Abstract proceedings

9th Annual Meeting
Danish Water Forum

KU Science, Auditorium A2-70-04
Thorvaldsensvej 40
DK-1870 Frederiksberg

29 January 2015

Edited by L.F. Jørgensen and B.K. Jensen

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Alternatives to groundwater based water supply: what are the challenges and solutions?

*M. Rygaard, DTU Environment**

Abstract
20% of the world's major aquifers are mined at unsustainable rates and many other groundwater resources are markedly affected by abstraction at the sub-catchment scale, even in Denmark. Besides physical water stress also political water stress, industry demands, and new regulation drive an international development from "traditional" to "alternative" water supply.

Water reuse is an alternative that gets a lot of attention these years for good reasons, because it relieves stress on conventional water resources, is cost effective and can have reduced impact on the environment in comparison to other alternatives, such as desalination. The growing awareness of water reuse and the increasing number of international reuse cases make these systems less controversial than previously thought, although some challenges in relation to water quality still remain.

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Challenges and experiences with a two-stringed water supply system.

*G.O. Gunnarson, Reykjavik Energy**

Abstract
Reykjavik Energy operates 5 utilities in the capital of Reykjavik, as well as in some of the other communities in the south-west corner of Iceland. The utilities are cold water, electricity, communication fiber optics, district heating and sewerage system. The presentation will introduce how cold water and district heating utilities are laid out in Reykjavik and how intakes and indoor systems are arranged. The pressure differences between systems needed for secure operating conditions will be addressed and other challenges and lessons learned.

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Mitigation of water loss at the supply side and water savings at the demand side – two sides of the same coin?

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Abstract

The challenges of rapidly increased urbanisation and diminishing of water resources threaten to tear the world apart. It is predicted that conflicts related to lack of water resources will be increasingly more common in the future. At the same time, the number of Mega Cities with intermittent water supply has been increasing for many years due to poor condition of the infrastructure in combination with high demand at the consumer side.

In the third world and in the newly industrialized world, the urban population is often growing with alarming two-digit percentages yearly. A good infrastructure is the very basis for economic development and water infrastructure is one of the most important, since it is the basis for both industrial development and for development of public health. Paying ability is low in such countries and increased water tariffs will often have adverse effect on both development and hygienic level. On the other side, the revenue from the low tariff is not big enough to maintain the pipes. The answer to the increased water demand has therefore traditionally been to use donations and soft loans to build more water treatment facilities and dams. This has typically been done in combination with pipe renewal in selected areas. Only half-hearted attempts have been done to improve network maintenance programs to reduce the physical leakage, since such programs correspond poorly with the development aid policy of short duration projects. The leakage often counts for half of the total water production in developing countries.

In the developed part of the world, the urban population is only growing at a few percent yearly and the network condition is generally in a good condition. 2-4% of the network is rehabilitated every year in the attempt to keep the average age of the pipes constant. However, lowering of groundwater tables or depletion of river flows sometimes force authorities to take action in order to reduce water demand. Further reduction of physical leakage seems increasingly expensive by using traditional methodology. On the other hand, "smart" technologies and restructuring of the infrastructure architecture makes far lower leakage rates economical feasible. Another direction is to reduce consumption to a level where it will not have adverse hygienic effects. This can be done by taxation and by using secondary water sources such as treated waste water and salt water for inferior purposes.

To sum up, reduction of water demand rarely is desirable in developing countries since it contradicts the very reason for developing the infrastructure. In such places an increased focus on long term maintenance programs in combination with better planning of new assets should be the way forward.

At the other end stands the developed world, where water saving is only one among several means to achieve a more sustainable water supply. These means have to be balanced against each other in order to obtain both environmentally and economic sustainability.

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Automated and energy-optimized well field operation

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Abstract
Water utilities have increased focus on energy efficiency and CO_2-emissions caused by their operations. As part of FutureWater, a Danish innovation project, a new software tool is currently being tested in the first of three planned pilots in Denmark. The results so far are very promising. A 40% reduction in energy consumption is documented on a specific well field.

Optimization of well field operation is complex and has largely been a "trial-and-error" exercise for the operational managers. In addition, impacts on surroundings and quality need increasingly to be taken into account, thus complicating optimization even more.

A partnership of three major Danish water utilities, the Danish Technological University and the private company Orbicon, has developed uGraph WaterAbstraction. It is a well field model, which links different kind of information in order to assess the most energy efficient operation:

- Well bore physical condition
- Groundwater hydraulics
- Water quality conditions in aquifer
- Pump characteristics
- Raw water network hydraulic specification

Online real-time data from the SCADA system is transferred to a dynamic well field model, which continuously calculates a best fit model in terms of alternating setup of pumps and within a framework defined by acceptable levels of abstraction per well, lowering of groundwater table and water chemistry. Based on the best fit model, settings of the pumps are adjusted.

The model enables the user to embrace complex hydraulic conditions in the well field and to auto-calibrate physical properties such as well efficiency, pump curves and friction coefficient in the pipes. The model calculates both branch pipe systems and ring connected raw water networks.

The scope and framework of the project including the results achieved so far will be presented and the perspectives outlined.

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Optimizing wellfield operation in a variable power price regime

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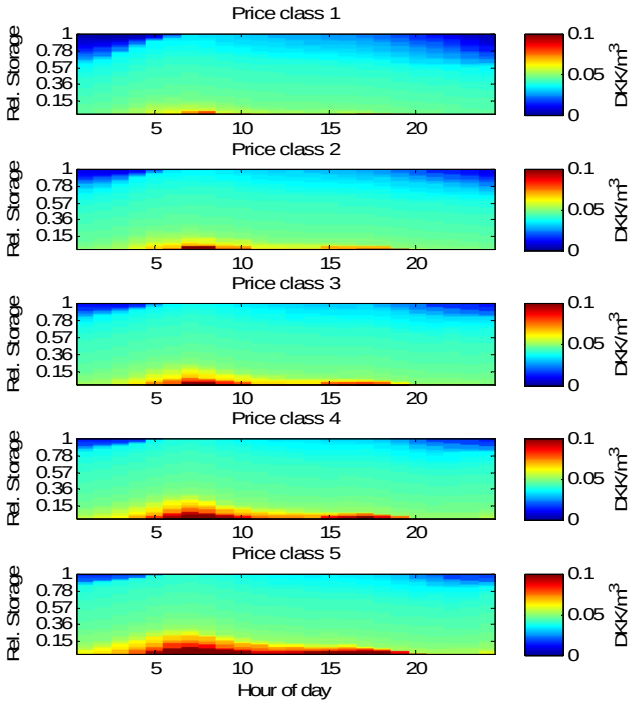
Abstract
Wellfield management is a multi-objective optimization problem. One important management objective has been energy efficiency in terms of minimizing the energy footprint (EFP) of delivered water (MWh/m3). However, power systems in most countries are moving in the direction of deregulated power markets and power price variability is increasing in many markets because of increased penetration of intermittent renewable power sources. In this context the relevant management objective becomes minimizing the cost of energy used for pumping and distribution of groundwater rather than minimizing energy use itself.

We estimated energy footprint as a function of wellfield pumping rate (EFP-Q relationship) for a wellfield in Denmark using a coupled well and pipe network model. This EFP-Q relationship was subsequently used in a stochastic dynamic programming framework to minimize total cost of operating the combined wellfield-storage-demand system over the course of a 2-year planning period based on a time series of observed price on the Danish power market and a deterministic, time-varying hourly water demand. In the SDP setup, hourly pumping rates are the decision variables. Constraints include storage capacity and hourly water demand fulfilment. The SDP was solved for a baseline situation and for four scenario runs representing different EFP-Q relationships and different maximum wellfield pumping rates.

Savings were quantified as differences in total cost between the scenario and a constant-rate pumping policy. Minor savings up to 10% were found in the baseline scenario, while the scenario with constant EFP and unlimited pumping rate resulted in savings up to 40%. Key factors determining potential cost savings obtained by flexible wellfield operation under a variable power price regime are the shape of the EFP-Q relationship, the maximum feasible pumping rate and the capacity of available storage facilities.



Value of water pumped into storage for every price class, every hour of the day and every storage level

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Effective decision-making using groundwater models

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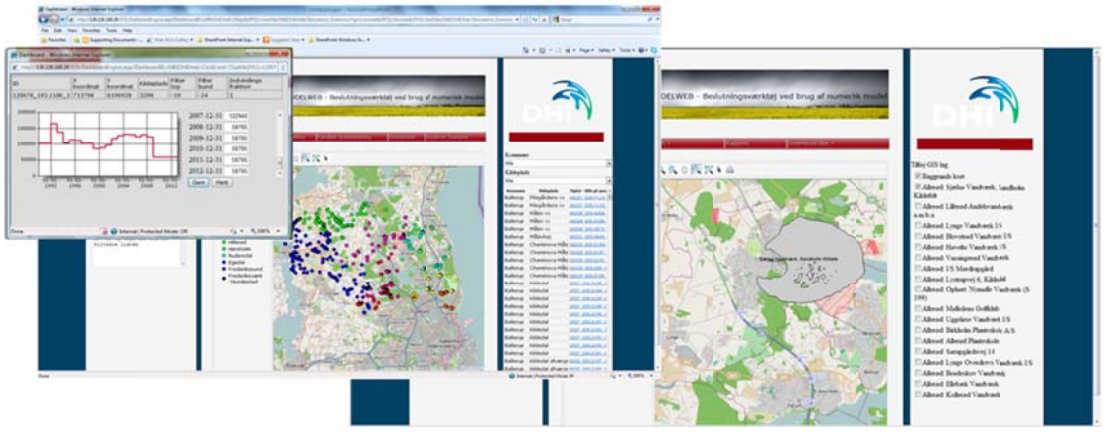
Abstract
Water and environmental managers must address problems that continue to growth both in scope and in complexity. Within a catchment, water managers may be concerned with quantifying or monitoring the surface and groundwater resources, the water quality and ecological status, and interventions such as increased groundwater pumping, climate adaptation, etc. This requires integrated planning that needs to address diverse and often conflicting demands on the water resource and water environment from a range of end-users and stakeholders. Hydrological models are important tools in decision-making to handle this complexity. However, it is also important to bridge the gap between the scientific and technical impact assessment of different management scenarios carried out by specialists on the one hand, and the socio-economic and environmental evaluations required by decision-makers, stakeholders and end-users.

