K. Rovik, Aquarden Technologies*

Abstract

One of the large challenges for industries is the treatment of problematic wastewater. Wastewater can be a toxic cocktail of medicinal drugs, hormones, industrial chemicals, endocrine disruptors, pesticides, and more, and poses a significant threat to our sensitive aquatic ecosystem. Discharge of hardly degradable components to receiving water bodies has negative consequences to flora, fauna, our sources for drinking water, and ultimately human health.

Today, industrial waste streams containing persistent organic and toxic components are either sent to incineration at high costs for businesses, or undergo biological, mechanical, or chemical treatment. None of the latter alternatives completely removes pollutants. As a consequence, governments set ever more ambitious sustainability standards, forcing industries to implement ‘greener’ wastewater solutions that also incorporate reuse of resources.

Aquarden’s newly launched Waterox system addresses the need for an energy-effective and cost-effective technique that completely eliminates the non-biodegradable organic content in wastewater. The process is based on SCWO (Supercritical Water Oxidation), which operates under high pressure and high temperature, and is an excellent medium for oxidizing and removing the most persistent organic pollutants. The patented Waterox system is compact, modular, fully automated, and remote controlled. The systems are placed onsite at industrial plants close to the source of contamination.

The presentation will introduce the main principles of SCWO and give examples on how this new and intelligent way of treating problematic wastewater helps companies in for instance the pharmaceutical, chemical and biotech industries as well at hospitals and landfill operations to comply with increasingly strict environmental legislation, to reuse water and energy, and to apply best available technique (BAT).

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Understanding combined sewer overflow with Calibrated Models

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Abstract

Kalundborg Forsyning supplies sewer systems in the municipality of Kalundborg in Denmark. The municipality consists of a medium sized town with 16,000 inhabitants and four larger villages. During heavy storms, the storm water and wastewater flow in the sewer system is a challenge, as the existing sewer can only handle a limited amount of flow. The solution in such circumstance is to provide structures in the sewer system, diverting untreated flow above a certain volume in the sewer system into water bodies. These structures also known as weirs, altering the flow characteristics, are commonly used to prevent flooding and to control the untreated volume discharged to water bodies. The discharged water volumes, called combined sewer overflows (CSOs), are a major pollution concern in urban drainage management.

Modelling is well-suited to understand the extent of CSOs in a community. Mathematical models can compute important parameters such as the numbers, durations and volume of CSOs during various storm intensity situations. Models are also useful to investigate if CSOs are in compliance with government regulative requirement and for upgrading and reducing overflow discharge from weirs. Kalundborg Forsyning has a goal to run working models of the complete sewer system of the municipality. An important part of this process is the calibration and verification of the models as well measurement campaigns. Calibration ensures that the simulated results fit reasonably well with the flow and level observations in the short-term measurement campaign.

The measurement campaigns are crucial for calculating important parameters such as reduction factor, initial loss, catchment imperviousness, water balance from the catchment and the entire sewer network as well to minimize the differences between normal simulation result and real life measured field data. After the calibration have been carried out and the goodness of fit of the model is established, Long Term Statistics (LTS) simulation is then applied with standard rain series to calculate flow rates, water levels, the annual average overflow volumes, the overflow frequency and the return period for single event overflow volumes and floods.

Based on a goodness of fit between model water level/flow and reality water level/flow, it is possible to have a reasonable trust in the CSOs discharge volumes and numbers to be computed in the model LTS simulations.

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Use of Life-cycle assessment for including the environmental dimension in the decision making process in the water utility

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Abstract
Life-cycle assessment (LCA) is internationally acknowledged as the most comprehensive tool for assessing the environmental impacts of a product or system. LCA is being used more and more on water systems for evaluation of environmental impacts especially when it comes to comparing impacts from changes in the water cycle. Also in water utilities in Denmark LCA is used for identifying environmental hot spots and choosing technologies having lowest possible environmental impact. Research projects are started up on LCA of climate change adaption technologies (green or concrete) and impacts of freshwater withdrawal (used in well field operation) in 3VAND which is a cooperation of research projects within the three largest cities of Denmark.

At HOFOR LCA is today being used for assessing environmental impacts and incorporating the results in the decision making and communication of our drinking water or waste water management. This presentation will focus on three cases where LCA-results are used for strengthening the environmental part of decision making and communication of e.g. effects of changes in the drinking water production to our customers. The cases are LCA of 1) Central softening of drinking water; 2) Transport of excavated soil; and 3) Steps to improve water safety and quality of drinking water processes.

The first case is an LCA of central softening of drinking water for Copenhagen including processes at the waterworks such as building of the pellet reactor, energy and chemicals for the softening process – these are all processes that lead to higher environmental impact. In the households, effects of the softened water are identified such as lower electricity consumption for heating water, reductions in laundry detergent, prolonged service life of domestic household appliances, etc. The result of the LCA including both effects at waterworks and in the households in the LCA showed that the net environmental impact was negative, meaning that central softening is preferable from an environmental point of view.

The second case was used for choosing which soil depot to deposit soil from excavations done in the city where networks are established or pipes are replaced frequently. The LCA-results gave us new knowledge on the different routes and their environmental impacts. The results are now being used for negotiations with entrepreneurs on where to deposit soil from the utility’s excavations. A map of most environmentally routes to soil deposit from excavations in HOFOR area was drawn based on the LCA-results, Fig. 1.

Last, the third case evaluates the impacts of introducing UV disinfection and activated carbon filtration to improve safety and water quality. The results show that the additional treatment steps increase the environmental burden from the production and delivery of drinking water. However, the question is whether reduced risk and added security can make up for an extra CO₂-emission?

Figure 1 Map of HOFOR area showing the environmentally preferable routes for transport of excavated soils.

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A multi-disciplinary on- and offshore case study used as background for coastal zone architecture modelling

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Abstract
The overall objectives of the Geocenter project SaltCoast, is to analyse and quantify the significance and dynamics of past and future sea level on saltwater intrusion into groundwater aquifers of low-lying coastal areas. To reach the goal the architecture of the sub-surface is used as basis for a groundwater model and the hydraulic impact from past ice sheets on the current hydraulic system is analysed. Based on the model, future climate change impacts on saltwater intrusion and water resources are predicted.
This presentation will focus on the challenging task to combine on and offshore geophysical methods as well as groundtrouthing to construct a model that describes the geological setting across the present coastline. The study area is located in the border region at the south-western corner of Denmark.
Onshore exceptional geophysical and geological databases include 3200 line kilometres of airborne transient electromagnetic (SkyTEM) data, 38 km of high resolution seismics, conventional oil seismic, new deep investigation wells, and numerous geological logs are available. Offshore multichannel reflection seismic archive data acquired between 1995 and 2001 has been supplemented by new high resolution shallow water multichannel reflection data from the Danish Wadden Sea. The data are unevenly distributed especially offshore, which makes the modelling challenging.
A broad geological overview and understanding was obtained by joint interpretation of the geophysical and the geological data. The geological complexity varies significantly across the model area. Cross-cutting tunnel valleys, erosional unconformities, delta units and large glaciotectonic complexes are among the identified geological features.
The onshore data allowed the construction of a detailed voxel model with lithofacies attributes supplemented by a number of bounding surfaces. The results from onshore were extrapolated into the offshore part in order to better understand the offshore geology with sparse data coverage. The very detailed offshore data here enabled, on the other hand, detailed 2D studies of erosional, sedimentary and glaciotectonic structures.
The study shows that it is possible to combine on- and offshore data in areas with varying geological complexity and data density and to construct a combined coastal zone model. Such a model is critical for accurate predictions of saltwater intrusion and submarine groundwater discharge.

