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Session 1: Groundwater

Increased freshwater and groundwater regeneration by conversion of coniferous forests to deciduous forests on Zealand, Denmark.

J.R. Christiansen, KU Life[1] and P. Gundersen, KU Life[2]

Abstract

Evaporation from deciduous forests is less than from coniferous forests at the same precipitation. Thus, the amount of water percolating below the root zone, that can reach streams or groundwater, will be higher under deciduous than coniferous forest. Conversion of existing Danish coniferous forests therefore represents a potential to generate more near-surface runoff, shallow groundwater and deep groundwater. So far there has not been much focus on this instrument. This is the background to examine how much more surface or groundwater that could potentially be formed by converting existing coniferous forests to deciduous forests of Zealand and Lolland-Falster. The annual infiltration (mean ± SE) was significantly lower ($p<0.0001$) from coniferous forests (147 ± 11 mm year^{-1}) than for deciduous forests (262 ± 14 mm year^{-1}) on Zealand. Using the numbers for the average seepage of coniferous and deciduous forests, as well as the areal distribution of the two forest types on Zealand and Lolland-Falster (National Forest Inventory data), the increased amount of infiltration by converting all existing coniferous forest to deciduous forest was estimated. Furthermore, it was assumed that around 53% of the percolation becomes deep groundwater, while the remaining 47% seeps into streams and lakes (Refsgaard and others 2003, http://www.vandmodel.dk/FK1-kapitel6.pdf)). Thus, the total amount of enhanced percolation to the near-surface and deep groundwater reserves for Zealand and Lolland-Falster were 37 million m^3 year^{-1} and 20 million m^3 year^{-1}, respectively. The potential increase in groundwater recharge is not evenly distributed throughout the municipalities of Zealand (Fig. 1). The increase in percolation mainly depends on the forested area in each municipality, and the current proportion of coniferous forest. Therefore, municipalities with high settlement percentage (Copenhagen and suburbs) do not possess a potential to enhance percolation by conversion because forest area is already low and mainly covered by deciduous forest.

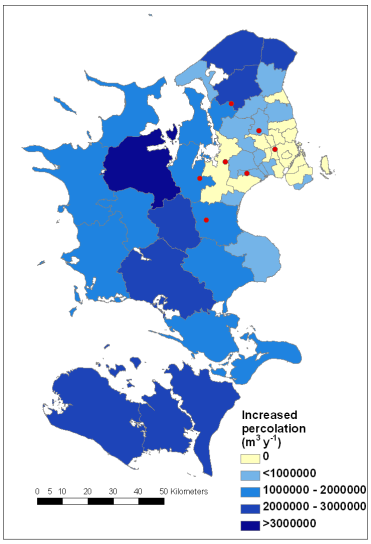

Figure 1 The annual potential increase in percolation ($m^3 y^{-1}$) by converting coniferous to deciduous forests in municipalities of Zealand and Lolland-Falster. Red dots mark the waterworks supplying Copenhagen.

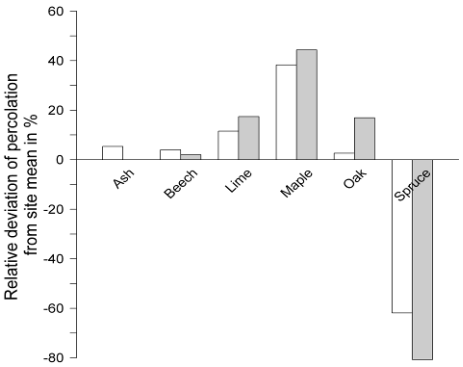

Figure 2 Relative deviation of species-specific percolation from the mean percolation at two sites (Mattrup (white bars) and Vallø (grey bars)). From Christiansen et al. (2010) Global Change Biology 16, 2224-2240.

However, this issue does not only concern conifers vs. deciduous forest, because the percolation under various deciduous species differs markedly as well (Fig. 2). Maple stands have been shown to have the largest percolation while beech stands in general have the lowest percolation (Fig.2). In afforestation or by converting coniferous forests to deciduous forests, it is therefore also necessary to integrate the choice tree species, as infiltration varies between species. Moreover, precipitation and soil type will influence the amount of percolation.

It can be concluded that there is a large potential to create more surface water and groundwater by converting existing coniferous forest to deciduous forest on Zealand and Lolland-Falster. Besides, that the pressure on the water resources on Zealand becomes less, the increased percolation will also be beneficial to the aquatic environment. However, this pre-study has not included a number of factors that will affect the percolation under forest: 1) rainfall distribution, 2) soil type distribution and 3) detailed deciduous and coniferous forest

distribution. Inclusion of these factors will improve the analysis and provide a timely estimate on the potential for increased recharge of water reservoirs by land use changes in Danish forests.

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Nitrate in Danish groundwater during the last 60 years

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Abstract

This presentation assesses the long-term development in the oxic groundwater nitrate concentration and nitrogen (N) loss due to intensive farming in Denmark. Firstly, up to 20-year time-series from the national groundwater monitoring network enable a statistically systematic analysis of distribution, trends and trend reversals in the groundwater nitrate concentration. Secondly, knowledge about the N surplus in Danish agriculture since 1950 is used as an indicator of the potential loss of N. Thirdly, groundwater recharge CFC (Chlorofluorocarbon) age determination allows linking of the first two dataset. The development in the nitrate concentration of oxic groundwater clearly mirrors the development in the national agricultural N surplus, and a corresponding trend reversal is found in groundwater (see Figure 1). Regulation and technical improvements in the intensive farming in Denmark have succeeded in decreasing the N surplus by 40% since the mid 1980s while at the same time maintaining crop yields and increasing the animal production of especially pigs. Trend analyses prove that the youngest (0-15 years old) oxic groundwater shows more pronounced significant downward nitrate trends (44%) than the oldest (25-50 years old) oxic groundwater (9%). This amounts to clear evidence of the effect of reduced nitrate leaching on groundwater nitrate concentrations in Denmark.