To address this gap DHI have developed and applied new decision support frameworks in both Denmark and internationally with the objective of developing web based solutions that simplify the use of very complex models and ensure these are used more actively in decision processes. In the paper, we present such a tool for groundwater management and planning in Denmark. From our experience, some of the key for issues related to utilising a hydrological model as an active tool in a decision process are:

- The use of the model need to focus on the user requirements, e.g. groundwater permits, drought management, water allocation, etc.
- The model system should be adapted to the work process of the specific user, e.g. outputs are readable available in a format that is used, input and definitions are clearly understandable etc.
- Transparent decision process. Sharing of model results directly with stakeholders increases the transparency of the decision process and the importance of the model as a key tool.
- No local installation. A web-based approach could simplify the process of having software installed locally, and enable access from different platforms.

Therefore, in collaboration with the Helsingør and Allerød municipalities, DHI has developed web applications supporting water permitting and water resource assessments and protection. They enable the user to define scenarios, execute the models and retrieve results in the form of relevant indicators. These tools make it easier to utilise models without compromising the complexity and details in the tools. The systems are tailor made to the needs of the user, and all input and outputs from the system are processed in a way so no prior model knowledge is required. The output from the scenarios can be tailored towards existing systems, enabling the hydrological model to be a seamless part of the current decision process.



Example of a web based solution for a Danish county

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The use of groundwater treatment in Denmark: To which extent and for what purposes have exemptions been granted?

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Abstract
In 2012 COWI, on behalf of the Danish Ministry of the Environment and the Danish Nature Agency, made a survey on advanced water treatment at Danish drinking water utilities. The purpose was to map the situation after the structural reform in 2007, where the responsibilities on water supply etc. were transferred from the counties to the municipalities.

The survey showed that during the five years covered by the investigation, 48 of the 98 municipalities had evaluated 81 requests on advanced water treatment in four categories: main components (mainly aggressive carbon dioxide), inorganic trace elements (almost exclusively arsenic); organic micro pollutants (BAM and chlorinated solvents); and finally micro biological parameters (mainly coliforms).

In 2012, around 50 million m^3 drinking water (around 10% of the annual distributed quantity) was affected by the 74 (mainly temporary) facilities for advanced treatment in operation.

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Designed Water – A Challenge to the Concept of Simple Treatment

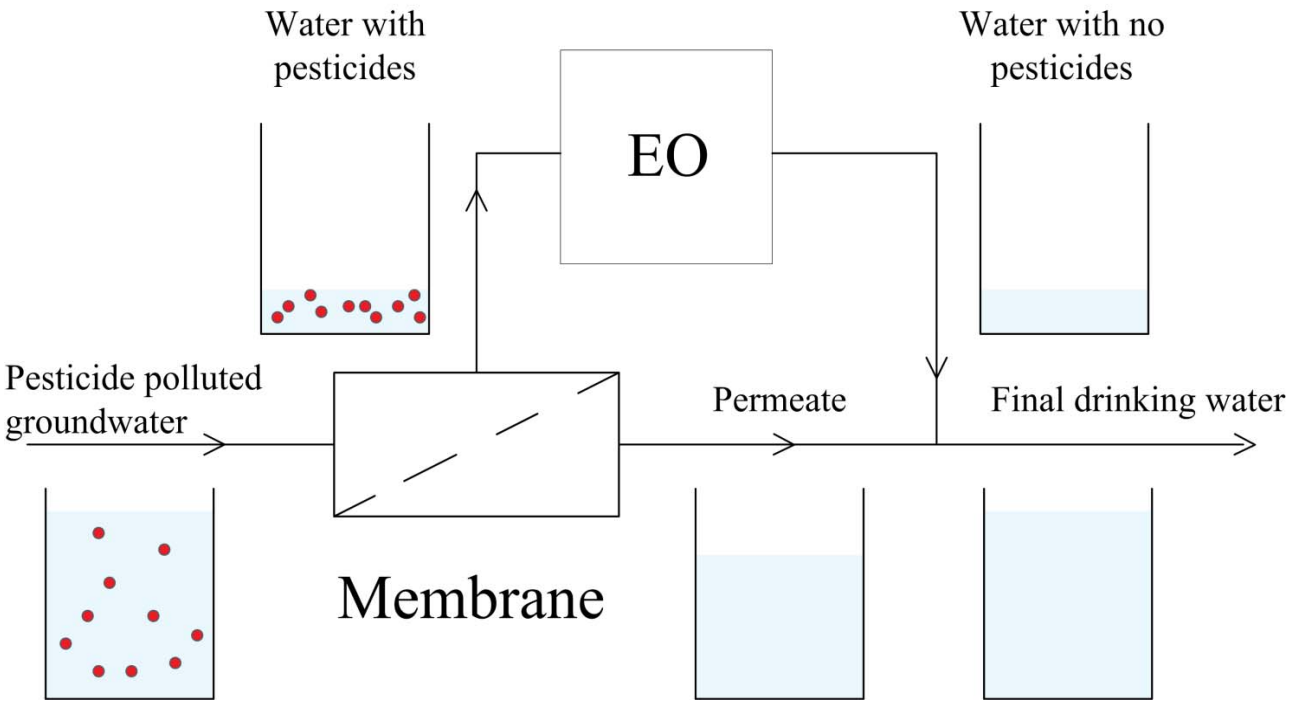
H.T. Madsen, E.G. Søgaard**, Section of Chemical Engineering, Aalborg University,*

Abstract

When you open the tap to pour yourself a glass of water, the quality of that water is very much dependent on where in Denmark you live. If you live in Esbjerg the water will be very soft and low on minerals while if you live in Hvidovre (Copenhagen) or Odense, the water will be hard and with a high mineral content. As a consumer, the only way of influencing the quality of the water is by moving, or by, God forbid, buying bottled water. Furthermore, our drinking water resources are under pressure from different kinds of pollutants such as pesticides and arsenic, with pesticides being found in close to half the groundwater and a fourth of the drinking water. The reason for the difference in water quality and why the pollutants pose a threat to the drinking water is very much due to the way we have chosen to treat drinking water in Denmark.

In Denmark we adhere to the principle of treating the water as little as possible. This means that main part of drinking water today only undergoes aeration and sand filtration, also known as "simple treatment". Simple treatment mainly removes gases and redox active species such as iron and manganese, while leaving the remaining part of the water composition basically unaffected. However, by applying combinations of membranes and other state of the art water treatment techniques, it will be possible to achieve a much higher degree of freedom over the exact drinking water quality. Such a scheme will allow for production of drinking water designed with a specific hardness and mineral content, while ensuring complete removal of pollutants and microorganisms.

As an example of this concept we have studied the effect on the efficiency and energy consumption of coupling electrochemical oxidation with NF/RO membrane filtration to remove the pesticide BAM from tap water. The results are highly encouraging and show the way for how we could produce drinking water of higher quality in the future, and hereby bring Danish drinking water production technology to the forefront of the global market.



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Removal of pesticides with filter sand from rapid sand filters at Danish waterworks

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Abstract
Aerobic rapid sand filters for treatment of groundwater at waterworks were investigated for the ability to remove pesticides. Previous investigations have shown that the herbicide mecoprop (MCPP) is removed in the full-scale rapid sand filters at Kerteminde waterworks (Hedegaard et al., 2014). The potential of microbial pesticide removal was investigated with filter sand from the rapid sand filters at Islevbro and Sjælsø waterworks plant I and II. The investigations were performed in microcosms with filter sand, treated water and ^{14}C-pesticides in initial concentrations of 0.04-2.4 µg/L. The pesticides mecoprop (MCPP), bentazone, glyphosate and the degradation compound *p*-nitrophenol are all among the 20 most frequently detected in Danish drinking water well (GEUS, 2013), and including a transformation product of bentazone these were chosen for the investigation due to their different physio-chemical properties.

All the investigated pesticides were removed from the water phase in microcosms with filter sand from all three investigated sand filters. The biological removal was largest at Sjælsø waterworks Plant II, where i.e. up to 43% of the initially added glyphosate was mineralised (recovered as $^{14}CO_2$). This investigation shows that there is a potential for using already existing rapid sand filters at Danish waterworks for treatment of pesticide contaminated groundwater.

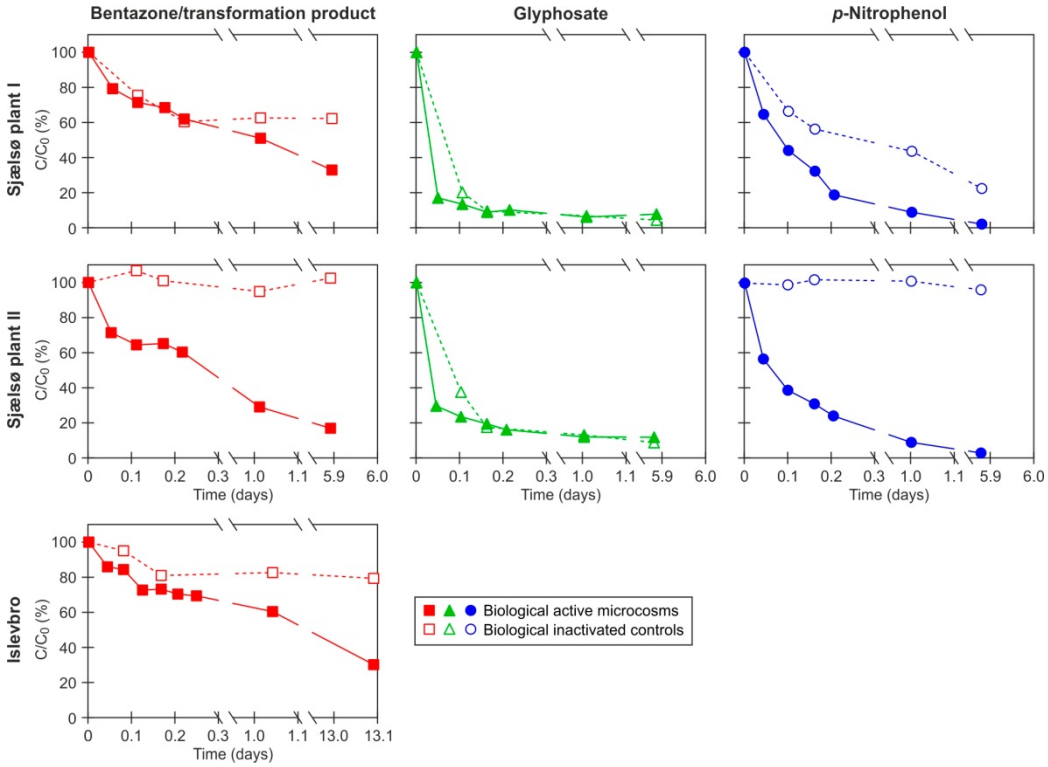

Figure. The removal potential of bentazone/transformation product, glyphosate and *p*-nitrophenol in filter sand from three different waterworks (modified from Hedegaard and Albrechtsen, 2014).