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Addressing the Chinese water challenges with hydroeconomic modelling

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Abstract
Population growth and rapid development of the Chinese economy have increased water scarcity and put the natural water resources and aquatic ecosystems in the North China Plain under pressure. Dry rivers, decreasing groundwater tables and strongly polluted surface water are some of the consequences of this development. As a response, the Chinese authorities have launched 2011 No. 1 Central Policy Document, with the Three Red Lines setting strict targets related to water scarcity and water quality. These policy documents mark an important step towards sustainable management of the Chinese water resources. The targets are, however, highly coupled and attempts to meet all targets with uncoordinated regulation will therefore likely fail. Water allocation, groundwater pumping, hydropower production, wastewater treatment, river water quality, water for ecosystems and water diversion are all elements of one large coupled management problem, which underlines the need for decision support tools that can deal with water management in an integrated manner.

A traditional stochastic dynamic programming (SDP) approach was used to minimize the basin-wide total costs arising from water allocation, water curtailment and water treatment. One-step-ahead sub-problems were solved for all combinations of discrete reservoir storage, Markov Chain inflow classes and monthly time steps. A water quality module to handle conservative pollutants, first order depletion and non-linear reactions was introduced. This compromised linearity of the objective function which was handled by outsourcing complicating decision variables to a genetic algorithm, which calls a linear program to determine the remainder of the decision variables. This hybrid formulation keeps the optimization problem computationally feasible and represents a flexible and customizable method. The proposed hydroeconomic optimization modelling approach has been applied to the Ziya River Basin, a part of Hai River in North China. The model provided valuable decision support, such as long-term optimal reservoir operation and optimal allocations to the water users. Finally, the model can also be used to assess costs of meeting constraints such as minimum water quality or to economically prioritize investments in waste water treatment facilities based on economic criteria.

While the SDP-based model provides important decision support for the Ziya River Basin, the method scales poorly to more complex management problems with multiple state variables, e.g., reservoirs and aquifers. Future research will target this computational limitation by switching to a Model Predictive Control-based approach. This will allow inclusion of a more realistic representation of the system, e.g. delayed yield in agriculture along with multiple reservoirs, aquifers and water quality aspects.

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Using robust decision making to support seasonal water management in the Chao Phraya River basin, Thailand

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Abstract
A robust decision making application is demonstrated that supports seasonal water management in the Chao Phraya River basin in Thailand. The approach uses ensemble simulation and data mining tools to identify uncertain factors that may lead to unacceptable performance. The approach has the potential to support decision making through evaluation of decision performance under uncertain future conditions that may not be possible to characterize in terms of probabilities.

The Chao Phraya River basin supports significant dry season irrigation, particularly for growing rice, and the management of reservoir storage to support dry season irrigation has emerged as a challenge. Dry season irrigation in Thailand is managed through a mixture of non-binding recommendations about the maximum extent of rice cultivation, along with incentives to grow less water-intensive crops. Recommendations are made at the beginning of each dry season based on reservoir storage.

The extent of rice cultivation during the dry season frequently exceeds recommendations, and management authorities lack authority to prevent river withdrawals for irrigation. In practice, this means that authorities have to provide enough water to irrigate the actual planted area because of downstream municipal water supply requirements and water quality constraints. This results in dry season reservoir withdrawals that exceed planned withdrawals, reducing carryover storage to hedge against insufficient wet season runoff, which varies considerably from year to year.

The dry season planning problem in Thailand can therefore be framed in terms of decisions, objectives, constraints, and uncertainties. Decisions include recommendations about the maximum extent of rice cultivation and types of incentives given for growing less water-intensive crops. Objectives are to maximize benefits to farmers, minimize the risk of inadequate reservoir storage at the start of the following dry season, and minimize the amount spent on incentives. Constraints include downstream municipal water demands and water quality requirements. Uncertainties affecting the decision include the actual extent of rice cultivation, dry season precipitation and reservoir inflow, and precipitation and reservoir inflow in the following wet season.

A robust decision making approach is used to provide analytical support to this decision making process. The approach is based on a river basin simulation model and a crop water demand model. The crop water demand model estimates irrigation water demands, and the river basin simulation model estimates reservoir drawdown required to meet demands given forecasts of precipitation, evaporation, and runoff. An ensemble of uncertain model inputs is generated by randomly sampling from hydrological data and crop areas observed in the historical record. The input ensemble is used to generate an ensemble of results and indicator values for each of the decision objectives: farmer benefits, end-of-wet-season reservoir storage, and the cost of incentives. Threshold values are defined for each of the objectives to identify ensemble members for which objective values are unacceptable. The PRIM data mining algorithm is then used to identify input values associated with unacceptable model outcomes. The approach will be tested with stakeholders and decision makers to assess whether it is useful for evaluating and refining decisions given uncertain future conditions.

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Room for Rain

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Abstract

The PhD-project ROOM FOR RAIN is a partnership between University of Copenhagen, the Danish architecture firm Gottlieb Paludan Architects and the Danish engineering firm Ramboll. The overall aim of the PhD-project ROOM FOR RAIN is to synthesise knowledge about urban public space and rainwater drainage in order to develop decision supporting tools and strategies for future climate change adaptation of urban streetscapes in Denmark. The PhD-project is rooted in the discourse of landscape based stormwater management1 and builds upon an understanding of landscape and urbanity as inseparable dimensions.

The main hypothesis of ROOM FOR RAIN is that by combining landscape based stormwater management and technical solutions in the transformation of the urban streetscapes in Copenhagen, uncontrolled flooding and resultant damage to buildings and infrastructure will be reduced while the liveability of the road and streets may be improved.

Through that lens stormwater management may be regarded as a key driver to develop our urban transportscapes and break their monofunctional status and thereby change our current understanding of the street as a predominantly technical environment. From a design and an architectural approach roads and urban streets have for many years been overlooked and neglected urban public spaces, despite that they are some of the public outdoor spaces that we are in most contact with in our everyday life. The presentation will highlight examples supporting the above-mentioned hypothesis and unfold the mechanisms behind this.