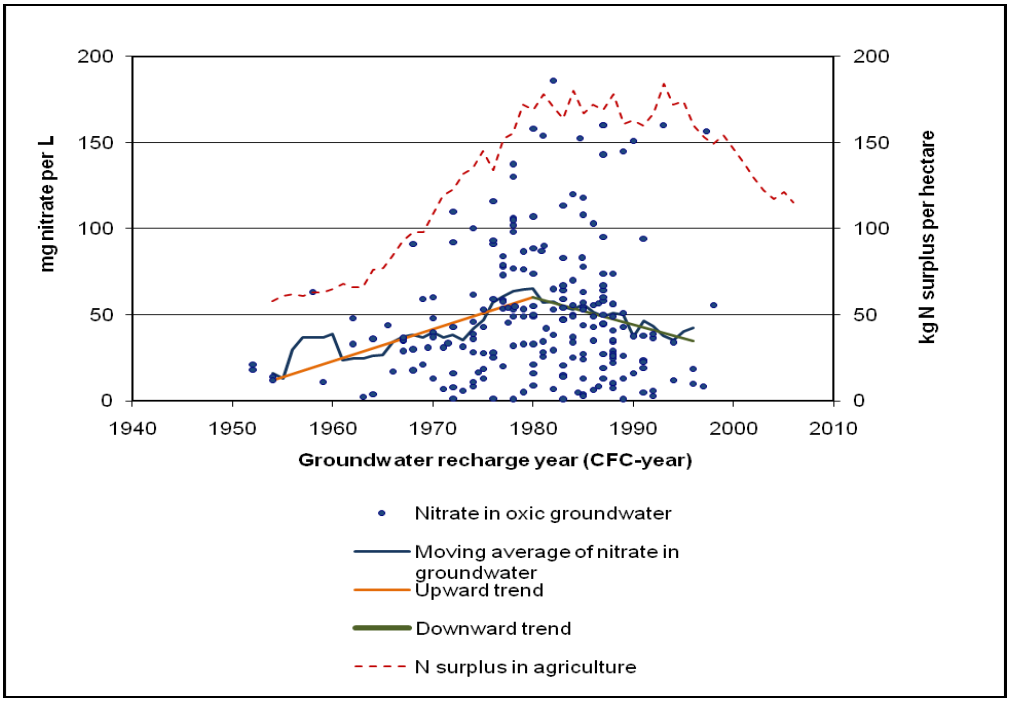

Figure 1. Time series of N surplus in agriculture and nitrate in oxic groundwater versus recharge age (CFC age) on an annual mean level.

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Competitive adsorption of arsenate and phosphate onto calcite

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Abstract

Arsenic in groundwater is worldwide a serious health problem and the problem has also been noted in Denmark. The current drinking water limit of 5 µg/L is exceeded many places in aquifers in Denmark, and in those cases the water quality delivered from the water works depends on the efficiency of the water treatment, which is not always unproblematic. In order to assess the risk that arsenic imposes on the water resource, we need a proper understanding of the processes controlling the groundwater arsenic content.

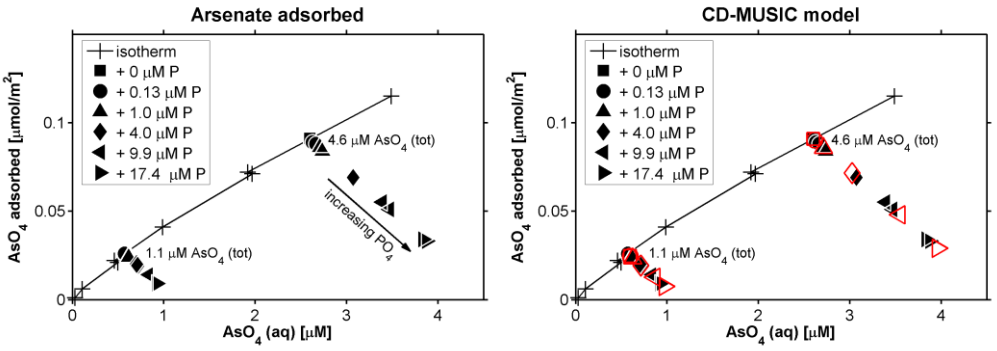
Adsorption and desorption of arsenic on limestone are surmised to be important processes controlling the mobility of arsenic. Changes in the concentrations of competitive anions, like phosphate, silica or bicarbonate may possibly cause competitive displacement of arsenic from the sediment surface complexes and lead to sudden unexpected increases in the arsenic content of well waters. Such changes could easily be induced by the influence of agriculture or by pumping for water abstraction.

The competitive adsorption of arsenate (As(V)) and phosphate onto calcite was studied in batch experiments using calcite-equilibrated solutions. The solutions had circum neutral pH (7-8.3) and a wide span in the activity of Ca^{2+} and CO_3^{2-}. Both simultaneous and sequential addition of arsenate and phosphate was studied. The results shows that adsorption of arsenate onto calcite is strongly reduced by the presence of phosphate, whereas phosphate adsorption is only slightly reduced. Simultaneous and sequential addition (3 hours apart) yields the same reduction in adsorption, which underline the high reversibility of the system. The reduction in adsorption of both arsenate and phosphate is most likely due to competition for the same sorption sites at the calcite surface, considering the similarity in sorption edges, pKa's and symmetry of the two anions.

The strong reduction in arsenate adsorption suggest that adsorption of arsenate onto calcite is of minor importance in most groundwater aquifers, as phosphate is often present at concentration levels sufficient to significantly reduce arsenate adsorption.

The CD-MUSIC model for calcite was used successfully to model adsorption of arsenate and phosphate individually. Based on these models the competitive effect of the binary system was well predicted by the model. This is in contrast to the constant capacitance model (CCM) where we were unable to predict the competition based on individually fitted models.

This study clearly shows the importance of competition studies, especially i) when estimating the mobility of an ion in the environment and ii) for validation of models.



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Soil fungi produce non-degradable water-soluble PAH metabolites.

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J.H. Christensen, KU Life[2]

Abstract

This study investigated the production and mineralization of water soluble polycyclic aromatic hydrocarbon (PAH) metabolites produced by the soil fungus *Cunninghamella elegans*. Eleven soil fungi were screened for their ability to metabolize ^{14}C-phenanthrene, ^{14}C-fluoranthene and ^{14}C-pyrene into water soluble compounds. Eight fungi produced water soluble metabolites from all or some of the PAHs. The composition of the water-soluble PAH-metabolites from the most effective solubilizer *C. elegans* was analyzed by an ultra-performance liquid chromatograph interfaced to a quadrupole time-of-flight mass spectrometer. Thirty eight metabolites were detected. All of 34 identified metabolites were sulfate-conjugated. The mineralization of ^{14}C-metabolites, produced by *C. elegans*, was compared to mineralization of the parent ^{14}C-PAHs in soil slurries. It was hypothesized that the increased bioavailability and metabolic activation of the metabolites would increase mineralization in soil slurries compared to mineralization of the parent PAHs. Unexpectedly, the mineralization of the ^{14}C-metabolites was in all cases extremely slow compared to the mineralization of the parent ^{14}C-PAHs. Slow ^{14}C-metabolite mineralization was not caused by metabolite toxicity, neither was co-metabolic mineralization of ^{14}C-metabolites stimulated by the presence of active PAH-degraders. High water solubility, low lipophilicity and extremely slow mineralization of the metabolites indicate a potential problem of leaching of fungal PAH-metabolites to the groundwater. Reference: ES&T, 2010, 44:1677-1682.