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Introduction of specific pesticide degrading bacteria into waterworks sandfilters

- *A technology for remediation of pesticide polluted drinking water*

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Abstract
Contamination with organic micropollutants like pesticides, solvents, and pharmaceuticals forces waterworks in many areas of the world to either close down abstraction wells or to purify the water before it is distributed to the consumers. In Denmark 2,6-dichlorobenzamide (BAM), a degradation product of the herbicide dichlobenil, has closed down numerous abstraction wells due to its presence above the 0.1 µg/L threshold limit set by the European union.

BAM is a highly recalcitrant compound, but recently a BAM-degrading bacterium, *Aminobacter* sp. MSH1, was isolated. We are currently investigating the possibility of using the bacterium to degrade BAM at waterworks during their normal simple water purification process.

To investigate the potential for remediation of groundwater polluted by trace concentrations of BAM, we established a pilot waterworks sand filter. The waterworks treated polluted groundwater at rapid flow conditions, as normally used in water supply. Bioaugmentation of the sand filter with a specific BAM-degrading *Aminobacter* sp. MSH1 resulted in significant BAM degradation to concentrations below the legal threshold level (0.1 µg/L), and this occurred without adverse effects on other sand filter processes such as ammonium and iron oxidation. However, efficient degradation for longer time periods was difficult to maintain due to loss of MSH1 bacteria, especially during backwashing. By limiting backwash procedures, the degradation was prolonged, but bacteria (and hence degradation activity) were still lost with time. Protozoa were observed to grow in the filters to a density that contributed significantly to the general loss of bacteria from the filters. Additionally, the concentration of easily assimilable organic carbon (AOC) in the remediated water may have been too low to sustain a sufficient population of degrading bacteria in the filter.

Shortcomings in transferring degradation rates obtained in batch experiments to a rapid sand filter system are discussed, revealing that further optimization is necessary to obtain and control more temporally stable systems for water purification.

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Removal of organic micropollutants from drinking water by electrochemistry: Experiences obtained with pesticide residue BAM

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Abstract

Pesticides and pesticide residues are the most important micropollutants found in Danish groundwater aquifers and responsible for large quantity of groundwater currently being unusable for drinking water production. One very good example is the pesticide transformation product (PTP) 2,6-diclorobenzamide (BAM) that is a daughter product of the previously commonly used pesticide dichlorobenil. Of the total number of groundwater aquifers that are included in the Danish groundwater monitoring programme, around 50% have been found to be contaminated with pesticides and PTPs, and in 19–20% of these cases, the primary contaminant was BAM. Traditional Danish drinking water treatment has been shown to be ineffective against BAM and most other pesticides and PTPs, and their removal has, where necessary, typically been attempted by active carbon (AC) adsorption – a well-known water treatment technique with pros and cons.

Electrochemistry offers a potentially efficient alternative to AC adsorption for pesticide removal at Danish waterworks. Electrochemistry does not include addition of additional chemicals, but use electrodes to facilitate transport of electrons to and from electroactive ions and molecules in the water, resulting in degradation of organic molecules such as pesticides and PTPs. The principle technique studied in the present project is termed electrochemical oxidation (EO), which is a technology within the family of Advanced Oxidation Processes (AOPs). In recent years, electrochemical oxidation technology has developed from fundamental research on synthesis of new electrode materials aimed at high oxidation power, resistance and durability, as well as laboratory studies of treatment efficiencies of various polluted aqueous matrices into commercial available products. However, concurrent to the incipient market dissemination of the technology, much more research is still needed in order to fully understand the effect of the technology on the water matrices and the produced effluents. One challenge is elucidating degradation pathways and identifying oxidation intermediates with the aim of ensuring discharge of an environmentally safe effluent.

This project demonstrated that BAM can indeed be removed from tap water by EO. Detailed model solution studies in inert and electroactive electrolyte solutions elucidated the degradation pathways and the quantity of degradation intermediates (DIs) formed during the treatment. Especially the presence of chloride in groundwater, although in small amounts, has caused initial concerns related to harmful byproduct formation, but our study revealed that even though the degradation pathways was much more complex in a chloride rich electrolyte, the quantity in DIs was at the same level or lower than in inert sodium sulphate electrolytes. All DIs formed during the treatment were removed at prolonged treatment times and complete TOC removal was obtained.

EO was shown to be a capable alternative to AC adsorption targeting a potentially broader range of micropollutants. The energy consumption of the process found in this project was in the high end with respect to expected demands required for full scale treatment, but additional studies have shown that optimization of the process is possible through combinations of EO with NF or RO membrane filtration.

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Diversity and metabolic potential of the microbial communities in rapid sand filters at Danish waterworks

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Abstract
Rapid sand filters (RSF) are commonly used to prepare drinking water from groundwaters, yet the microbial diversity and the metabolic pathways occurring in these ecosystems have been poorly characterized. Hence, to describe the microbial communities in RSFs and characterize their ecology, we have analysed the largest set of 16S rRNA data obtained from pre- (PF) and after filters (AF) so far. In addition, we extensively investigated the dominant metabolic pathways in a single RSF by conducting a metagenomic survey.

We have found a taxonomic richness similar (ca. 200 to 800 observed OTU0.03s) to what has been reported for communities in other engineered bioreactors, although RSFs receive very low energy inputs compared to other environments. Nitrospirae, Proteobacteria and Acidobacteria were the dominant phyla in all PFs and AFs (89%±19 and 87%±15 respectively).

Although few taxa were shared between waterworks (ca. 30 OTU0.03s), their relative abundance was strikingly high (87%±5 in PFs and 75%±18 in AFs). Additionally, a high number of OTU0.03s in the core taxa of the PFs and AFs were phylogenetically close to taxa with known physiologies such as those performing ammonium, nitrite, iron, manganese and methane oxidation, and these OTU0.03s represented 79%±2.3 and 66%±0.6 of all sequences in the PF and AF core taxa, respectively.

Metagenomic carriage of functional metabolic pathways in RSF was similar to those predicted from 16S rRNA based 454 survey, and potentially responsible for major contaminant removal processes.

Using DNA sequencing, we obtained a detail picture of microbial communities which may related to the functions of the RSFs, however significant abundance of taxa with unassigned physiologies suggest a further study to unravel the role of each microbial taxa in RSFs.

This work has been conducted in the framework of DWBiofilters project.

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Stratification of nitrification activity, kinetics and microbial density in rapid sand filters treating groundwater. What is the link with loading?

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Abstract
Rapid sandfilters are a sustainable technology commonly used to treat groundwater up to drinking water standards. Besides physical straining of particles, rapid sand filters are microbially active environments, where the action of specific microorganisms drives the removal of unwanted compounds from the water. Ammonium removal is of particular interest, as residual concentrations can promote after-growth in the distribution system and potentially lead to oxygen depletion and formation of toxic nitrite. Although rapid sand filters have been used for decades to remove ammonium from groundwater, their operation is based on empirical approaches and little is known about the microorganisms involved and their kinetics. Filters are therefore commonly seen as "black boxes" where only the influent and effluent ammonium concentrations are known. In this work, we investigated nitrification in a filter with the following specific questions: Where in the filter does it occur? What are the kinetics? How is the activity linked with the presence of specific nitrifying microbial types, namely Ammonium Oxidizing Bacteria (AOB) and Ammonium Oxidizing Archaea (AOA)?
Our investigations took place in the after-filters at Islevbro waterworks, in the greater Copenhagen area. The depth profile through the filter revealed that ammonium was completely removed in the top 15 cm of the filter, out of the 70 cm of total filter depth. Filter material samples were collected from three depth layers: 0-10 cm (top), 20-30 cm (middle) and 35-50 cm (bottom), and were exposed to a series of ammonium loadings in an offline assay [1]. All depth layers were active for nitrification, although activity of the top layer was higher than the middle and bottom layer, suggesting stratification of activity. Nitrification kinetics was investigated in each layer separately, using a 1-D biofilm model to interpret the observed behaviour at each loading condition by estimating the specific growth and decay parameters. The estimated parameters were different for each depth layer, ultimately revealing a different intrinsic kinetic behaviour.
The AOB and AOA densities were investigated at the three depths and ranged within the same order of magnitude. AOB densities decreased with depth, while AOA densities remained relatively constant, yielding an increased AOA to AOB ratio at the bottom of the filter. AOB growth was observed during the offline experiments while the AOA density did not change, indicating that AOB were the active microbial group during the lab experiments. However, the ammonium loading range investigated in the offline assays was much higher than the actual loading in the deeper layers of the filter, where almost all ammonium has already been removed. The AOA density and the actual filter loading at the different depths shows a clear negative correlation pattern. This observation indicates that loading selects for the dominant nitrifying microorganisms, namely AOA at the bottom filter layers and AOB at the top of the filter.
Stratification is caused in a filter by poor re-distribution of the filter material during backwashing, which leads to the same filter regions being exposed to high or load ammonium loadings depending on their location in the filter. Re-distribution of the filter material is dictated by the specific backwashing practice and by the filter material bulk density, which was also stratified due to the presence of a mineral coating on the external surface of the grains that make the filter material lighter [2].
All in all stratification may affect filter performance and efficiency by e.g. concentrating ammonium removal in a specific filter region and leaving the rest of the filter inactive for nitrification. Thus, we suggest using this type of analysis to examine the effect of stratification and the link between activity and loading to optimize filter operation by avoiding filter overdesign and keeping a safety margin for peak loads.

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The work was conducted within the DW-Biofilters project and the authors would like to thank DSF and DTU for founding.

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Phosphorus addition can increase nitrification in biological rapid sand filters for drinking water treatment

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Abstract

Biological rapid sand filters are used in over 2500 Danish water works for drinking water treatment. In these filters, ammonium (NH_4^+) is removed through nitrification, which is a biological process. The microorganisms conducting the process require besides NH_4^+ other nutrients, such as phosphorus (P), for growth and activity. Nitrification can be hampered by lack of P, if the concentration is too low. Incomplete nitrification during treatment is problematic, as it might cause microbial aftergrowth, oxygen consumption, or formation of the toxic nitrite (NO_2^-), in the distribution system. As a substantial number of Danish water works experience problems with incomplete nitrification, we investigated if P addition could enhance NH_4^+ removal in the biological filters, and therefore increase the water works' effluent water quality.