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1 E.g. Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID) and Water Sensitive Urban Design (WSUD)
Monitoring eight different SUDS solutions in Hornemanns Vænge

M. Holmbo Lind, Sweco Danmark*

Abstract
Since 2007, sustainable urban drainage systems (SUDS) have been suggested to play a part in solving challenges with excess water in urban areas in Denmark. The following year’s heavy rainfall events and resulting damages have furthermore pushed decision makers and utilities to implement new and untraditional concepts of storm water management. Since 2012, SUDS solutions have been implemented in Denmark at a larger scale and every year more are being realised. However, there are still many unknowns in the efficiency and lifetime of these new methods. This calls for the implementation of monitoring programmes in new installations as proposed in the Hornemanns Vænge project in Valby, Copenhagen, commissioned by HOFOR.

In the Hornemann Vænge project eight different SUDS solutions will be installed and monitored. The parameters investigated includes hydraulic operation, construction cost for the SUDS elements, cost of landscape elements and cost of the maintenance of the SUDS and landscape elements respectively, over a three year period.

This presentation will cover the monitoring programme and the general concepts of the SUDS solution of the project.

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Benløse Bypark: A Proactive & Engaged Approach

N. H. Mclean Goring & T. Stausgaard Munk, Rambøll*

Abstract
Since the eye-opening flood of July 2011, Copenhagen has been working full throttle to future-proof the city against such damages again. With the impacts of climate change we can expect up to a 40% increase in cloudburst intensity in the next 100 years, meaning the situation will only get worse. However, this flood only hit the east coast of Zealand and it is not easy to convince those who have not been affected, that they should invest in solving a problem they do not appear to have, yet.

Municipalities have been advised to undertake flood modelling to identify areas at risk. Ringsted Municipality, together with Ringsted Utilities, have identified the area of Benløse as a potentially high risk area. In order to obtain public and political support they have combined the climate adaptation project with disconnecting of the sewer system and uplifting of the local park, Benløse Bypark. This synergy between projects allows Ringsted to take a proactive approach to climate adaptation while also engaging the locals with the prospect of an improved park.

Rambøll have designed an improved, multifunctional town park through an iterative process with public participation meetings. The new park will provide additional activities, better access and improved safety while also providing an area for controlled flooding during extreme rain events.

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The role of the utility in climate adaptation planning

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Abstract

This presentation describes Greater Copenhagen Utility’s (HOFOR) role in planning, coordinating and implementing Copenhagen’s Climate Change Adaptation Plan and Cloudburst management strategy, when it comes to involving private citizens to participate.

Detailed hydraulic modelling of the seven catchments in the city resulted in the preparation of a cloudburst managing plan with more than 350 interventions at a budget of 1.3 billion euro.

More than 80 interventions are planned on private streets and areas. Among the planned projects are designated Cloudburst boulevards, Retention spaces and Green roads.

Information and involvement of private citizens early in the process is vital for including the private areas, which is necessary for the overall climate change adaptation and cloudburst system to function successfully.

As a result, the role of the Greater Copenhagen Utility in this project deviates from normal procedure, and therefore a change of mindset is needed to apply a multitude of relative smaller projects in an overall cloudburst management.

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GISMOWA – GIS assisted monitoring of drinking water quality

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Abstract
In-depth knowledge of the water distribution system is crucial to develop water quality baseline data at representative sites and to provide a pro-active approach to deal with emerging water quality issues. GISMOWA is a new risk-based analysis tool to identify and prioritise pipe segments for monitoring water quality and to comply with existing monitoring guidelines. The tool was designed to integrate in a GIS environment multiple parameters categorized as 1) Weaknesses in the system, e.g. residence time, 2) External threats, e.g. contaminated sites, and 3) Sensitive consumers, e.g. hospitals.

A multi-criteria decision-making approach was applied to evaluate multiple sampling site parameters and map zones particularly suitable for water quality monitoring. Applied on Danish water distribution systems, GISMOWA was shown to be a transparent and simple-to-use tool that facilitates complete overview of the distribution system, sensitive consumers and consumers in general, which is a precondition for a HACCP-based monitoring strategy of drinking water.

Figure 1 Example of suitability maps for three selected parameters projected onto the main piping network in Odense, Denmark. Data collected from VCS Denmark. Green shows pipe segments of low suitability and red visualises pipe segments of high suitability for monitoring.

Figure 2 Example of weighted overlay results projected onto the main piping network in Odense, Denmark. Thin blue lines outlines the main piping network, while fat lines show pipe stretches particularly suitable for monitoring of sensitive consumers (blue), microbial regrowth (red), and intrusion of contaminants (green).

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Early warning of unacceptable pathogen concentration in raw water intake in Götaelv, Gothenburg, Sweden

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Abstract

River water is a dominant source of raw water for production of drinking water all over the world. River water is usually contaminated either permanently or intermittently by waste water. Hence production of drinking water from river water is associated with a high risk of being influenced by pathogens or faecal indicators.

The drinking water treatment includes barriers to remove or inactivate the pathogens present in the raw water. However the barriers have a limited ability to reduce the concentrations of pathogens. The treatment efficacy depends on the specifications of the barriers such as contact times, membrane pore size etc. By using quantitative microbial risk assessment (QMRA) and assuming or measuring the pathogen concentrations in the raw water, the sufficient log reduction by the treatment barriers can be calculated to achieve an acceptable risk of infection of the consumers. Similarly, in an existing drinking water treatment system, the treatment efficiency can be determined, and based on an acceptable risk of infection, a maximum accepted concentration in the raw water can be determined.

We have combined our hydraulic models for estimating pathogen concentrations in the water in Göta river (Sweden) with QMRA, to be able to give early warnings for unacceptable high concentrations of pathogens in the raw water for the Gothenburg Water Supply at Larjeholm.

We will in the paper to show how the model results combined with determination of acceptable concentrations can be used for drinking water management.

An outline of the hydraulic models is shown in Figure 1.

![Figure 1 Details of the hydraulic model of the Götaelv](image)

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Drinking water application of a real-time bacteria monitoring system

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Abstract
In recent years, significant efforts have been made by companies in numerous countries to develop a bacteria sensor for real-time monitoring of bacteria in water. Recently, the Danish company Grundfos launched a fully automated monitoring system under the name BACMON. This system has low maintenance requirements and high sample throughput. Although results do not replace compliance monitoring nor supply information regarding which type of bacteria are present, the monitoring system fulfills many of the water sector’s requirements for real-time bacterial monitoring, marking an important step towards providing 24/7 security from bacterial contamination.

The Research Group for Energy and Environment, VIA Engineering has recently investigated this monitoring system in a number of drinking water applications. The presentation will describe the sensing technology utilized by the device, list some of the lessons learned with respect to practical use and discuss important details related to interpretation of results.

Several cases will be presented, including lab-scale spike tests and full-scale application. The graph below shows an example of results for the bacteria and non-bacteria categories. Finally, the presentation will conjecture about the future of bacteria monitoring in drinking water applications.