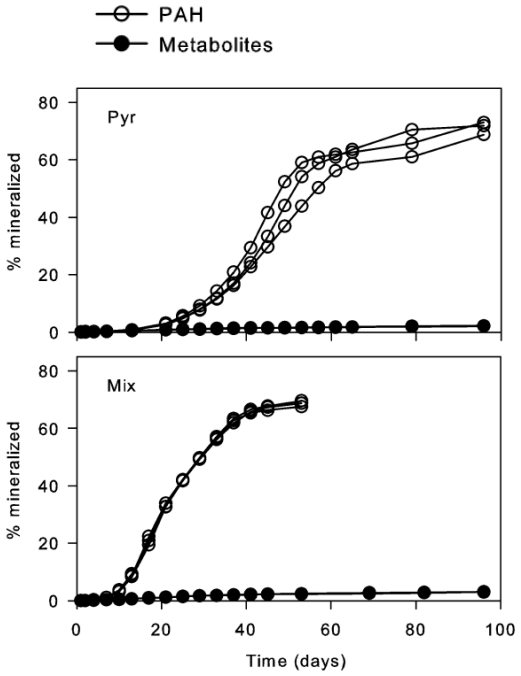

Figure 1. Mineralization of ^{14}C-PAHs and ^{14}C-metabolites in soil slurries (n=3). Pyr: pyrene: Mix: mixture of phenanthrene, fluoranthene and pyrene.

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Stable sulfur and oxygen isotope fractionation in sulfur compounds - What can be learned in terms of sulfur cycling processes in contaminated sites

F. Einsiedl, DTU Environment[1]

Abstract

The gradually increasing anthropogenic impact on aquatic systems over the last 60 years has altered the groundwater quality in many areas around the world. However, groundwater represents the main drinking water resource in nearly all European countries. Particularly Denmark uses groundwater as the only drinking water resource. Therefore, the task of ensuring good status of groundwater demands an improved understanding of the efficiency and limitations of microbially driven reactions on the degradation of pollutants in contaminated groundwater systems. Stable isotope technique has proven to be powerful in characterizing biogeochemical processes in complex groundwater systems.

There is recent evidence that at the fringes of contaminant plumes mixing of anoxic polluted groundwater with uncontaminated groundwater from outside the plume, containing electron acceptors such as oxygen, nitrate and/or sulfate, regulates the degradation of contaminants in porous groundwater systems. In contrast, it was assumed that the degradation of organic contaminants in the plume core is limited due to the depletion of electron acceptors.

Therefore we elucidated the sulfur and oxygen isotope signatures in various sulfur compounds that were controlled by bacterial sulfate reduction and linked these values to the microbial community distribution in the aquifer. The goal was to reach an integrated understanding of sulfur cycling processes at the plume fringe of contaminated aquifers relative to their importance for biodegradation processes. In this presentation we show that sulfur cycling is an important process driving microbial degradation of contaminants at the fringe of the contaminant plume. We propose that elemental sulfur, sulfite and thiosulfate may be key-intermediates during biotic and abiotic oxidation of hydrogen sulfide, with the latter formed during bacterial sulfate reduction. Thereafter mainly elemental sulfur may be used by the specific microbial community found in this aquifer for the oxidation of organic contaminants such as toluene.

We conclude that reoxidation processes of hydrogen sulfide to sulfite, thiosulfate, elemental sulfur and dissolved sulfate by oxygen and Fe(oxides) may affect sulfur cycling in contaminated sites and therefore attenuate concentrations of contaminants in groundwater.

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Extraction of nucleic acids from trichloroethene (TCE) degrading bacteria in extremely clayey groundwater sediments

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Abstract

Extraction of nucleic acids from clayey environmental samples has proven to be extremely problematic. Phosphor bindings between the nucleic acid and clay minerals such as kaolinite cause the nucleic acid to be bound tight to the sediment particles and thereby prevent extraction. For the present project our aim was to extract DNA and mRNA from a microbial community that is degrading TCE in clay rich groundwater sediment. Especially we were interested in extraction of mRNA of the functional gene *vcrA*. The *vcrA* gene

encodes a vinylchloride reductase that performs the final step in the degradation pathway of TCE. Therefore, the presence of *vcrA* mRNA can be used as an ideal biomarker for ongoing complete dechlorination processes being carried out.

In order to investigate the specific sorption effects between nucleic acids and our sediment, we performed a standard sorption experiment with ^{3}H-labelled DNA. Compared to other sediments with less clay and more organic matter, we observed a very pronounced sorption in our clayey sediment. Therefore we tested numerous reagents in order to reduce the effects of sorption, and found the G1 reagent to reduce sorption most.

To test the G1 reagents influence on DNA and mRNA extraction we set up a microcosm experiment with 100 g sediment, 200 ml water and 10^7 cells of the commercial dechlorinating culture KB-1 ml^{-1}. The addition of vinylchloride ensured a proper expression of the *vcrA* gene and samples were taken from the microcosms at appropriate timepoints. The addition of G1 reagent to the sediment prior to DNA and mRNA extraction gave significantly larger yields. The Mobio UltraClean soil kit was used for DNA and a modified protocol of the mRNA extraction method described by Nicolaisen et al., (2008) was used for mRNA extraction.

Keywords DNA/mRNA extraction, DNA/mRNA sorption to clay, TCE dechlorination, KB-1 culture, *vcrA* genes

Nicolaisen, M. H., J. Baelum, C. S. Jacobsen, and J. Sorensen. 2008. Transcription dynamics of the functional tfdA gene during MCPA herbicide degradation by Cupriavidus necator AEO106 (pRO101) in agricultural soil. Environ. Microbiol. 10:571-579.