Studies were conducted at laboratory-, pilot-, and full-scale. Two laboratory-scale columns (Tatari et al., 2013) were packed with sand from a filter with incomplete NH_4^+ removal. P (as phosphate, PO_4^{3-}) was added to one of the columns, the other column was a control without P addition. Both columns were operated under different NH_4^+ loading rates. NH_4^+ removal was substantially increased in the column were PO_4^{3-} was added. The stimulation with P was more pronounced at higher loading rates of NH_4^+.

With sand from a water works with complete NH_4^+ removal, two pilot-scale columns were operated. NH_4^+ loading rates were increased beyond the actual NH_4^+ removal capacity of the filters. Without additional P, NH_4^+ removal rates increased slowly from 2.8 to 4.5 g NH_4-N m^{-3} h^{-1} over 23 days, and NO_2^- effluent concentrations increased. Increasing NH_4^+ loading and P concentration simultaneously however, NH_4^+ removal rapidly increased from 3.0 to 4.3 g NH_4-N m^{-3} h^{-1} in only 7 days. Quantifying ammonia oxidizing bacteria and –archaea, nitrite oxidizing bacteria, and *Eubacteria* showed that P addition in the filters enhanced growth of nitrifying microorganisms, thereby shifting the relative abundance of nitrifiers compared to other microorganisms. (Lee et al., in preparation)

Phosphorus addition to a full-scale rapid sand filter was furthermore studied at a water works with nitrification problems. The filter was operated under a comparably low NH_4^+ loading rate. Nitrification in the full-scale filter improved only slowly, even though P was added (Wagner et al., 2014), most likely because under the low NH_4^+ loading conditions, the microorganisms did not require higher concentrations of P than already present in the influent water. Furthermore, water sampling over depth of the filter showed that the added P was removed in the top 20 cm of the filter, where primarily iron (Fe) was removed.

The results of our studies let us conclude the following:

- Phosphorus addition to biological rapid sand filters can increase both the activity (NH_4^+ removal) and also the abundance of nitrifying microorganisms
- The increased activity under P addition was more pronounced under high NH_4^+ loading rates
- High iron content in the filter influent can decrease the (bio)availability of PO_4^{3-}, due to co-precipitation with iron(oxy)hydroxides

This work has important practical implications, as our findings show the possibility of using phosphorus addition to overcome incomplete NH_4^+ removal, and to increase the capacity to remove NH_4^+ in the water works' filters.

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This work was conducted within the project DW Biofilters and supported by the Danish Council for Strategic Research and DTU.

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Methanotrophs assisted bentazone's transformation product degradation

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Abstract
In several countries, drinking water supply is based on groundwater, simply treated by aeration and filtration prior to its distribution. This source of drinking water is increasingly threatened by contamination from pesticides and pesticide metabolites, including bentazone, a thiadiazine herbicide persistent in groundwater, and its transformation products. Anaerobic groundwater often contains methane, which is easily oxidized by methane-oxidizing bacteria (MOB) upon groundwater aeration. These bacteria have known cometabolic degradation properties against some class of organic contaminants.

Our main goal was to test whether MOBs enriched from rapid sand filters used to treat groundwater can cometabolically degrade bentazone's transformation product. Further, we evaluated the influence of methane and the transformation product's concentration on the latter's removal rate. In this study we used bioreactors, fed with drinking water and methane, inoculated with material from rapid sand filters rich in methanotrophs, to grow enriched methane-oxidizing biofilms.

Microcosms including biomass in drinking water, ^{14}C carbonyl-labelled bentazone's transformation product in concentrations ranging from 0.2 to 2000 ug/L with and without methane were investigated in triplicates. Abiotic control microcosms without methane containing autoclaved Filtralite and bentazone's transformation product were included.

Results showed rapid removal; after the 2 first hours only 25% and 27% of the initially added transformation product was detected with and without methane respectively. After 48 hours an average of 91% of the initially added compound was still detected in the autoclaved controls, while 3.7% was detected in microcosms with methane and 6.6% in microcosms without methane, with a clear removal delay in the methane provided microcosms. Mineralization results after 96 hours revealed an average of 29% of the transformation product detected as $^{14}CO_2$ in the microcosms with methane while this was 46% in microcosms without methane.

The relative abundance of MOBs was estimated with a qPCR analysis targeting *pmoA*, the gene coding for the subunit A of the methane monooxygenase, and compared between the reactors and the microcosms. The removal rate of bentazone's transformation product per gram of carrier material increased over time in microcosms, whether provided with methane or not. The methane- depleted biomass showed the largest increase and presented a 'long-term-starvation' advantage over the methane-provided microcosms. This behaviour revealed methane's negative effect on the compound's removal, proving the degradation pattern we observed to be inconsistent with a typical cometabolic process.

Research for further investigation of the enriched culture's potential in pesticides degradation is a necessary step for the better understanding of the process.

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Grundfos Lifelink

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Abstract
Progress towards achieving the Millennium Development Goals targets for water and sanitation coverage has been significant, however the Joint Monitoring Project (JMP) estimates that as of 2012, 47% of the rural population in Sub-Saharan Africa still lacks access to an improved water source. Similarly, 2015 estimates for sanitation coverage will leave 2.4 billion people without access to improved sanitation facilities, and 70% of this population will be in rural areas.

In order to address these rural disparities, new approaches beyond the business-as-usual will be required. Grundfos will present their corporate mission and how their partnership with multiple stakeholder can help them to reach two million people with renewable energy-powered water systems.

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Hasselager Kolt in China: System export of Groundwater-based Water Supply Systems

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Abstract
Hasselager Kolt Water Treatment Plant is probably the most modern rural water supply plant in Denmark. It uses state-of-the-art Danish water technology throughout the whole plant, including the Blue Control operating system, which enables the plant manager to monitor and regulate all equipment, from borehole to consumer, via smart phone, tablet, computer or a display on the control panel.

The Hasselager Kolt WTP was selected by a Working Group set up by the Danish Nature Agency as a model for export of Groundwater-based Water Supply Systems to China as part of a Danish Groundwater Partnership with the Shandong Province and eastern China. The initial response from the Chinese partners was very positive, and led to a demand for a two-string water supply system in new urban areas in Jinan, while the demand for rural water supply yet has to mature.

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Danish technology and experience for groundwater mapping in SE Asia

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Abstract

During many years, use of groundwater has been a key to our success of supplying healthy and safe drinking water the Danish consumers. The need for detailed knowledge about hydrogeological structures and conditions is obvious to ensure sustainable abstraction of groundwater in terms of quantity and quality. Therefore, we have obtained expertise and developed equipment related to groundwater mapping ranking among the best in the world, and now have a unique opportunity to export our knowledge on groundwater to the rest of the world.

In many countries in SE Asia the situation related to drinking water supply is very critical, and the need for more water resources can be desperate.

In Thailand, for instance, drought and flooding effect most of the country and in some places both occur in the same year. Many cities and huge industrial zones are desperately lacking water resources to such a degree that it effects the development of the country. As a consequence, the Thai Government has started a detailed mapping of groundwater aquifers, and Danish technology and experience is highly appreciated in solving this task.

In other countries, like Malaysia and Indonesia, the situation is also very critical, and climate change makes the situation worse year-by-year. Even in the capital city of Kuala Lumpur in Malaysia days with absolutely no water in the taps occur due to restrictions after longer and longer drought periods.

Very recently a consortium has been established with several Danish players each representing unique techniques and products in relation to groundwater mapping. The group consists of 8-10 companies and institutions both from the public and the private sector. The purpose of the cooperation is to go to market together and to offer the clients in SE Asia a concept for the solution of water shortage.

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SkyTEM, an international success. How and why?

Per Gisselø, SkyTEM Survey Aps*

Abstract
SkyTEM Surveys Aps is a young and fast grown high-tech company spun out of the research environment at Aarhus University and the national groundwater mapping campaign. Today it offers a unique technical solution for geophysical mapping of groundwater resources, mineral exploration and geotechnical applications. The company operates in the international market and have after some years found a marketing approach where it reach its customers by local partners, own sales forces and in some cases SkyTEM branches.

We will present the SkyTEM solution and how a relative small high-tech company can become successful in a large, global marked.

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Danish Groundwater Bodies and their chemical status

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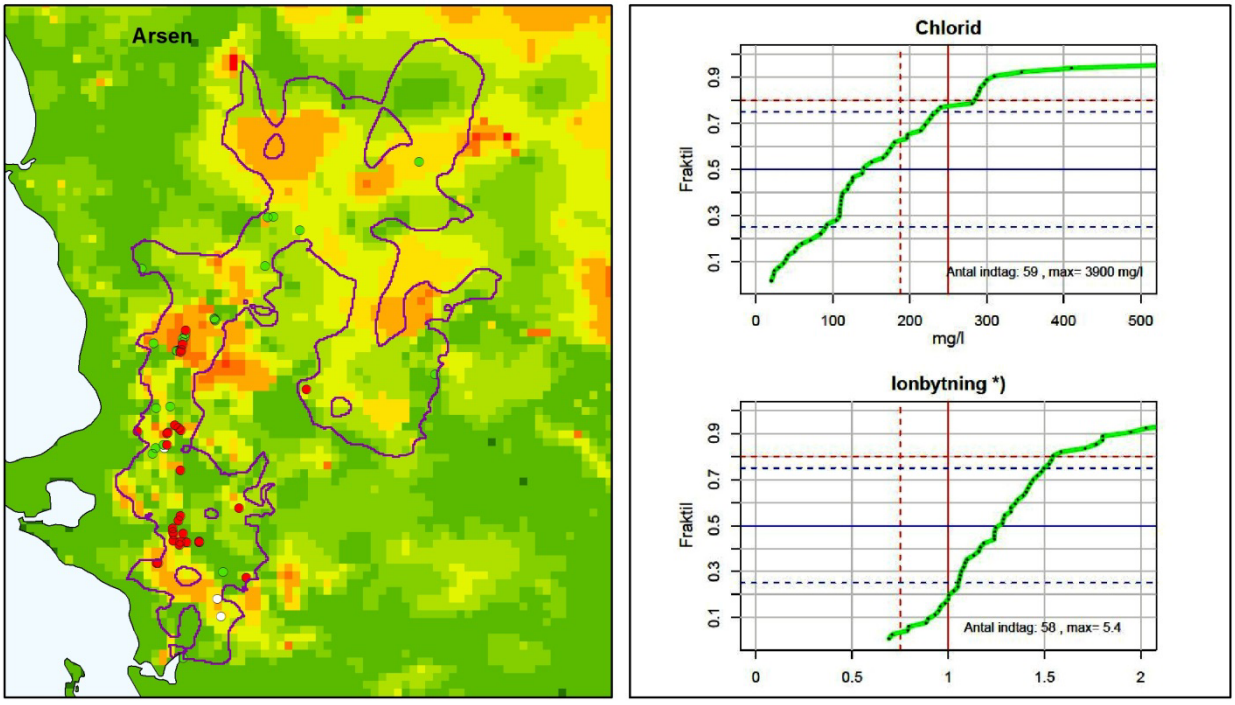
Abstract
The Danish Groundwater bodies have been designated to the next water plan 2015-2021, with the national hydrological model as basis. This means that the aquifers in the model are grouped in groundwater bodies, and the different geological layers are linked in a transparent way to the groundwater bodies.