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The impact of backwashing on nitrification in biological rapid sand filters under different ammonium loading conditions

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Abstract

Biological rapid sand filters can be a simple yet robust treatment process in removing both particles and dissolved contaminants in the production of drinking water. Biological removal of contaminants is performed by a complex community of microorganisms that colonize and grow on the filter media (Gülay et al., 2014; Tatari, 2014). One compound of concern in these filters is ammonium, which is removed biologically through the nitrification process. Nitrification is generally thought to be a two-step process involving ammonia-oxidizing bacteria (AOB), which oxidize ammonium to nitrite, and nitrite-oxidizing bacteria (NOB), which further oxidize nitrite to nitrate. There are many parameters that can affect nitrification performance (Lee et al., 2014), including operating parameters such as backwashing.

Backwashing is a major operating parameter that is needed to ensure proper operation of these filters. Backwashing is used to remove biomass and particles that accumulate on the filter material over a filter run. It is often thought that backwashing can decrease the biological performance of a filter due to the excessive removal of biomass. The goal of this research is to determine the impact that backwashing has on both the nitrification process, and the nitrifying organisms established on the filter material under various ammonium loading and backwashing conditions.

Backwashing experiments were conducted on two pilot scale biological rapid sand filters at Islevbro waterworks, in west Copenhagen. The pilot columns were operated in parallel and filled with filter media from one of the full scale filters. The pilot columns were initially operated for several months to establish steady state conditions and to validate the performance of the pilot filters with the full scale filters. After this a series of short term (6-8 hours) ammonium load shift experiments were performed by increasing the ammonium concentration and/or flowrates of the pilot columns. The load shifts were designed not to alter the overall performance, or biological make-up of the pilot columns, and used to examine the ammonium removal rate before and after backwashing, and over the filtration run. These experiments showed that backwashing had little to no effect on either ammonium removal or ammonia-oxidizing bacteria, which showed only a 9% decrease after backwashing. Over a 23 day filter run, there was no change in ammonium removal, and ammonia-oxidizing bacteria only increased by approximately 14%. This strongly indicates that the ammonia-oxidizing bacteria are robust and well established and that the system is operating at steady state.

To access the effect of backwashing under long term increased ammonium loading conditions, the ammonium concentration to one of the pilot columns was increased from 0.1 to approximately 1 mg NH4-N/L for 50 days. The column was backwashed normally on days 23 and 45 and ‘intensely’ backwashed on day 50. Ammonium removal and biomass increased from day 0 to 23, but much of the increase in removal and biomass was lost after backwashing. The increased removal was transient and the newly developed biomass fragile and not yet well established. After another 22 days, the second backwash, on day 45, showed little effect on ammonium removal, and even the ‘intense’ backwash on day 50 did little to change the ammonium removal in the pilot column. The long term increased loading results showed that early on the newly formed biomass was not well established and easily removed by backwashing. Subsequent backwashes had little effect on ammonium removal though, indicating the biomass can quickly become established in these filters. These results show the robustness of well-functioning biological filters in removing ammonium from drinking water under different loading conditions.


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Assessment of Distributed Temperature Sensing as a tool to identify the spatial variability in contaminant loading to surface waters

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Abstract

Fiber optic Distributed Temperature Sensing (DTS) has been recently introduced to hydrological studies as a tool to identify spatial variability in groundwater discharge to streams, lakes, and fjords based on the temperature differences between surface water and groundwater. The fiber optic cable is placed on the sediment-water interface and measures the temperature distribution of the sediment surface, thereby indicating locations of concentrated groundwater discharge. Depending on the available cable length, the intensity of surface water-groundwater interactions can be mapped over larger areas. As the technique is suitable for the detection of areas with concentrated groundwater discharge, the underlying idea of this study is to trace contaminants entering with groundwater discharge to a stream, thus delineating areas of interest for remediation.

In Hagfors, Sweden, a former dry cleaning facility historically released a significant amount of perchloroethylene (PCE) to the soil and groundwater also polluting a stream, Örbäcken with approximately 500 kg of PCE per year. A DTS field study has been carried out along the stream to identify locations of concentrated groundwater discharge indirectly suggesting locations of increased PCE load. Vertical groundwater fluxes have been estimated based on vertical sediment temperature profiling in areas of increased groundwater discharge. The chemical analysis of groundwater from identified locations has been used to assess the capability of DTS to detect the entry of contaminants to the stream and the spatial distribution of contaminant loading. The combination of the two temperature tracing methods provides (1) areas and (2) flux (m³/year) of high groundwater discharge and combined with the chemical analysis it is possible to (3) estimate total load of PCE to the stream (kg/year).

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Detailed study of the calcium carbonate system in a calcareous fen in Vasby

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Abstract
The geographical extent of calcareous fens and the biodiversity of their distinctive flora of rare calciphile species have decreased over the past decades. This is a result of agricultural, industrial, and suburban developments and increased extraction of groundwater, thus altering the hydrology and geochemical settings in the fens. The rarity of the flora and the extinction of the habitat have motivated the United States of America and EU to protect the calcareous fens.

Earlier studies have shown that the existences of calcareous fens are directly controlled by the regional groundwater flow systems and the chemical composition of the groundwater. Therefore it is necessary to obtain a better understanding of the hydrology and geochemistry controlling the environment for future protection and dissemination of the calcareous fens.

The focus of this study was limited to one Danish calcareous fen, Vasby Fen, located north of Sengeløse in the eastern part of Zealand, Denmark. The aims of the study were to;

1. Characterize the geochemical processes that have led to the chemical composition in the discharging groundwater in the calcareous fen;
2. Characterize the geochemical processes maintaining the alkaline conditions within the calcareous fen.

Results show that Vasby Fen differs from most previous studies of calcareous fens due to a high concentration of SO4 and a distinct vertical variation in the chemical composition between the shallow(0-1m.b.s) and the deeper groundwater(2-3 m.b.s.). Interpretation of the data led to the conclusion that the high concentration of SO4 in Vasby Fen is a result of chemical processes occurring upstream from the fen and subsequently transported by the groundwater. The distinct vertical variation in the chemical composition is deriving from the presence of two different hydrological flow systems, with different chemical compositions, within the fen.

The study additionally showed the importance of combining and integrating hydrogeochemistry and hydrogeology in order to understand the complexity of the dynamics controlling the extent of the calcareous fen.

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Controls on the spatial and temporal variation in \( \delta^{18}O \) and \( \delta^2H \) of water in Danish precipitation: major processes and small scale climatic influences.