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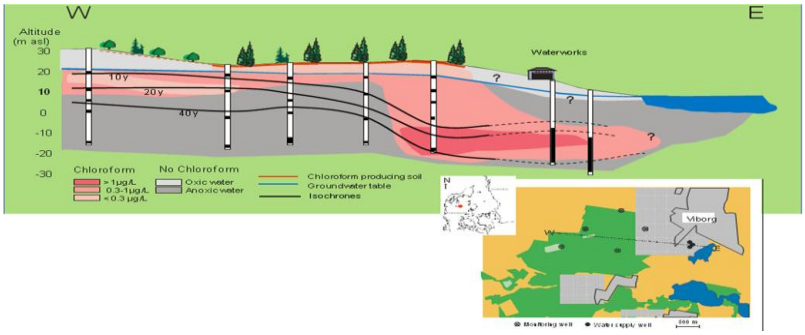
Apparent pollution of groundwater caused by natural formation of chloroform in forest soils

O.S. Jacobsen[1], C. N. Albers[1].T. Laier, GEUS[1], D. Hunkeler, University of Neuchatel[2]

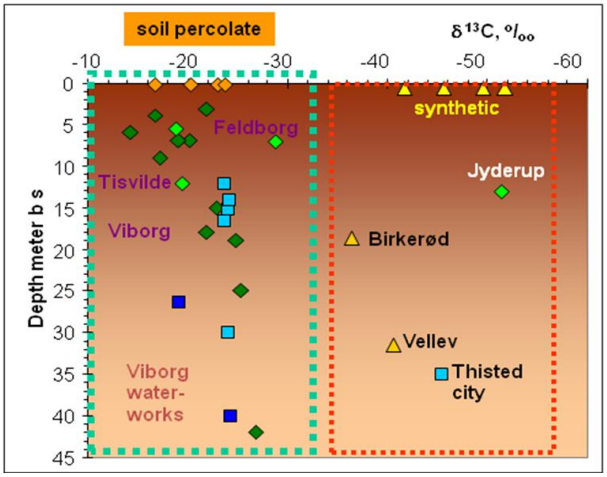
Abstract

Halogenated compounds are known to be formed in natural environments. Many of these compounds are similar to industrially produced compounds and are toxic or carcinogenic. High concentration of chloroform in groundwater is usually attributed to anthropogenic input, but we have found that the groundwater beneath some pristine areas contained chloroform exceeding 1 µg/L. We investigated four coniferous forests over a period of several years in order to measure the net-formation of chloroform. Field measurements of atmospheric and soil air concentrations of chloroform were monitored. Analyses of soil air at 40 cm depth revealed an extremely large spatial variation in chloroform concentration exceeding two orders of magnitude. Up to 100 ppbv was found in soil air under the spruce forest, to be compared to an ambient atmospheric concentration of 0.02 ppbv. The concentration of chloroform in soil air showed seasonal variation similar to that of CO_2. Chloroform formation during incubation of undisturbed top-soil samples was found to be largest in soils from dense coniferous stands with well developed humus layers, while low chloroform formation occurred in soils from beech forest and agricultural grassland. Stable carbon isotopic analyses of chloroform from the uppermost groundwater in different parts and from soil water showed values from $\delta^{13}C$ = –13 ‰ to –27 ‰, quite different from those of industrial products and from contaminated groundwater ($\delta^{13}C$ = –46 ‰ to –63 ‰) reported in the literature. We suggest that the mechanism behind the formation of chloroform is an unspecific chlorination of organic matter, caused by microbial activity in the

soil. The large spatial variation supports the hypothesis that fungi play an important role in the natural formation of chloroform.



Groundwater flow of chloroform in a forest system (Viborg Hedeplantage)



Isotope data from natural and polluted locations

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Session 2: Water resources

Scarcity and competition for water – the less than straight forward correlation between water availability and water-related conflict and cooperation

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Abstract

Few people in the world watch complacently when their water source runs dry. Depending on the perceived cause for the water shortage, people join in attempts to repair their water supply infrastructure, negotiate their access to alternative water sources, confront the water users perceived to over- or mis-use available water, seek agreements to ration the limited quantities of water available or seek to mobilize resources for the development of new water resources. Thus, water shortages make people act – sometimes in cooperation with others, sometimes by challenging the water use and -management of others.

This paper explores the link between water availability and the occurrence and nature of water-related conflict and cooperation. The paper is based on a mapping of water-related events which have taken place between 1997 and 2007 in five districts in Africa, Asia and Latin America which differ widely with respect to water availability combined with a mapping of hydrological resources in those districts. The paper suggests that rather than absolute water availability, it is the variability of water availability – both within the course of the year and between years – that contribute to prompt water-related conflict and cooperation. As climate change increasingly manifests itself, such variability in rainfall is expected to increase in many parts of the world, leading to more frequent and more unpredictable periods of water shortage which in turn may spur more water-related conflict and cooperation.

Yet, the paper argues, while sometimes being the direct cause of water-related conflict and cooperation, climatic variability in water availability is often either amplified or overshadowed by economically or politically generated variability in water availability leading to water shortage for some and abundance for others in water-stressed as well as in water-affluent environments.

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Time-lapse gravity data used to calibrate a river bank storage model

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Abstract

The estimation of hydrological model parameters by calibration to field data is a critical step in the modeling process. However, calibration often fails because of parameter correlation. Here it is shown that time-lapse gravity data can be combined with hydraulic head data in a coupled hydrogeophysical inversion to decrease parameter correlation in ground water models. This is demonstrated for a model of riverbank infiltration where combined inversion successfully constrains hydraulic conductivity and specific yield in both an analytical and a numerical groundwater model. A sensitivity study showed that time-lapse gravity data is especially useful to constrain specific yield. Furthermore, we demonstrate that evapotranspiration, and river bed conductance are better constrained by coupled inversion to gravity and head data. When calibrating four parameters, the six correlation coefficients were reduced from unity when only head data was employed, to significantly lower values when gravity and head data were combined. The calibrated parameter values are

not very sensitive to the choice of weighting between head and gravity data over a large interval of relative weights.

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Characterizing surface water - groundwater interactions of Danish lowland stream using distributed temperature sensing

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Abstract

Interactions between surface water and ground water are integral compound of stream characteristics, influencing biogeochemical mechanisms and ecological conditions of the stream. Occurring at different spatial and temporal scales, these interactions often defines and streamlines the physical habitat conditions. In this study natural heat has been used as a conservative tracer to identify these exchanges using Distributed Temperature Sensing (DTS) system. The temperature signature of surface water closely resembles the interactions between meteorological and geomorphologic features of the associated catchment thereby closely following the seasonal changes while the temperature of the groundwater remains stable at within 8 to 10 C^0. This difference in temperature can be used to locate the groundwater inflows into the stream.

Distributed temperature sensing (DTS) is a measurement technique of recent origin in the fields of hydrologic and ecological systems for real time monitoring of temperature over high spatial and temporal scales. This system uses conventional fiber optic cables to measure stream temperature as a continuous profile along the length of the cable. A 2 km fiber optic cable with DTS system has been installed in stream Elverdamsåen located in mid-Sjælland. The resultant temperature data from this 2 km reach, measured with

1 m spatial and 30 sec temporal resolution identified zones of colder temperature indicating stream interactions with the groundwater.