The chemical water analyses in the national database JUPTIER were linked to the groundwater bodies through a process in which the screens in each groundwater well was assigned to a specific geological layer and thus to a specific groundwater body. All chemical analyzes from the period 2000-2013 were used to assess the chemical state of the groundwater bodies. In cooperation with the Nature Agency a manual for the procedures was developed.

The main principle was that all assessments should be made by a series of algorithms, programmed in such a way that every result is reproducible and any change of the boundary conditions easily implemented. The state of the groundwater bodies follows the EU guidance documents and directives as far as the data quality can justify it. Background values of a number of natural occurring substances as Arsenic and Nickel were found in order to handle the very diverse natural groundwater qualities across Denmark.



Map showing high concentrations of arsenic and graphs showing distribution of chloride and Na/Cl (ionbytning) ratio in a groundwater body. Horizontal lines in the graphs indicate 25-50 and 75 % quantiles and the 80 % quantile, where the concentrations should be below the threshold value (vertical full red line). 'Antal indtag' = number of screens.

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Spatial variation of iodine in drinking water and groundwater in Denmark

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Abstract
Over the last decades the attention towards contaminants in the drinking water has increased significantly in Denmark and worldwide. However, the beneficial effects of drinking water quality are largely ignored despite the fact that drinking water is a potential source of essential and possibly essential elements for humans. One such example is iodine. Iodine excess and iodine deficiency can both cause health problems. However, the focus worldwide falls mainly on the deficiency, as it is *"the single most important preventable cause of brain damage"* according to WHO. Even though some evidence for substantial spatial variation of iodine in Danish drinking water existed, comprehensive hydrogeochemical or geostatistical studies were not carried out. To address this knowledge gap, a Danish GEOCENTER project was conducted between 2011 and 2014.

The main objectives were (1) to map iodine concentration and speciation in drinking and ground water in Denmark, (2) to study the spatial patterns and the governing factors, and (3) to evaluate the importance of the spatial variation of drinking water iodine to the populations' nutrition (health). Two types of data were used for fulfilling these objectives: (1) from two sampling campaigns designed as part of this project, and (2) historical groundwater data (two datasets: 1933-2011 and 2011-2014) extracted from the public geological and hydrological database, Jupiter. The samples from the sampling campaigns were analysed for iodide, iodate, total iodine and the major constituents. Only total iodine data was present in the historical datasets.

Here, we present an overview on the major findings which are reported also in two peer-review papers and a PhD thesis [1-3]. The main focus will be on the complex spatial variability of both iodine concentration and speciation (Figure 1) and how this is reflected in the dietary iodine intake in Denmark, and international implications hereof.

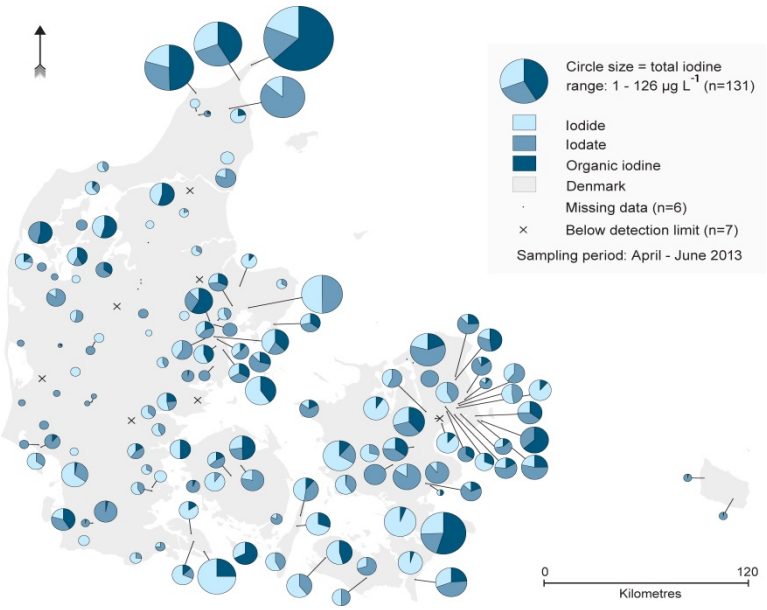

Figure 1 Spatial variation of iodine concentration and speciation in treated drinking water (sampling at exit waterwork) (from Voutchkova, *et al.* [1])

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Discharge of biogas effluent and microbial pollution of drinking water wells in Vietnamese pig farming households

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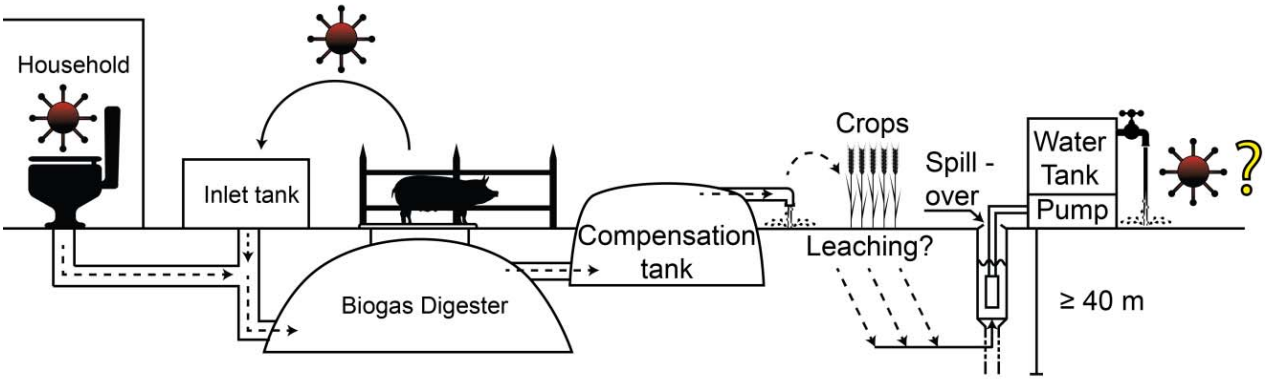
Abstract
Animal manure contains nitrate and zoonotic and enteric pathogens such as *Campylobacter*, *Salmonella*, *Escherichia coli* (*E. coli*), hepatitis E virus (HEV), porcine circovirus type 2 (PCV2) and rotavirus. These can contaminate drinking water by leaching through the soil to groundwater sources, thereby comprising human and animal health. In Vietnam, 77% of pigs are raised on small-scale household-based farms. Pig manure management includes composting in heaps, anaerobic digestion for biogas production and fertilization of fish ponds, household gardens and agricultural land.

A study was conducted on 18 households with drilled tube wells in Nhat Tan commune, Kim Bang district, Hanam province in northern Vietnam (six households with a biogas unit and pigs; six households with pigs but without biogas and six households without either pigs or biogas) to determine whether viruses and other microorganisms found in drinking water extracted from drilled tube wells were associated with farmers keeping pigs and operating biogas units.

The results showed that the concentration of *E. coli* in well water samples varied from 0.02 to 22 CFU/mL, exceeding Vietnamese limits for drinking water. The mean nitrate concentration in well water was 0.02 mg/L which is below the Vietnamese statutory limit, and did not differ significantly among the three groups of farming households. Group A rotavirus (RV-A), HEV and PCV2 were found in 13%, 13% and 22% of the well water samples, respectively. The age of the well had a significant effect on the presence of PCV2 in water on households, with the odds of a well testing positive increasing by a factor of 1.21 ($P < 0.05$) per year. In addition, the presence of PCV2, HEV and RV-A decreased with depth of well.

The detection of viruses in well water samples were significantly linked to the presence of pigs at the household. Within households raising pigs, having a biogas unit did not increase the presence of porcine viruses in well water compared to households without a biogas unit. In contrast to PCV2, somatic coliphages was not a significant predictor for occurrence of HEV and RV-A in well water, and therefore we suggest PCV2 as a future indicator of porcine viruses present in water.



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Detection of small organics in water – the MUSE project

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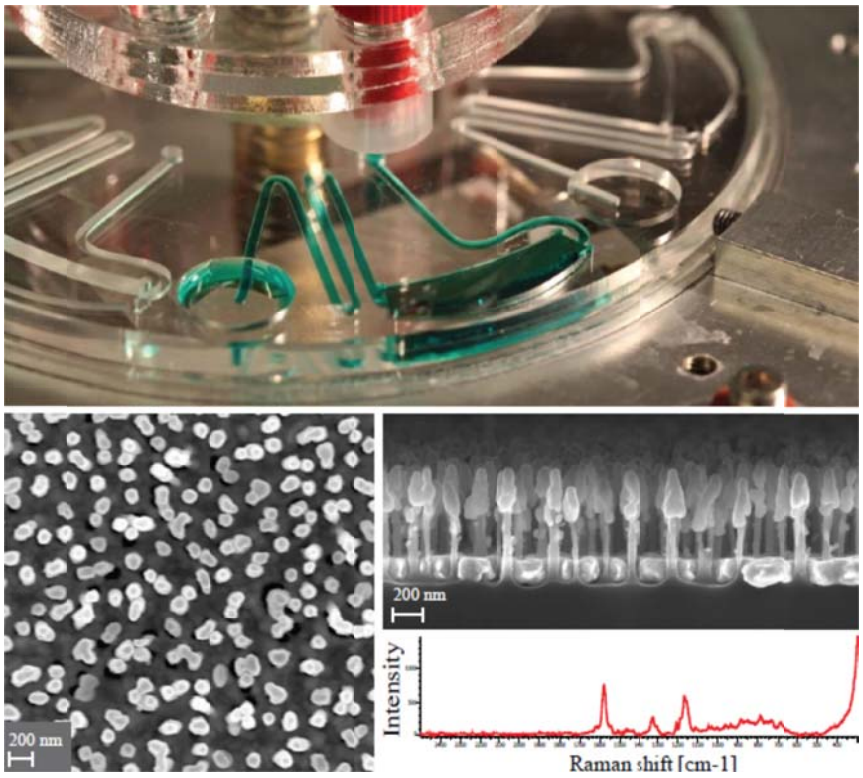
Abstract

Detection of small, persistent organic molecules in liquid samples is a challenge, as these molecules are not biodegraded nor treated in waste water treatment plants. The "Multi Sensor DVD Platform" (MUSE) project is aiming at detecting hormones and pharmaceuticals in water using nanotechnology. By utilizing an in-house developed, low cost, nanograss microchip, it is possible to measure Raman signals of molecules in extremely low concentration (down to picomolar level). The chip localizes and concentrates the electromagnetic field of a laser beam in so-called hot-spots, which enables detection of the weak Raman signal by Surface-Enhance Raman Spectroscopy (SERS).