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Abstract

The utilization of \( ^{18}O \) and \( ^2H \) as tracers for hydrological studies is increasing due to cheaper analytical methods recently developed, combined with the ease of sampling. The spatial and temporal variation in \( \delta^{18}O \)- and \( \delta^2H \)-values of water in the hydrological cycle can yield information on paleo-climatic conditions, delineate groundwater flow paths, and quantify hydrological fluxes or surface water-groundwater interaction and rainfall-runoff processes. Moreover, temperature increases within the next century are expected to shift the isotopic composition of precipitation fast compared to residence times of water in the hydrological cycle. Crucial for the successfully application of \( \delta^{18}O/\delta^2H \) tracer methods, the temporal and spatial \( \delta^{18}O/\delta^2H \) variability in precipitation has to be known. Since 2012, monthly samples of accumulated precipitation at six stations distributed across the Jutland high ridge have been collected. The project is initiated by the HOBE project (Hydrological Observatory) in collaboration with IAEA (International Atomic Energy Agency). For the current study a 2½ year dataset is analysed in order to detect seasonal fluctuations and climate parameters governing the \( \delta^{18}O/\delta^2H \) composition of Danish precipitation. One of the aims is to derive a local meteoric water line (LMWL), which by comparison with water sampled from different hydrological compartments can be immediately used to infer important hydrological processes. The LMWL for the Jutland catchment is \( \delta^2H=7.4\delta^{18}O+5.36 \). The samples show a good linear correlation (\( r^2=0.3 \)) to monthly average surface temperatures. However, \( \delta^{18}O \) correlates even better with monthly averaged relative humidity (\( r^2=0.37 \)). Furthermore, two groups can be distinguished, i.e. (i) spring and summer where an average humidity of 76\% (stdv.±4\%) causes the \( \delta^{18}O \)-value to be more enriched (-7.2‰), and (ii) autumn and winter months with average humidities of 85\% (stdv.±6\%) which are accompanied by more depleted \( \delta^{18}O \)-values of -8.4‰.

These results suggest that the evolution of \( \delta^{18}O \) is influenced by relative humidity on site. Hence, through humidity differences between rain and the atmosphere, evaporation is induced on the falling raindrop, enriching the remaining water in \( \delta^{18}O/\delta^2H \) via kinetic non-equilibrium fractionation especially during spring and summer month. This process is typical for arid areas and until now, this phenomenon has only been suggested in literature to potentially occur in more humid inland areas during summer month.

The study gives new process insights in the evolution of \( \delta^{18}O/\delta^2H \) composition in near coastal humid areas. Additional, the derived LMWL can serve as a baseline for future hydrological \( \delta^{18}O/\delta^2H \) tracer studies in Denmark and neighbouring countries.

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Sequential Gaussian simulation of gauge-based rainfall to assess uncertainty in the spatial representation of interpolated rainfall

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Abstract
This abstract describes a PhD project that is a part of the research activities related to the HOBE (“Hydrological Observatory”) project. Study areas are the Skjern catchment in western Jutland (2500 km²) and its largest subcatchment (Ahlergaarde, 1050 km²). The objective of the study is to assess the uncertainty arising from the interpolation of gauge-based rainfall measurements using a stochastic simulation technique, sequential Gaussian simulation (SGS), coupled with ordinary kriging (OK). The rainfall gauge data set that was used is a 16-year data record (1990-2006), comprising data from 45 gauges located within and in close proximity of the Skjern catchment. The rainfall data was bias-corrected (i.e. accounting for wind-induced undercatch, wetting loss etc.) prior to this study.

While OK is a popular interpolation techniques, it is unable to capture the spatial variability of rainfall, thus underestimating the associated uncertainty. SGS allows the generation of an arbitrary number of realizations that are conditioned on the data but are “noisier” than the kriging results at unobserved locations, thus considered to better capture the spatial variability. When aggregating the different realizations of SGS rainfall to time series and propagating these through a hydrological model, the impact of spatial uncertainty on model results can be assessed.

The application of SGS requires a) the data to follow a Gaussian distribution and b) since it is coupled with OK, a semi-variogram. Considering a), a square-root-transformation was applied, after which the rainfall data was considered to be app. normally distributed. With regard to b), a selection criterion was defined: only days at which all gauges in and around the Skjern catchment registered rainfall amounts > 1 mm were selected (n = 226). This was intended to ensure a more robust variogram analysis. Subsequently, the sqrt-transformed rainfall data for the selected days was normalized, the pooled semi-variogram estimator calculated and a spherical model was fitted. The pooled semi-variogram model was then applied to every day of the data set (re-scaled by the variance of each day) during the SGS.

SGS was only performed for the Ahlergaarde catchment due to the high computational costs of running this algorithm. When performing the SGS, grid locations were visited following a random path. At every visited grid location, OK determined the kriging estimator and variance at that location, which in turn defined the parameters of a normal distribution. A value was then randomly sampled from this distribution and added to the conditioning data set. In addition, a perturbation factor of 5% was imposed on the gauge data for every realization, representing uncertainty on the gauge data itself. Also, to account for zeros in the gauge data, a corresponding percentage of the (ranked) SGS values were set to zero after the simulation. Finally, the data was back-transformed. Subsequent analyses were carried out with regard to e.g. the impact of the number of SGS replicates generated or the length of the simulation period on the uncertainty in the annual value at both catchment and grid cell scale.

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Developing national scale real-time hydrological modelling system for both surface water and groundwater in Denmark

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Abstract

Hydrological models are important tools to support decision making in water resource management in the past few decades. Nowadays, frequent occurrence of extreme hydrological events has put focus on developing real-time hydrological modelling and forecasting systems. Among the various types of hydrological models, it is only the rainfall-runoff models for flooding events that are commonly used in the online real-time fashion; and there has never been a tradition to use integrated hydrological models for both surface water and groundwater with large scale perspective.

At the Geological Survey of Denmark and Greenland (GEUS), we have setup and calibrated an integrated hydrological model that covers the entire nation, namely the DK-model. So far, the DK-model has only been used in offline mode for historical and future scenario simulations. Therefore, challenges arise when operating the DK-model in real-time mode due to lack of technical experiences and stakeholder awareness. In the present study, we try to demonstrate the process of bringing the DK-model online while actively involving the opinions of the stakeholders. Although the system is not yet fully operational, a prototype has been finished and presented to the stakeholders, which can simulate groundwater levels, streamflow and water content in the root zone with a lead time of 48 hours and refreshed every 6 hours. The active involvement of stakeholders has provided very valuable insights and feedbacks for future improvements.

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30 years of geophysical data – one groundwater model structure

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Abstract
In Denmark, geophysical data and models are always stored in the national geophysical database, hereby making them broadly available to practitioners and researchers. This comprehensive dataset provides groundwater modellers with a unique possibility when working with regional scale hydrological models. These regional scale structures can be generated using boreholes to link between hydrostratigraphical classes and formation resistivity. Subsequently, they can form input to a groundwater model calibration or serve as a basis for further geological analysis.

We present the results of an automatic method for parameterization of a 3D model of the subsurface, integrating lithological information from boreholes with resistivity models. The objective is to create a direct input to regional groundwater models for sedimentary areas, where the sand/clay distribution governs the groundwater flow. The resistivity input is all-inclusive in the sense that we include data from a variety of instruments (DC and EM, ground-based and airborne), with a varying spatial density and varying ages and quality. The coupling between hydrological and geophysical parameters is managed using a translator function with spatially variable parameters, which is calibrated against observed lithological data. In other words, the translator function interprets the geophysical resistivities into a 3D clay fraction model and the 3D clay fraction model is then turned into a zonation for the hydrological model by a K-means clustering.