The stream under consideration exhibits three distinct thermal regimes within 2 km reach length as identified from the DTS system. These thermal behaviours are due to two major interactions occurring within this reach. A focused groundwater inflow into the stream at the upstream portion of reach cools the overall system approximately by 1 C^0 and confluence of a stagnant agricultural drainage further downstream introduces convective heat input into the stream system. Effective representation of these interactions in the energy balance model is vital to simulate different thermal behaviours exhibited by the stream. This research demonstrates the effect of reach level small scale surface water -groundwater interactions on heterogeneous behaviour of stream temperature.

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Session 3: Drinking water

Assessing the most sustainable alternative for production of drinking water – ASTA a decision support system Alternatives fulfilling the EU-Water Framework Directive

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Abstract

Decisions can be based on a wide variety of criteria ranging from a personal intuition to scientifically based research. This study is dedicated to the development of a decision support system which integrates sustainability into the decision making process of water utilities.

The term "sustainable development" is often quoted from the Brundtland Commission from '86. In '92 in Rio the definition of sustainable development was brought a step further as a balance of 3 dimensions: Environmental protection, Economic growth, and Social development. Although sustainability is narrowed down to 3 dimensions it remains complicated to evaluate.

The purpose of this study was to develop a decision support system incorporating quantitative sustainability when evaluating alternatives for water supply. The purpose of the decision support system is to Assess the most SusTainable Alternative - ASTA. Sustainability is in this context defined as Economic, Environmental (including water use impact) and Social aspects. These three aspects are called Key Criteria and are subdivided into Criteria and furthermore into Indicators which are quantified when different alternatives are evaluated.

The sustainability assessment is carried out by integrating different tools for evaluating the three Key Criteria:

- Environmental aspects: Evaluated by Life-Cycle Assessment (LCA),
- Economic aspects: Evaluated by Cost-Benefit Analysis (CBA),
- Social aspects: Evaluated by Multi-Criteria Assessment (MCA)

The three types of assessments are integrated by a Multi-Criteria Assessment frame which ties the evaluations together to obtain a joint decision support result.
To develop ASTA we assessed four alternatives (A1-A4) of technologies for water supply which all fulfil the regulations on the freshwater scarcity (Water Framework Directive) being challenged by the intensive water abstraction near Copenhagen, Denmark.

A1 Substitution of 20% of all households' water supply by non-potable water (rain water and well water)
A2 Preventing non-acceptable low water flow in streams by transferring water in the habitat
A3 Moving well sites further away in order to distribute the pressure on the freshwater scarcity (+ 20 km)
A4 Extracting and treating surface water from a lake (ultra- and nano-filtration, UV radiation)

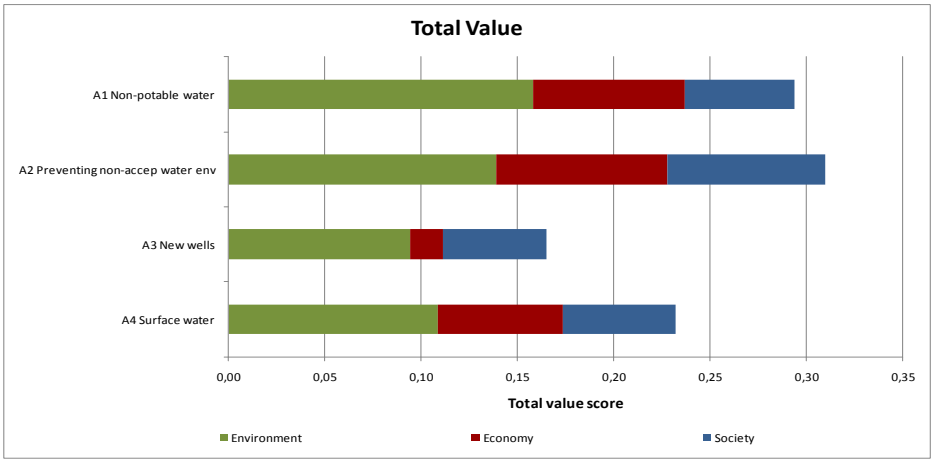

Figure 1 Assessment of the four alternatives A1 – A4 for drinking water supply assessed by the decision support system ASTA integrating sustainability (environmental, economic and social aspects) into the decisions.

Preliminary results are presented as Total Value-score having the strength of keeping all values on a local scale (only considering the alternatives in focus) allowing for easy and quantitative comparison of the result of the alternatives. The evaluation of A1-A4 showed that A2 is preferable from a sustainability viewpoint. Finally, ASTA will also add value to the water utilities' decision-process by making decisions transparent and well-argumented in accordance with the principles of sustainability as defined by this study.

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Multi-objective optimization of the management of Søndersø waterworks

A.K. Hansen, DTU Environment[1], D. Rosbjerg, DTU Environment[1], P. Bauer-Gottwein, DTU Environment[1], Henrik Madsen, DHI[2]

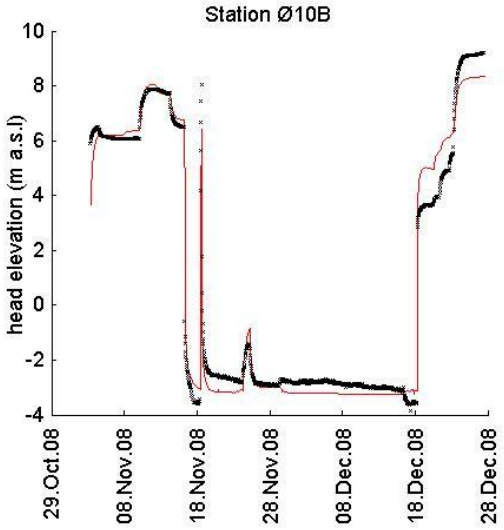
Abstract

In Denmark 98 % of the fresh water used for private households, industry and irrigation comes from groundwater, and in the last 10 years, the abstraction of groundwater has been around 600 million m^3 of water per year. Groundwater is a limited resource and the energy consumption for the water works is considerable. An improved groundwater management can increase the exploitable groundwater, save energy, protect the groundwater from contamination, and ensure the water quality.

A well field model called WELLNES (Well field Numerical Simulation Shell) has been developed, which can simulate the hydraulic head in and around a groundwater well field. The well field model is a combination of a groundwater model, a well model, and a pipe network model. With this model it is possible to obtain good predictions of the groundwater level in the well field and the pressure in the distribution pipes and thereby also good predictions of the energy used for abstracting the water.

Søndersø water works is used as case study. It is located northwest of Copenhagen and abstracts 8 million m^3 of water per year from 21 wells. West of the well field is a contaminated site, and it is paramount for the water works to avoid polluted water entering the wells. The WELLNES model for this area can predict the energy consumption of the waterworks within 1.8% of the observed energy consumption.