Particularly 17β-estradiol (E2), which is a very potent female hormone, is of interest to the MUSE project due to its persistence in Nature. It is mainly used in contraceptive pills, from where it finds its way into lake and sea waters. Similarly diclofenac (DCF) is used as an anti-inflammatory agent in gels and is likewise found in these waters. Both the effect of E2 and DCF on wildlife has not yet been fully understood, but they (and many others) are being monitored closely by the European Committee in order to ensure good water quality.

The MUSE project also aims at integrating the SERS sensor on a DVD-like platform, where the Raman signal can be excited by the integrated laser in such DVD systems. By placing the sensor on a disc it is possible to utilize the rotational forces to move liquid in micro channels, which is an easy way to compact liquid handling on the microliter scale. Before the sample reaches the detection chamber it can pre-concentrated (if necessary), filtered and aliquoted into smaller samples. This enables additional analysis on the same sample by other sensors placed on the disc.



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Looking back to see ahead - using historic time series of groundwater level to assess the impact of future climate and land use change on groundwater formation under forests

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Abstract
Land use change can be considered as a soft geoengineering tool to generate more or less percolation to the groundwater by reducing or increasing evaporation. Because of the different levels of water consumption by vegetation types more or less water will be lost as evaporation.

In forests, tree species can be used as a direct measure to control the amount of water that percolates and evaporates. Recently, the tree species effect on the catchment water balance was investigated using the MIKE SHE model (Sonnenborg et al. 2014) where it was shown that replacing coniferous tree species (high water consumption) with broadleaved species (lower consumption) increased groundwater head in the primary reservoir with up to three meters and increased minimum median discharge by up to 8% in a sandy catchment.

With the desire to increase the forested area in Denmark it is relevant to still consider the impact of the forest cover on water resources and how this can be used to maximize or in some other setting minimize water yield. However, the effect of land use change is measured in decades and model simulations must be backed by evidence from the field.

In 1956 and 1960 two unique drainage experiments were established on Sealand, Denmark to assess what effect soil drainage (pipes and ditches) would have on the growth of coniferous and broadleaved tree species. Today these experiments can also be viewed as long term insights to how climate, forest management and land use change impacts the water balance in forests and hence groundwater formation. For over 5 decades groundwater heads were monitored in open wells on a monthly basis and now provide valuable historic time series of forest hydrology.

We propose to use these time series as inputs to hydrological models that integrate soil, vegetation and atmosphere dynamics to assess the long-term impact of climate variability and land use change on groundwater formation under forests. We will show examples of how changes in the vegetation cover and soil drainage over time affects soil hydrology.

By establishing a solid knowledge of how past climatic variability and stand dynamics impact the water balance we will be able to see ahead and assess how future climate change will impact the water balance of forests. In turn this knowledge can be utilized in larger modelling contexts to more realistically represent land use change as a soft geo-engineering tool, including forests, to shape regional water resources.

References

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Possibilities to combine future drinking water supply systems and cloudburst mitigation infrastructure

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Abstract

Densely populated cities around the world faces two major water problems:

- Not enough local water for drinking water supply
- More than enough rainwater that have to be handled

The challenge concerning the production of sufficient amounts of drinking water locally have existed for more than 150 years in the Copenhagen area, and this challenge has been solved by establishing regional waterworks supplying drinking water to the city.

In more recent years the problems concerning managing an increasing volume of rain water have presented new possibilities for adding quality to the city through green ditches, lakes and canals.

Since the mid 1990s, HOFOR (Greater Copenhagen Utility) have exploited new ways to use "local water" of secondary quality as a substitution for regionally produced drinking water. Rain water may present new possibilities for substituting regionally produced drinking water depending on the quality and thus the treatment required to obtain drinking water quality. In addition to the quality of the water, a steady supply of water is needed for drinking water supply, which makes the use of cloudburst water even more difficult.

HOFOR depend on regionally produced drinking water based on clean groundwater, but we continue to follow up on the possibilities in the changing climate and advances in technology.

Reference

City of Copenhagen (2011) *Copenhagen Climate Adaptation Plan*
City of Copenhagen (2012) *Copenhagen Water Supply Plan*

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Need for a hydrogeological management framework as a basis for the urban water resources ?

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Abstract

The handling of rain in urban areas often requires the possibility to use SUDS (Sustainable Urban Drainage System) based on infiltration in order to supplement the traditional pipe and basin solutions. In practice, we have recently seen several examples where SUDS have not been possible due to poor infiltration and drainage conditions. SUDS solutions therefore require a thorough knowledge of the geology and hydrogeology.

Managing the urban water resources in a changing climate requires knowledge of surface hydrology, drainage systems, geological and groundwater conditions. A prerequisite for this is detailed, near-surface mapping with systematic use of new and existing data.

It is time consuming to provide a basis for decisions, as there is only little tradition at urban level to make systematic collection and updating of geological / hydrogeological data, and survey results are often fragmented. For example, in the same area different geological / hydrogeological models can exist, developed for several purposes. To access all possible information and assess the need for new data collection, these all need investigation. The new data collection (e.g., drilling and mapping) is sometimes in vain, as already sufficient knowledge about the area may be available but not accessible. Thus, there is a national need for a system for the integration of relevant data to assure access and application of both new and existing data in the best way possible.

In 2012, The Danish Water Technology Foundation granted funding for a two-year project: "Development of a 3D geological / hydrogeological model as the basis for the urban water cycle". The project partners are VCS (VandCenter Syd), the Municipality of Odense, Alectia and I-GIS, with GEUS as project manager.

This is a pilot project for the area of Odense municipality, which can be developed into a nationwide system. Use of new data types is investigated in order to provide new knowledge about the subsurface hydrogeology in the urban area. Besides, an inventory of all data containing geological information in selected areas will be implemented. A major outcome of the project will be recommendations for the management of the knowledge collected in the project, to bring forward lessons learned.

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Modelling of stormwater infiltration for stream restoration. Beder (Aarhus) case study

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Abstract
Stormwater management using Water Sensitive Urban Design (WSUD) is emerging as an alternative to traditional structural engineering solutions. Here stormwater infiltration is analyzed as a means for increasing the flow in a stream with unacceptably low flows during the dry season. The analyses were carried out by developing a hydrogeological model of the Beder area in Aarhus, Denmark. The model area is characterized by the presence of a secondary unconfined aquifer that partly contributes baseflow to the local streams and partly to recharge to the underlying primary aquifer.

The model was applied to assess the impact of stormwater runoff infiltration on (1) the water balance; (2) stream flow of the local stream Hovedgrøften; and (3) the risk of polluting the primary aquifer. The hydrogeological model was developed in a deterministic groundwater model (MIKE SHE) which was coupled dynamically to a hydrodynamic 1-D river model (MIKE 11). Geological data based on spear mapping, geophysical data and lithology from local boreholes were used to set up the geological model. Groundwater observation and stream flow measurements were used for model calibration and validation. Different scenarios were analyzed in order to evaluate the impact of implementing stormwater runoff infiltration. The 'Baseline scenario' was run for a 5 year period and was used to establish the water balance, the stream flow and the groundwater flow. The 'realistic infiltration scenario' simulated stormwater runoff infiltration from a 6.8 ha area, as suggested by the Aarhus municipality, with approximately 25% imperviousness. This scenario was used to track the flow path of infiltrated stormwater, and to quantify both the water balance and the stream flow of Hovedgrøften and compare them with the 'Baseline scenario'. The 'potential infiltration scenario' simulated stormwater runoff infiltration from the whole Beder area of 1.5 km2. This scenario was used to quantify both the water balance and the stream flow of Hovedgrøften and compare them with the 'Baseline scenario'.

Results show that the water balance is moderately affected by the recharge from the WSUDs and that 25-27% of the infiltrated stormwater would reach the stream and 67-73% the primary aquifer for both scenarios. The infiltrated stormwater poses a risk to the primary aquifer, as particle tracking showed that the infiltrated water would reach the primary aquifer. Stormwater infiltration in the 'potential infiltration scenario' was shown to contribute an additional 11% to the Hovedgrøften stream flow during a very low stream flow period and by 0.1% in the 'realistic infiltration scenario' (these result were based on the assumption that all stormwater runoff was infiltrated).

Stormwater infiltration in Beder was shown to have a small impact on the streamflow of Hovedgrøften. This is because the impervious area available for stormwater runoff infiltration is small compared to the catchment area of Hovedgrøften. A more impervious catchment would have greater potential for increasing the contribution to streamflow.

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Biocides in urban waste water treatment plant influent: dry and wet weather concentrations, mass loads and possible sources

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Abstract
In recent years, exterior thermal insulation systems became more and more important leading to an increasing amount of houses equipped organic renders and paints. These materials are usually with biocides in order to protect from algae and fungi growth. It is known that these biocides, e.g. terbutryn, carbendazim or diuron, leach out of the material through contact with wind driven rain and, hence, they are present in combined sewage during storm events.

The present studied focused on the occurrence of these biocides in five waste water treatment plants in Denmark and Sweden during wet as well as dry weather. It was discovered, that the organic biocides are detectable not only during wet weather but also during dry weather periods with concentrations up to 4.5 µg L^{-1} (propiconazole). Time resolved sampling (12 x 2 h) showed that the emissions during dry weather correlate with household activities, while they correlate with stormwater content during rain events.