We present the methodology by show-casing a study were a regional groundwater model is constructed by including lithological information from 3100 boreholes over an 710 sqkm area. The geophysical models spans more than 30 years of data collection and includes approx. 225,000 DC models, and 35,000 airborne as well as groundbased transient electromagnetic models. The final model was calibrated to hydraulic data, and benchmarked to a model structure obtained from the National Water Resource model of Denmark. Finally, we show how this new model approach can be used to represent dynamic boundary conditions for more local scale models using the MODFLOW-USG.

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Addressing structural uncertainty of groundwater model predictions with ensemble of automatically generated models from AEM geophysical data and borehole data

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Abstract
Subsurface structural uncertainty is a major contribution to uncertainty in groundwater model transport- and travel path/time-predictions. However, the contribution from subsurface structural uncertainty is often neglected, and for practical and methodological reasons, models are represented using a single deterministic structure. In most cases, deterministic approaches will greatly underestimate the uncertainty of groundwater model predictions.

We present a method where an ensemble of subsurface structure models can be automatically generated from borehole information and airborne electromagnetic (AEM) geophysical data. Resistivity distributions obtained from the AEM data are inverted together with lithological descriptions into clay fraction values in an ACT-inversion. The output is subsequently clustered into categories using k-means clustering. Utilizing sequential indicator simulation the categories are simulated onto a regular grid, forming an ensemble of subsurface structure realizations. The uncertainty captured in this ensemble represents variable data coverage.

Each structural realization is assumed to have uniform hydraulic properties within the clusters. The values of these properties are estimated with a steady state MODFLOW-USG groundwater model by calibrating the model to head and flow observations. Based on the ability of each structural realization to fit the hydraulic dataset, a subset of behavioral models is selected for predictive purpose. In the present case well capture zones are predicted for each realization using mod-PATH3DU. From the ensemble of behavioral models, we estimate the uncertainty of well capture zones (see figure 1). The results are compared to a deterministic subsurface structure model, for which particle endpoints fall within the capture zone uncertainty area, see black dots in figure 1.

In addition to addressing groundwater model predictive uncertainty, the proposed method honors all available data, lithological, geophysical and hydrological. At the same time it is automatic, objective and entirely reproducible.

Figure 1 Probability map of well capture zone from ensemble. The colours represent percentages of the realizations where a particle endpoint falls in that given area. Black dots are particle endpoints of a deterministic structure model.

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Detailed geological modelling in urban areas focused on structures relevant to the near surface groundwater flow in the context of climatic changes

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Abstract
This case demonstrates two practical examples from the city of Odense (DK) where new geological modelling techniques have been developed and used in the software GeoScene3D, to create detailed voxel models of the anthropogenic layer and the uppermost soil layers (to approx. 6 m below terrain). The voxel models have been combined with a regional hydrostratigraphic layer model.

The two models can be described as 3D geological property models: One is part of a pilot project partly financed by VTU (Foundation for Development of Technology in the Danish Water Sector) and involves many different datatypes such as borehole information, geophysical data, human related elements (landfill, pipelines, basements, roadbeds etc.). The resulting geological model is based on an assumed sand-clay fraction in the different soil types. The other model is from a specific case where the voxel model is serving as input to a hydrological model, used for modelling the surface near water flow. Here the voxel model is based on K-values (transmissivities) of the different soil types.

In the last few years, focus on detailed geological modelling in urban areas has increased. The models serve as important input to hydrological models. This focus is partly due to climate changes as high intensity rainfalls are seen more often than previous, making surface near water flow and recharge of surface water an important topic. In urban areas, this arise new challenges. There is a need of a high level of detailed geological knowledge of the uppermost zone of the soils, which typically is problematic due to practical limitations in the nature of the typically used geological layer models. Furthermore, to accommodate the need of a high detail, all relevant available data has to be used in the modelling process. Human activity has deeply changed the soil layers, e.g. by constructions as roadbeds, buildings with basements, pipelines, landfill etc. These elements can act as barriers or pathways regarding surface near groundwater flow and can attribute to local flooding or mobilization and transport of contaminants etc.

A geological voxel model is built by small boxes (a voxel). Each box can contain several parameters, ex. lithology, transmissivity, or contaminant concentration. Human related elements can be implemented using tools, which gives the modeller advanced options for making detailed small-scale models. The cases demonstrate the workflow and the resulting geological models for the two areas.

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Smart Interpretation – A new tool for fast geological modelling of AEM data

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Abstract
When using airborne geophysical measurements in e.g. groundwater mapping, an overwhelming amount of data is collected. Increasingly larger survey areas, denser data collection and limited resources, combines to an increasing problem of building geological models that use all the available data in a manner consistent with the geologists knowledge on the geology of the survey area.

In the ERGO project, funded by The Danish National Advanced Technology Foundation, we address this problem by developing new usable tools, enabling the geologist to utilize her geological knowledge directly in the interpretation of the AEM data and thereby handle the large amount of data.

In the project, we have developed the mathematical basis for capturing geological expertise in a statistical model. Based on this we have implemented new algorithms that have been operationalized and embedded in user friendly software. In this software, the machine learning algorithm, Smart Interpretation, enables the geologist to use the system as an assistant in the geological modelling process. As the software ‘learns’ how the geologist interprets the geology from the geophysical data, the system suggest new interpretations at other data locations.

In this presentation we present the workflow, and demonstrate the application of the results from the ERGO project.

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Mapping opportunities for rainwater infiltration around Horsens State Prison

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Abstract
The Municipality of Horsens, Road and Traffic Department would like to investigate the rainwater infiltration potential in the area around The Prison to avoid flooding and erosion of the festival site. Focus is on the stage area west-northwest of the prison, as well as the northern part of the area.

ALECTIA combine geophysical mapping, hand drilling, geotechnical borings and subsequent slug and infiltration tests to examine the infiltration potential. The geophysical mapping has been carried out by use of the CMD-Explorer from GF Instruments. The instrument measures the apparent electrical conductivity below the surface by induction, and is pulled by an ATV, driving 5 km/h, measuring at a sampling interval of 0.5/sec, equivalent to one data point for each approx. 0.7 meters.

Based on the geophysical mapping, 2D maps of the electrical conductivity 2.2, 4.2 and 6.7 meters below terrain are produced, covering an area of more than 8 hectares.

Together, the geophysical mapping, geotechnical borings, and the infiltration tests provide an indication of where to place the infiltration installations. Preliminary results indicate infiltration possibilities in multiple areas around the prison (see Figure 1).