Multi-objective optimisation is performed to find the best way of operating the water works with respect to two objectives. The first is to minimize the risk of pollution from the contaminated site and the second is to minimize the energy consumption. The constraint is that the waterworks has to provide a given demand of water, and the control variables are the status of the pumps, which can be either on or off. The multi-objective problem is solved by genetic algorithms. The results show that it is possible to save 4% of the present energy consumption and still have the same risk as today. This saving can be achieved only by changing the pumping configuration of the waterworks. Additional saving can be achieved if newer and more effective pumps are installed at the waterworks.



Observed (crosses) and simulated (solid line) head levels in a production well.

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BIOTREAT - Biotreatment of drinking water resources polluted by pesticides, pharmaceuticals and other micropollutants

Jens Aamand, GEUS[1]

Abstract

A short presentation of a newly initiated (1st January 2011) FP7 project named BIOTREAT will be given. BIOTREAT brings together six research institutions and four SMEs to develop much-needed water treatment biotechnologies for removing pesticides, pharmaceuticals and other organic micro-pollutants from contaminated drinking water resources. These biotechnologies will be developed into prototype biofilter systems ready for subsequent commercialisation. The biofilters will contain non-pathogenic pollutant-degrading bacteria, with the bacteria being immobilised on specific carriers to ensure their prolonged survival and sustained degradative activity. Through beyond state-of-the-art research, BIOTREAT will ensure that these novel water treatment biotechnologies are highly transparent, reliable and predictable. Two complementary biotreatment strategies will be followed, one based on metabolic processes whereby the bacteria completely mineralise specific micropollutants and the other based on cometabolic degradation utilising the ability of methane- and ammonium-oxidising bacteria to unspecifically degrade a range of micropollutants for which specific degraders are not yet available. The biofilter systems will be carefully validated through cost-benefit analysis and environmental life cycle assessment. A road map will be drawn up for post-project exploitation, including individual SME business plans. Effective dissemination of the BIOTREAT results will be ensured by close collaboration with an End-user Board comprised of re-

presentatives from waterworks, water authorities, industry, etc. In addition to bringing considerable advances to water treatment biotechnology, the main outcome of BIOTREAT will thus be prototype biofilter systems (metabolic and cometabolic) ready for commercialisation in a number of highly relevant water treatment scenarios, including existing sand filters at waterworks, mobile biofilters placed close to groundwater abstraction wells, sand barriers between surface waters and abstraction wells, and protective barriers in aquifers.

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Sustainable drinking water treatment - biological filters (DW BIOFILTERS)

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Abstract

Biological (rapid sand) filters are a widespread environmental biotechnology used at thousands of waterworks in Denmark. These filters should be seen as bioreactors where microbial processes (removal of e.g. ammonia, manganese, ferrous iron, methane, sulfides and natural organic matter (NOM)) probably are more important than the simple physical straining processes. Furthermore, new observations indicate a promising potential for degrading organic micropollutants (pesticides, MTBE, gasoline compounds and pharmaceuticals) combined with these processes.

The underlying microbial processes are, however, poorly understood, limiting the management of filters resulting in start up problems and insufficient treatment. The project will improve the biofilters by molecular investigations of the microorganisms responsible for the individual processes in the filters (e.g. nitrification); and by down-scaling the filters to provide insight in the process mechanisms kinetics and effect of environmental factors. Management of the filters (e.g. back flushing, flow rate, carrier type) will be investigated at pilot and full scale, supported by mathematical models. The sustainability and climate friendliness will be evaluated by life cycle assessment (LCA).

The project will provide science-based procedures for optimized operation of biological filters in drinking water treatment with subsequent improved efficiency and robustness in the removal of the bulk compounds: ammonium (nitrification) iron and manganese. This will be based on insight into the microbial processes and identification of controlling parameters, bottle necks or inhibition of microbial removal of the bulk compounds.

Diagnostic tools will be developed to evaluate if the microbial communities are optimal for the processes in focus (e.g. nitrification). This will be based on molecular approaches, investigating for essential/core species and 'diagnostic diversity measures'. This activity may lead to identification of essential/core organisms which can be produced as starter cultures to inoculate or seed new or malfunctioning filters. A national map of abundance and diversity of nitrifiers and co-dominant members in different sand filters will be produced.

Mathematical models for the biological filters at full scale will be developed as a base for optimization tools for the filters. The project will also facilitate further development of biologically based, sustainable drinking water treatment technologies, including potential removal of organic pollutants such as selected pesticides and pharmaceutical compounds (i.e. artificial estrogens). Finally, the project will provide a scientifically based evaluation of the environmental impacts of the biological filters viewed in a life cycle perspective.

This project is need-driven and strongly focused on one drinking water technology and an array of its applications, and will be conducted by a dedicated, relatively small group in the water sector: one strong university, one of the major industry companies, 4 end-users (the major Danish water suppliers), and a strong international involvement: consisting of a leading university, a knowledge center and a technology supplier.

The project will support the training of 4 PhDs and 2 PostDocs. The gained knowledge will improve the companies export potential, and will be disseminated globally through scientific papers and to the national stakeholders by the Danish Water Association. See also http://www.dwbiofilters.dk.

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Session 4: Water and Climate

A novel method for screening of flood risks related to rivers and creeks

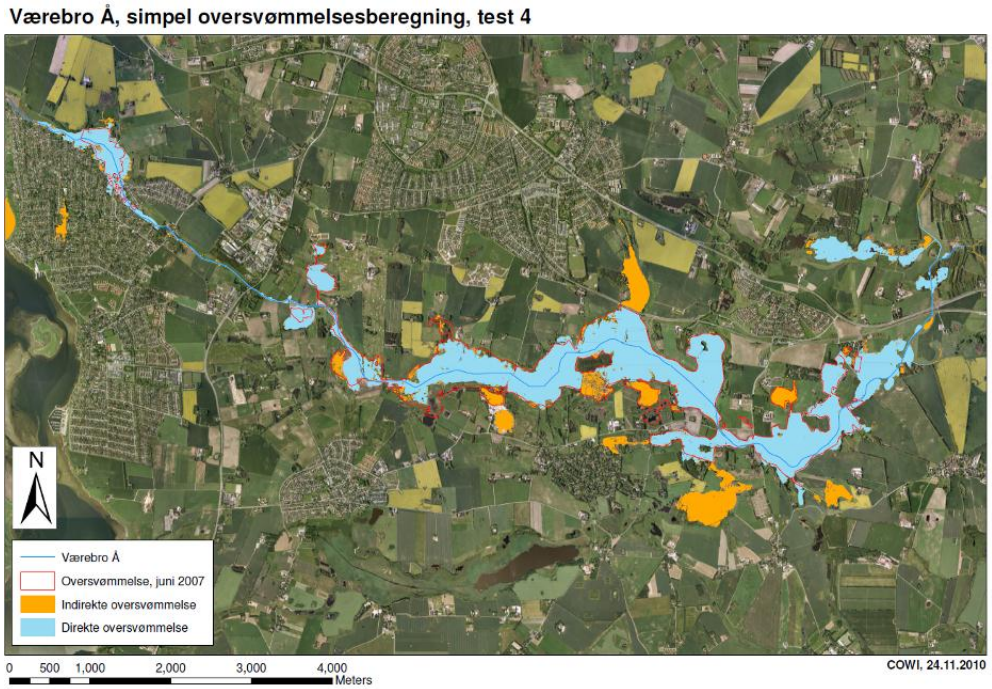
H. Garsdal, COWI[1] and A. Refsgaard, COWI[2]