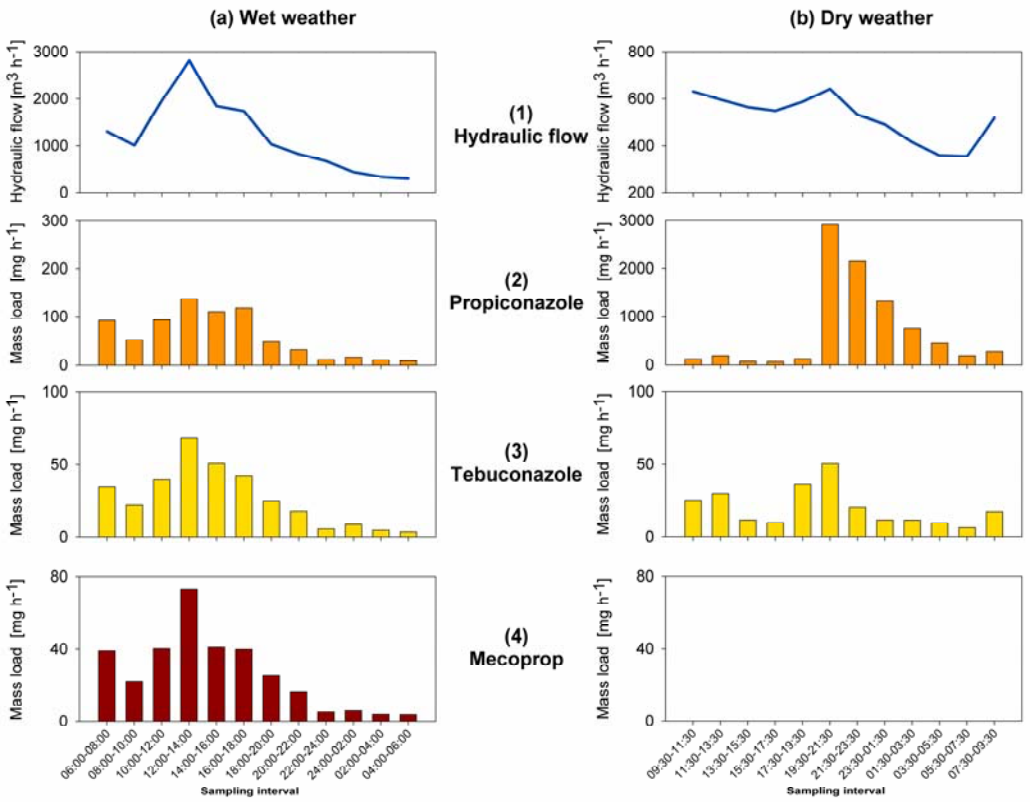

Figure 1: Diurnal cycle of biocides used in building material and hydraulic flow during (a) a wet weather day (28./29.10.2013) and (b) a dry weather day (4./5.6.2013) in the WWTP Bjergmarken (Roskilde, Denmark).

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The prokaryotic community structures of waterworks sand filters are shaped by groundwater chemistry

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Abstract
A safe and stable supply of drinking water is a major global challenge. Many waterworks use rapid sand filtration for treatment of anaerobic groundwater before it is distributed to the consumers. The main functions of the filters are removal of iron, manganese, methane, ammonium and organic matter by processes which are mostly bacterially mediated. We hypothesize that the groundwater chemistry shapes the prokaryotic community structure of waterworks sand filters. The aim of this research was to examine the relation between the prokaryotic communities and the inlet water geochemistry, and further to identify the bacterial groups responsible for the most important water-purifying processes occurring in the filters.

We pyro-sequenced 16S rRNA from prokaryotic communities in sand filters from 11 waterworks receiving groundwater from different geological settings in Denmark. Concomitantly, physical-chemical parameters of the filters were measured. Analyses showed relationships between the iron, manganese, methane and ammonium concentrations and the prokaryotic community structures of the filters: (i) The iron-oxidizing bacterium Gallionella was present at all of the waterworks. Gallionella dominated particularly at the facility supplied with groundwater having the highest iron concentration. Abiotic iron-oxidation is generally believed to dominate in most waterworks; however, the widespread occurrence of Gallionella suggests that biological oxidation also takes place. (ii) Hyphomicrobium spp. were abundant at all waterworks, where they most likely perform manganese oxidation. (iii) Species belonging to the methanotrophic Methylococcaceae were abundant in sand filters of the six waterworks which had significant concentrations of methane in their inlet water, indicating that members of Methylococcaceae are important methane oxidizers in groundwater-treating sand filters. (iv) Ammonia-oxidizing Nitrosomonas and Crenarchaeota (Archaea) were found in the filters, albeit in relatively low abundance. Nitrospira, which probably plays a role in the oxidation of nitrite to nitrate, was also present.

Through combined metagenomic and physical-chemical analyses our study gives new insight into the composition of the microbial community of groundwater-treating rapid sand filters. Furthermore, relations found between groundwater chemistry and specific bacterial groups give indications of the key functional bacteria within the filters. This knowledge may be used to steer the biological processes in sand filters to ensure a stable supply of high quality drinking water.

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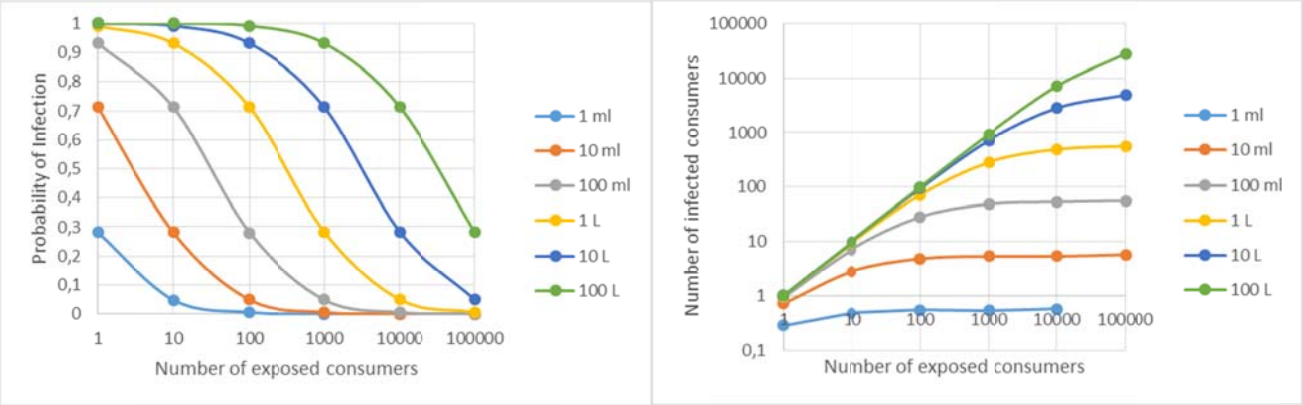
How many consumers are infected after intrusion of wastewater into a drinking water distribution network? – A Quantitative Microbial Risk Assessment

C. Jørgensen, G. Heinicke**, DHI.*

Abstract

The drinking water distribution network is an important barrier in all water supplies and protects the water and the consumers against contamination. However, water may intrude if there are leaks and the external pressure is higher than the internal pressure. Leaks may be caused by bursts, corrosion damages or leaky gaskets. Low-pressure events may be transient or sustained. Transient events are caused by sudden changes in water velocity due to operation of pumps and valves or sudden changes in water use and may last for milliseconds to minutes. Typical intrusion volumes are 5 ml/l to 500 ml/s. Sustained events are caused by maintenance of repair work on the network or main pipe bursts and last from minutes to hours. Typical intrusion volumes are in the litre range.

In this work, we have analysed the risk associated with intrusion of pathogens from wastewater into the distribution network by quantitative microbial risk assessment (QMRA). The calculations are based on an assessment of the exposure (pathogen dose) and the dose/response relations for four selected pathogens. The results are shown in the figure below.



The left part of the figure shows the average probability of infection by *Cryptosporidium, Giardia*, Norovirus and/or *Campylobacter* as a function of number of exposed consumers after intrusion of 1 ml to 100 L of wastewater. The number of consumers is proportional to the volume of delivered water and the dilution of the intruded wastewater. It is assumed that the wastewater is diluted homogenously in the drinking water. An acceptable risk often used is $P_{inf} < 10^{-4}$/year. The acceptable risk corresponds to exposure to a concentration of approximately 0.01 *E. coli*/100 ml during one day. One event/year with intrusion of 1 ml wastewater poses an unacceptable risk when less than 10,000 consumers are exposed. The right part of the figure shows the average number of consumers estimated to be infected as a function of the number of exposed consumers. 5 to 6 consumers are expected to be infected by intrusion of 10 ml of wastewater when more than 100 consumers are exposed. Further dilution reduces the probability of infection but not the number of infected because of linearity in the model at low doses.

The results have a relatively high uncertainty because the dose/response relations are uncertain, particularly at low dosages, and because the estimated pathogen concentrations are uncertain and vary in time. The results must therefore be used with caution, but they indicate that intrusion of even small quantities of wastewater (1 – 10 ml) is unacceptable.

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Sorbents for phosphate removal from agricultural drainage water

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Abstract
Phosphorus (P) is an essential macronutrient for plants. High fertilizer inputs resulted in P accumulation in soil, leaching of P to the aquatic environment and risks of eutrophication.

In Denmark, P loss originating from agriculture is a main contributor of P to surface water bodies. On average, 1,400 kg P/ha has accumulated in arable Danish soils, and P is continuously accumulating in some areas. In Denmark, more than half of the farmland is artificially drained and 1/3 of P losses occur as leaching through the soil profile to subsurface drains. Achieving good water quality as stated in the EU Water Framework Directive requires a substantial reduction of P loss from farmland. Installation of P sorbing filters at drain outlets is one of the possible solutions to reduce P load to the aquatic environment.

Efficient sorbents to be used in filters must possess high affinity to retain phosphate at low concentrations. In addition, high phosphate sorption capacity, fast bonding and low desorption are necessary. This study therefore seeks to identify phosphate sorbing materials (PSMs) that are capable of removing and retaining phosphate at low concentrations and with short reaction times. Additionally, the aim was to get a better understanding of the sorption reactions, related to different types of commercially available PSMs.