![Map of Horsens State Prison with infiltration potential areas highlighted](image.png)

Figure 1 Apparent Conductivity
4.2 meters below terrain

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Carcinogenic bracken compounds in surface stream water during base flow and storm events: A case study from Yorkshire, United Kingdom

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Abstract
The globally occurring bracken fern (Pteridium aquilinum) is widespread in the broadleaf forests of Denmark and densely populates several vegetation types on the British Isles. Bracken is toxic to livestock when consumed, and a group of potent carcinogens have been identified, of which the compound ptaquiloside (PTA) is the most abundant. Ptaquiloside has been shown to be highly water soluble, leachable from bracken fronds and litter, and present in the soil below bracken stands. This has raised concerns over whether the compound might pose a risk to drinking water sources.

We present here a study of:
1) The base flow and storm event concentrations of PTA in a UK stream fed by a bracken-dominated catchment throughout the growth season. During storm events throughfall from the bracken canopy was collected as well.
2) How simple drinking water treatments affect realistic PTA levels in source water. Treatments included boiling, sand filtration, jug filtration (available commercially for consumers) and storage in water tanks of various materials.

Stream water samples were taken as grab samples, while throughfall accumulated in glass jars set out below the canopy. Field blanks and fortified lab controls were included to ensure reliability of the analysis. Ptaquiloside concentrations were determined using LC-MS/MS after a clean-up using solid phase extraction. Results showed that PTA levels in the stream were highly dependent on precipitation, rising considerably after a short time lag, peaking at 2.28 µg/L, before quickly (<2 hours) decreasing again when this ceased. Collected canopy throughfall showed high amounts of PTA (up to 339 µg/L) leached from bracken fronds during rainfall, with no apparent deterioration of this source throughout the storm event. None of the drinking water treatment techniques completely removed PTA, with the jug filter for consumer filtration being the most effective, eliminating about 68% of the contaminant. The results are important for Danish water resource management, as this shows the very real potential for PTA leaching to groundwater.

Investigations on the stability of PTA in different types of Danish groundwater are currently taking place.

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More than meets the eye
– bacteria and their predators live side by side in waterworks sand filters

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Abstract
Waterworks sand filters function as ‘black boxes’ – raw water containing high concentrations of iron, manganese and ammonium goes in and, if well-functioning, purified water ready for human consumption comes out. It is well known that both abiotic and biotic processes occur in the filters, the latter performed by bacteria residing in the filters. The black box has been opened and recent papers are describing the bacterial communities of sand filters e.g. Albers et al.2. However, the bacteria are not alone in the filters, the organisms that feed on them – the protozoa – also resides within waterworks sand filters.

We have in our research observed protozoa to be present in a handful well-functioning sand filters that we have investigated. These microscopical unicellular organisms in filter samples were dominated by flagellates and amoebae. The role that the protozoa have in the functionally of the sand filters is not established, though their presence shows that a complex food-web exists in the filters. Specifically, we focused our studies on the effect of introducing specific degrader bacteria to sand filters for bioaugmentation purposes.

We applied the degrader bacterium Aminobacter sp. MSH1 as a model organism. MSH1, which is able to degrade the pesticide metabolite 2,6-dichlorobenzamide (BAM), was introduced to sand filter systems at two different densities. The introduction of MSH1 at high densities was followed by a >1000 fold increase of the protozoan population size. Concurrently, Aminobacter numbers were reduced by 29% of the initial numbers added to the systems. Further, small scale sand filter columns were inoculated with MSH1 and supplied with BAM contaminated water. The results of our column experiment showed that, while sand filter columns with no protozoan grazing maintained a higher number of degrader bacteria and degradation potential during the experiment compared to columns with protozoan grazing, all inoculated columns removed BAM efficiently.

Conclusively, we demonstrated that the protozoa living in sand filters graze on the introduced MSH1 bacterium reducing its abundance. However, we assess that protozoan grazing will not as a single factor result in a complete removal of introduced bacteria or in bioaugmentation failure in rapid groundwater treating sand filters.

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Monitoring the potential for microbial degrading of chlorinated ethenes in soil aquifers

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Abstract

Chlorinated solvents are common contaminants being responsible for spoiling of groundwater resources – globally as well as in Denmark. Cleaning up of such polluted sites is very costly and often not possible in terms of removal of contaminated soil volumes. However, chlorinated ethenes may be broken down, in situ, by microbial means. Degradation may take place even at anaerobic conditions by halo-respiring bacteria belonging, namely, to the genus Dehalococcoides. It may be a feasible remediation approach to ensure the presence of indigenous soil microorganisms, which can degrade the chlorinated ethenes and monitor the degradation process over time to ensure that the pollution is gradually disappearing within a reasonable time. Accordingly, such monitored natural attenuation needs to be supported by chemical analysis of the contaminant (PCE) and degradation products (TCE, DCE, VC), as well as presence of the microorganisms involved in the degradation process. Real-time PCR analysis of water sampled in the polluted aquifer can be applied to monitor the presence of Dehalococcoides bacteria and genes responsible for the degradation of VC, the final degradation product of chlorinated ethenes. The measurement of the degrader bacteria is based on primers targeting the 16S sequence of the Dehalococcoides group. Monitoring of the vcrA gene coding for the enzyme responsible for the final conversion of VC to ethene is preferred because VC is very toxic and often accumulating due to slower degradation rates than the upstream degradation products. The sensitivity of these measurements is very high, but depends on the sampled volume of groundwater from where DNA is up-concentrated by Sterivex filtration. The real-time PCR-based analysis offers a good opportunity to qualify decisions by authorities and other stakeholders when trying to predict the fate of chlorinated ethenes in aquifers.

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Innovative ICT solutions for sustainable water provision to underserved populations

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Abstract

Grundfos Lifelink Water Solutions helps build resilience to the effects of climate change by providing access to safe, sustainable and affordable water to people in developing countries. Lifelink systems can be installed in large or small water schemes in both urban and rural settings. In urban areas, Lifelink systems can be connected to the water network or a water storage tank. In off-grid rural areas, Lifelink systems take the form of communal water points and mini-grids, drawing water from the ground or water treatment systems through solar-powered pumps. To collect water, people charge a smart card with credit bought onsite or via their mobile phones, insert it into the dispenser and pay for the water they need.

The Lifelink system with groundwater supply uses submersible pumps with a permanent magnet motor for high energy efficiency operation. Each of the motor fitted with a built-in electronics enables the use of renewable energy – eliminating the use of diesel power generation and reducing CO2 emissions.

In addition to building resilience to climate change, the reliable supply of water from Lifelink systems can also provide communities with increased food security, as well as generate income. The water supplied by Lifelink units can be used to grow produce through greenhouse drip irrigation systems, as well as to water livestock. The community is able to sell the produce, as well as the water to others both in and outside the community. This allows the community to generate income, which it can invest in other adaptive measures towards climate change.

After the deployment of more than 40 units and reaching more than 100,000 people in the African region, Grundfos Lifelink has learned that people in developing countries are willing to pay for water if they have confidence that the system can be trusted. To earn this trust, the water service provider must price the water in collaboration with the local community, according to its capacity to pay. The revenue collected may be used to cover service and maintenance of the system, which helps eliminate extended downtime and disrepair from lack of resources, creating reliability. With an automated water kiosk, the users get the freedom to tap water when they choose and are not dependent on operating hours set by water vendors.