Abstract

A novel method for screening of flooding risk related to rivers and creeks has been developed and tested based on research funds from the Danish Ministry of Environment - "Miljøeffektiv Teknologi"- given in 2009.

The risk of flooding from rivers and creeks is directly connected to the expectations about water levels in these rivers and creeks as well as in connected lakes and wetlands under current and future climatic conditions. The best method to evaluate flooding is to apply advanced distributed hydrological models combined with dynamic hydraulic models for the catchment under consideration. However, for screening purposes this is neither technically nor economically feasible for all rivers and creeks and as such there is a need for less advanced and faster methods yet reliable and robust.

COWI has developed a flood screening method based on sound hydraulic principles combined with GIS-analyses and the availability of precise topographical data. The method may easily be expanded to include damage risk by combining the flood risk with other GIS information and databases.



The flood extend during June 2007 extreme rain in the Værebro Å determined with COWI's screening tool

The core of the flood screening method is estimation of extreme flows based on measured discharge combined with methods to determine river water levels as a function of discharge and finally combine with digital topographical data and determine flood extends and flood depths on terrain. The method includes also inter- and extrapolation methods to rivers and creeks with sparse or no data as well as to non-measured river reaches. In short the method includes the following steps:

1) determination of the discharge (e.g. a 100 year event in the future climate)

2) translation of the discharge to water levels
3) interpolation of water levels to other parts of the river/creek under consideration
4) determination of flood extend and water depth maps

Discharge and water level data as well as observed flood extend from Værebro Å and Stor Å have been used to test the method. Furthermore, results have been compared with results from advanced hydraulic simulations using the MIKE software package. Conclusions from these tests and comparisons show that the method is very promising as a less advanced screening method.

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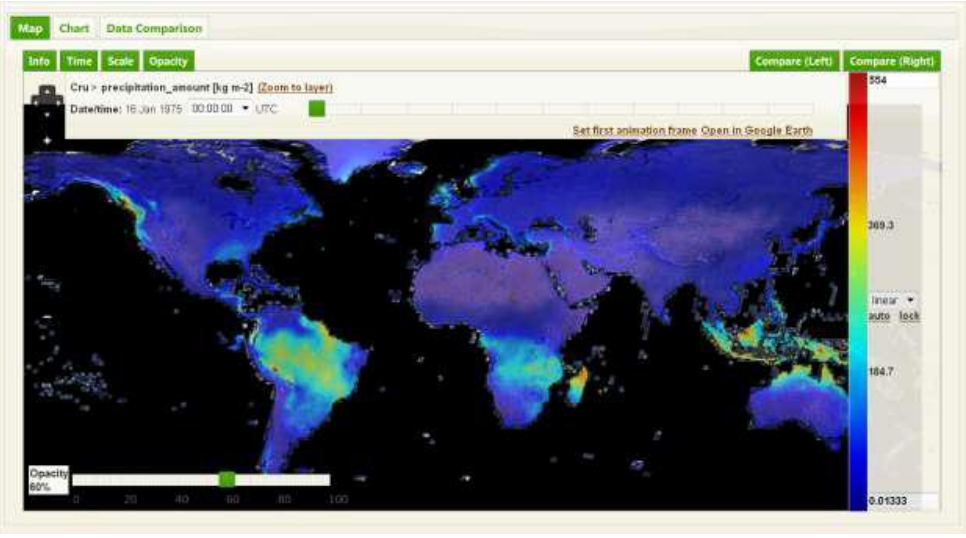
A climate decision support system for decision-makers and stakeholders

M.B. Butts DHI Denmark[1], M. T. de Sales DHI Denmark[1], T. T. Trung DHI Singapore[2], Xue Lei DHI Singapore[2], Veradej Phipatanasuphorn DHI Singapore[2], O. Larsen DHI Singapore[2], J. Høst-Madsen DHI Denmark[1]

Abstract

The relationship between climate variability, climate change and water is one of the most crucial for our society and for a wide variety of ecosystems. Climate change adaptation is about reducing the risks and costs (and exploiting possible benefits) from climate change and climate variability. The challenge for decision-makers and stakeholders in the water sector is to understand these climate changes, to determine where and how regions and sectors are vulnerable and to implement appropriate adaptation measures.

To facilitate these processes a web-based decision support tool for climate change applications has been developed. The motivation being the need to provide the relevant information about climate change, climate vulnerability and the impacts of adaptation measures in a way that can be easily understood by policy-makers, decision-makers and stakeholders. A web–based approach was adopted as this provides an intuitive and easy-to-use presentation of data that can be accessed by a wide variety of users at different geographical locations. Powerful mapping and graphics allow climate information to be easily communicated among stakeholders and decision-makers. The system is illustrated using recent climate change projects carried out by DHI.



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Estimation of changes in water resources in North-East Sealand from climate model projections

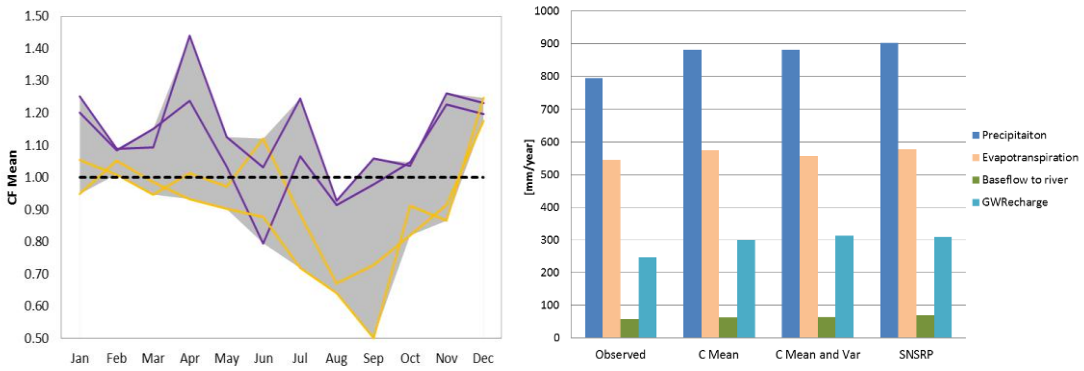
M.A. Sunyer, DHI[1], H. Madsen, DHI[1]