Fifteen different PSMs were tested. Some was discarded after the first screening, while five remaining calcium or iron based PSMs were fractionated into four size fractions for thorough investigation. Of the five tested commercial available PSMs the iron oxide based CFH showed the best sorption properties: CFH is capable of sorbing phosphate at both base flow and high peak concentrations and retaining >90% of the sorbed phosphate regardless of the time of reaction and concentration. Sorption by CFH is a fast reaction although CFH also sorbs more when reaction time increases. No secondary iron phosphate is detected on the surface of CFH and the exothermic heat of reaction and pH range suggest that adsorption by surface complexation is the sorption mechanism. CaO based Filtralite® P has a high affinity towards phosphate at high concentrations and the sorption kinetics is rapid if pH is high (>~10). However, Filtralite®P does not fulfill the requirements of an efficient PSM as it desorbs already sorbed phosphate when P solution concentrations decrease, and because it only works at alkaline pH. The fact that Filtralite®P is prone to desorb at neutral to acid pH, the sorption is considered due to precipitation of amorphous calcium phosphate that dissolves at neutral to acid pH.

Based on this study a model to dimension filter diches and estimate the lifetime of PSM has further been developed. The focus of this study was solely on P sorbing aspects of the PSMs, despite the hydraulic conductivity of PSM is equally important in a P removal structure. Even though this study points to iron oxide based CFH as being the best PSM, the size and size distribution of the filter material has proven to cause problems for the hydraulic conductivity. Hence, the PhosCap project that is collaboration between University of Copenhagen, Aarhus University and two industrial partners, attempts to address this challenge. Combing the properties of two of the tested filter materials in SupremeTech, one with a high hydraulic conductivity and one with a high sorption affinity, capacity and retention, has resulted in a recent filled patent (patent no. PA 2014 70572).

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Experimental selection of surfactant for enhanced alkaline hydrolysis of organophosphorous pesticide contamined soil and groundwater

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Abstract

A 20,000 m^2 former chemical dump site in the North-Western part of Denmark is contaminated with 200-300 tons of organophosphorous pesticides and pesticide manufacturing wastes, a significant fraction of which consists of the highly toxic pesticide parathion. The majority of contaminant mass is present as sorbed phase and residual dense nonaqueous phase liquid (DNAPL). A European Commission-funded demonstration project (www.northpestclean.dk) was initiated in September 2010 with the objectives of determining the effectiveness of using *in situ* alkaline hydrolysis to treat the organophosphorous pesticide DNAPL. A primary challenge for effective treatment was in situ mixing, and establishing sufficient contact between DNAPL and hydroxide used to achieve alkaline conditions (pH 12) in the aqueous phase. Surfactants were tested as a novel method for enhancing treatment by *in situ* alkaline hydrolysis. The purpose of the surfactants is two-fold: to increase the solubility of the pesticides in the alkaline solution for increased hydrolysis, and increased mobility of the DNAPL by lowering the interfacial tension. The range of commercially available surfactant formulation is immense, and selection of formulations for further testing was challenging. Surfactants based on nonylphenol ethoxylate as active ingredient were initially identified as promising candidates, but these compounds are banned for use in Denmark due to concerns of their environmental fate, necessitating the selection of alternative surfactants.

The objectives of this project were to select a surfactant formulation for further pilot-scale testing at the field site. First a literature search was conducted to identify of potential surfactants used under alkaline conditions in industry, and surfactants recommended by US EPA as alternatives to nonylphenol ethoxylates. Second, candidate surfactants were evaluated based on their stability under alkaline conditions, acceptability for *in situ* use, biodegradability and previous use for subsurface remediation. Laboratory experiments were performed in duplicate to test the effects of candidate surfactant formulations on the pesticide DNAPL solubility and reactivity under highly alkaline conditions at comparable surfactant concentration. Surfactant formulations with the best performing active ingredient groups were further tested at two concentrations with the presence of site soil. Eighteen parent compound and hydrolysis products were analyzed as evaluation parameters.

Nine surfactant formulations, comprised non-ionic, anionic and amphoteric types, from three suppliers were identified in the theoretical selection process. The formulations represented four groups of active ingredients, including alcohol ethoxylate, alkyl polyglycosides, alkane sulfonates and carboxylated propionate. The alcohol ethoxylate formulations showed the best performance with respect to solubility enhancement of the DNAPL, although no enhancement in the pesticide reactivity was observed. Subsequent batch studies with site soil revealed internal differences between the four non-ionic ethoxylate formulations with respect to both solubility and reactivity. The best performance was obtained with the Ecosurf EH-9 and Tergitol 15-S-12 surfactant formulations; Ecosurf EH-9 was selected for pilot-scale testing at a concentration of 30 g/L. Pilot scale testing is currently ongoing.

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Drinking water N-pollution and public health effects: Nitrate exposure of the Danish population during the last 35 years

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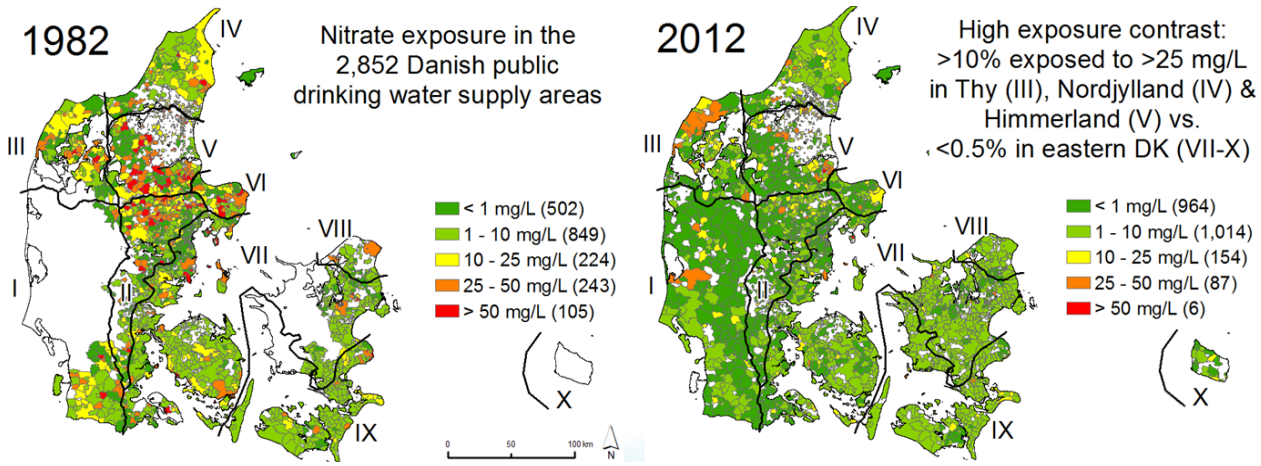
Abstract

In Denmark, drinking water supply is highly decentralized and fully relying on simple treated groundwater. At the same time, Denmark has an intensive agriculture, making groundwater resources prone to pollution with nitrate. Nitrate in drinking water has been suspected to negatively affect human health, amongst others as a cause of cancer. However, no clear evidence has been found, yet.

Drinking water quality data covering the entire country for over 35 years are registered in the publicly-accessible database Jupiter. These data were analysed to determine the fraction of population exposed to elevated nitrate concentrations. Data from 2,852 water supply areas in the 98 Danish municipalities were for the first time digitalized, collected in one dataset and connected to the Jupiter database. Public water supplies are extensively registered; private wells supplying only few households are neither monitored nor registered sufficiently. The study showed that 5.1% of the Danish population was exposed to nitrate concentrations > 25 mg/L in 2012. Private well users were far more prone to exposure to elevated nitrate concentrations than consumers connected to public supplies. While the fraction exposed to elevated nitrate concentrations amongst public supply users has been decreasing since the 1970s, it has been increasing amongst private well users, leading to the hypothesis that the decrease in nitrate concentrations in drinking water is mainly due to structural changes and not improvement of the groundwater quality as such. A combination of this new drinking water quality map with extensive Danish health registers will permit an epidemiological study on health effects of nitrate, namely gastrointestinal cancers, as long as the lack of data on private well users is addressed.



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Cost Benefit in reducing Water Loss in water distribution systems

*T. Sønnichsen, Water Consumer Council for Gladsaxe and Gentofte**

Abstract
In many countries water losses in the drinking water systems are very high – more than 25%, even 50%. In areas, where access to water is limited, too much water is lost. Cleaning river water is costly and one should believe that programs to reduce losses are feasible. In many countries the Government subsidizes the water sector, which leads to lower consumer prices. But there are too few efforts on reducing water loss or to encourage water sawing. Water meters are not always existing or functioning, or illegal sales of non-measured water occurs.

At least in Denmark, high water prices encourage private water users to reduce their water consumption by modernizing sanitation systems e.g. by installing water saving closets. Some governments, like the Danish, have increased the water prices by introducing TAX and VAT, up to 31% of the water price.

The Danish population has on average reduced the domestic water consumption from 1993 to 2013 from 150 liters/person/day to 107 liters/person/day. In the same period the average buying price for water have increased from DKK 14,-/m^3 to DKK 63,-/m^3 (National Board of Environment).The next ten years the water prices are expected to increase to DKK 100,-/m^3 (Gladsaxe Municipality).The question is if this radically higher water price will ask for new technologies in the houses, such as rainwater flushing closets etc.

Many water companies maintain their many km long cast iron pipes by renewing pipes from iron to pipes of polyethylene. These programs are very expensive and have not yet shown any reduced water loss. In our area up to 300 leakages per year leads to water loss of more than 10 % of the produced drinking water from the water company-owned parts of the water pipes. Beside this 125 leakages per year are occurring in the private and public owned pipes leading to the houses.The total water loss in Denmark is estimated to be between 10 and 20 million m^3 drinking water per year. Enough water for 500.000 consumers.

What can be done to reduce this heavy loss of drinking water?

1. Data-logging along the water pipes detecting new leakages of the pipes quicker.
2. Revised strategies for exchanging iron pipes into PE.
3. Using anodes as anti-corrosion of iron pipes as in the district heating systems.
4. The water companies take over the ownership of private pipes into the houses

The water consumers as new elected board members since 2014 in the water companies in Denmark are taking part of and responsible to encourage the water companies with more feasible priorities.

The water consumers have saved water during the years mainly because of the higher water prices. We are now expecting that the water companies will reduce their water losses from 10 % to 4 %.

My cost benefit analyses and feasibility study shows feasibility of efforts to reduce water leakage from10 % to 4 %. The cost benefit analysis will be presented with key figures.

Goals and aims of public drinking water losses on or below 4% should be seen in the perspectives of the government possibly granting prolonging license or permissions of pumping groundwater, and EU rules on this subject.

It is sustainable and environmental safe to reduce the water spills, by reducing the number and size of the leakages. It is a good business case to reduce water spills down to 4 % and Danish proven technology might lead to attention in countries with similar challenges, leading to Danish export of the proven expertise.

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