Lifelink was designed with scaling-up in mind. It uses proven, low-cost, energy-efficient pump technology and offers after sales servicing and availability of spare parts, through a network of professional service partners to ensure a sustainable water supply. Lifelink’s remote monitoring function allows for centralized management of units in virtually any location and produces highly accurate, data to inform broader strategies and decision making.

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Integration of natural microorganisms at rapid sand filters with groundwater composition

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Abstract
Biological rapid sand filters (RSF) are commonly used for drinking water production at thousands of waterworks across Denmark, Europe and worldwide. A RSF consists of a sand bed through which the influent groundwater flows vertically by the gravitational force, and it is a place where common groundwater pollutants (e.g. ammonium, iron, manganese etc.) are removed. It has recently been revealed that specific groups of native microorganisms in RSFs have an important role in removal of several primary pollutants; still their specific physiological needs for nutrients- and micronutrients is still poorly understood.

The aim of this work is to get a deeper theoretical and experimental insight in the physiological needs of the main microbial groups at RSFs toward micronutrients. Blending the groundwater recovered from different water-wells, often having different chemical properties, allows creation of well-defined inlet-water blends with a specific concentration of examined micronutrients, intended to improve physiological needs (incl. metabolic capacities) of targeted microbial groups. Implementation of technology at waterworks might ultimately improve RSF’s capacity up to 30 percent, without compromising the stringent drinking water regulations.

Microorganisms (Bacteria and Archaea) responsible for ammonium-, nitrite-, iron oxidation etc. were investigated at different depths in RSFs from two Danish waterworks by PCR-based approaches. It was revealed that investigated microbial groups had similar distribution-patterns between replicate RSFs at a waterworks, yet the microbial distribution as a function of RSF’s depth was different between investigated microbial groups. A range of laboratory batch-experiments, containing sand-material from individual RSFs (upper 25 cm profile) have been installed and run under conditions mimicking those found at waterworks. The removal of pollutants from inlet water enriched by particular micronutrients is monitored along with the abundance and structure of studied microbial groups in the batch-experiments, and later at the full scale RSFs.

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An ongoing hydro-biogeochemical characterization of a partly drained lowland in a clay till subcatchment

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Abstract

Riparian lowlands may have significant impact on the catchment nitrate balance. As a part of the strategic research project TReNDS (“Transport and reduction of nitrate in Danish landscapes at various scales”) extensive field investigations have commenced in the Fensholt subcatchment situated within Norsminde Fjord catchment, Odder, Denmark. The riparian lowlands are surrounded by a hilly landscape composed of mainly clayey till, and hence the landscape is heavily drained. Drainpipes are either disconnected at the hillslope bordering the riparian lowland or discharging partly through the riparian zone. The drainpipes thus conduct nitrate-rich agricultural drainage water to the riparian lowlands. The fate of the nitrate depends on the local scale flow pathways, thus the distribution of drainage discharge as either 1) surface runoff, 2) subsurface flow in shallow or deeper permeable layers or 3) subsurface infiltration to stream connected drain pipes. The major part of the lowland area consists of peat, sandy peat, organic silty clay, and clays, and the major flow-pathways controlling nitrate reduction largely depends on the hydraulic conductivity of the media, the pressure potential and the redox dynamics of the sediment.

The aims of the investigations are to (i) develop a 3D mapping of the riparian zone geology, (ii) identify the major flow pathways from hydro-geological characteristics and tracer experiments, (iii) determine the sediment geochemistry and nitrate reduction potential, (iv) investigate the coupled hydro-biogeochemical nitrate reduction rates as a function of seasonal soil water potential and redox dynamics, and (v) develop a process based model describing the hydro-biogeochemical N transport and transformation in riparian lowlands. For the investigations both traditional methods will be applied as well as novel approaches e.g. remote sensing using UAV’s (Unmanned Aerial Vehicles commonly known as drones), a newly developed redox probe, and novel uses of geophysical methods.

More information about TReNDS can be found at www.nitrat.dk. The project is partly funded by Innovation Fund Denmark and is a collaboration between Aarhus University, University of Copenhagen, GEUS, and other Danish and international partners.

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Hydraulic efficiency of a drainage well filter mitigating phosphorus losses in agricultural drainage water

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Abstract
Losses of phosphorus (P) in drainage waters contribute an estimated 33% to the total agricultural P load in Denmark. Targeting high risk areas of P loss and applying site-specific measures promises to be a cost-efficient approach. The Danish strategic research project “SUPREME-TECH” (2010-2016) (www.supreme-tech.dk), aims to provide the scientific basis for developing cost-effective filter technologies for P in agricultural drainage waters.

The P retention of drainage filters depends on the sorption properties, as well as the hydraulic efficiency at variable discharge rates. The present study aims to investigate the hydraulic efficiency of a full scale drainage well filter, composed of crushed seashells (2-4 mm) targeting P removal in agricultural drainage discharge. Continuous tracer tests using NaCl (5 mg/l) were performed. Based on frequently occurring discharge rate of the system two different flow rates were selected (2 and 0.1 l/s). Tracer tests demonstrated a homogeneous distribution of the tracer outside the filter and the presence of a vertical concentration gradient inside the filter. Analysis of the hydraulic properties as well as modelling will be presented.

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Chemical and microbiological characterization of industrial process water

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Abstract
At Arla Foods Ingredient, cheese whey proteins are up concentrated by ultrafiltration membranes, while the permeate stream is further processed with a two-stage reverse osmosis plant (RO1 and RO2) to collect lactose.

The potential for re-using the RO2 permeate of this last process step as water source is our interest. Whey – or even more upstream, milk – as a raw material consists to a large extent of water. By efficient reuse of process water (such as RO2 permeate) downstream in production flows or cleaning processes, ingredient producers can limit the intake of potable water and minimize discharge of waste water, thereby greatly reducing the water footprint of the dairy industry. However, microbiological safety and hygiene is of utmost importance in the food and dairy industry, and it has been reported in literature that lactose, urea, salts and other organic compounds are capable of passing RO membranes. This indicates that the process water can theoretically act as a growth medium, constituting a potential hazard.

In order to assess the risk of (re-)using the process water the safety must be guaranteed. By implementing the principles of process analytical technology to the process water streams the risk can be monitored continuously and in real-time. In the present study, urea has been identified to be the main chemical compound. Urea can be monitored by NIR spectroscopy, which opens up for rapid measurements. Concentrations were found from 50-150 ppm in RO2 process water.

To establish if urea in the estimated concentrations constitute a potential risk, the RO2 water was used as a growth medium to test if the low nutrient content was sufficient to support growth of different bacteria. A few of the tested organisms were able to grow. Since urea was the main compound found in the RO2 water, it is likely that urease active bacteria will be able to utilize this compound thereby allowing growth.