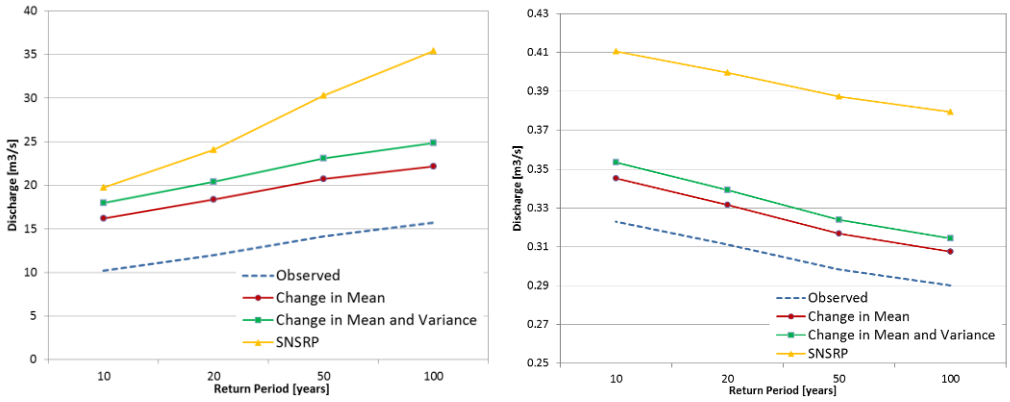
Abstract

Downscaling of climate model projections and assessment of the uncertainty associated to the downscaled data are the two main challenges that need to be addressed in climate change impact studies in order to provide a reliable estimation of changes at the local or regional scale.

In this study, an ensemble of four Regional Climate Models (RCMs) from the ENSEMBLES project for the SRES scenario A1B are downscaled to estimate changes in water resources in North-East Sealand, Denmark. Three different statistical downscaling methods based on a general change factor methodology are applied to the RCM models. The statistical downscaling methods considered are: mean correction (also known as the delta change method), mean and variance correction, and a Spatial Neyman Scott Rectangular Pulses (SNSRP) stochastic weather generator.

The downscaled climate variables are used as input to a MIKE SHE integrated hydrological model of the region for analysing the impacts of climate change in regional and sub-catchment water balance components and low and high flow conditions. Advantages and drawbacks of the different downscaling methods and the uncertainty in the downscaled projections are presented and discussed.





Estimated changes in mean precipitation for four RCMs (top left) and main components of the water balance in the Langvad river catchment, for the observation period and for the future scenario using the three downscaling methods: change in mean (C Mean), change in mean and variance (C Mean and Var) and the SNSRP model (top right). Extreme value statistics of annual maximum (bottom left) and annual minimum (bottom right) discharge in the Langvad river catchment

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Statistical modeling of long historical rain series

H.J.D. Sørup, DTU Environment[1], H. Madsen, DTU Informatics[2] and K. Arnbjerg-Nielsen, DTU Environment[1]

Abstract

Climate change will impact precipitation and notably precipitation extremes. Much research is directed towards understanding and describing changes on large scale variations. However, many applications need precipitation input at a scale much finer than what can be modelled by global and regional climate models. Some of the processes are poorly understood and must be described by stochastic models.

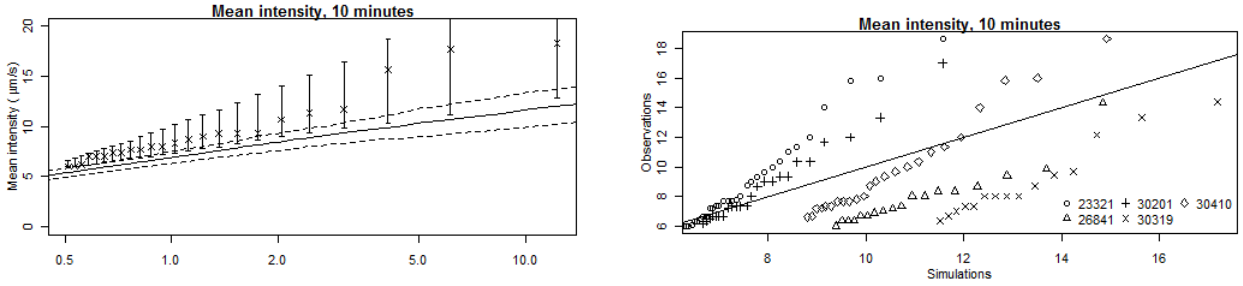
The purpose is to find models that can describe the stochastic properties of precipitation. The main means of testing the models is to generate long historical rain series using Markov chain models. If the properties of an entire historical series can be captured by the model the stochastic properties of the model can be used to infer properties of precipitation.

The data is extracted from tipping bucket rain gauge measurements from the Danish SVK system. The data has a temporal resolution of one minute and a volumetric resolution of 0.2 mm. The waiting times between consecutive tips is modelled. Precipitation is regarded as a continuous evolving process measured discretely, and the probability density functions of the states in the Markov chain models, are modelled using Box-Cox transformations and normal distributions. The distribution parameters are then modelled across states using continuous functions. The influence of a seasonal external explanatory variable is modelled as well. The seasonal variable seems very essential for the model behaviour.

Synthetic precipitation time series are simulated using a Monte Carlo algorithm, and are compared with the original time series. The comparison is done based on average properties of the extremes, based on one long historical time series, using the common Danish event definition and extreme precipitation definitions from Spildevandskomitéen. Furthermore the preferred model is tested with precipitation from four tipping bucket rain gauges that are completely independent of the one used for the modelling. None of the models reproduced the precipitation time series perfectly, but the preferred model performed acceptable. The model

is a first step towards a better understanding of the precipitation process. The presentation will discuss a palette of options to extend the model.

Figures: ***Left*** *– Simulated values of the best seasonal model (full line) with 95 % confidence interval (dashed lines) against the observations (crosses) with a 95 % confidence interval (whiskers) under the assumption that the extreme values are Generalized Pareto Distributed* ***Right*** *– Q-Q plot of the observed extreme values from five different rain gauges against their respective fitted models.*



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Analysis of changes in groundwater level at Zealand 2021 – 2050 for 2 different climate models inputs

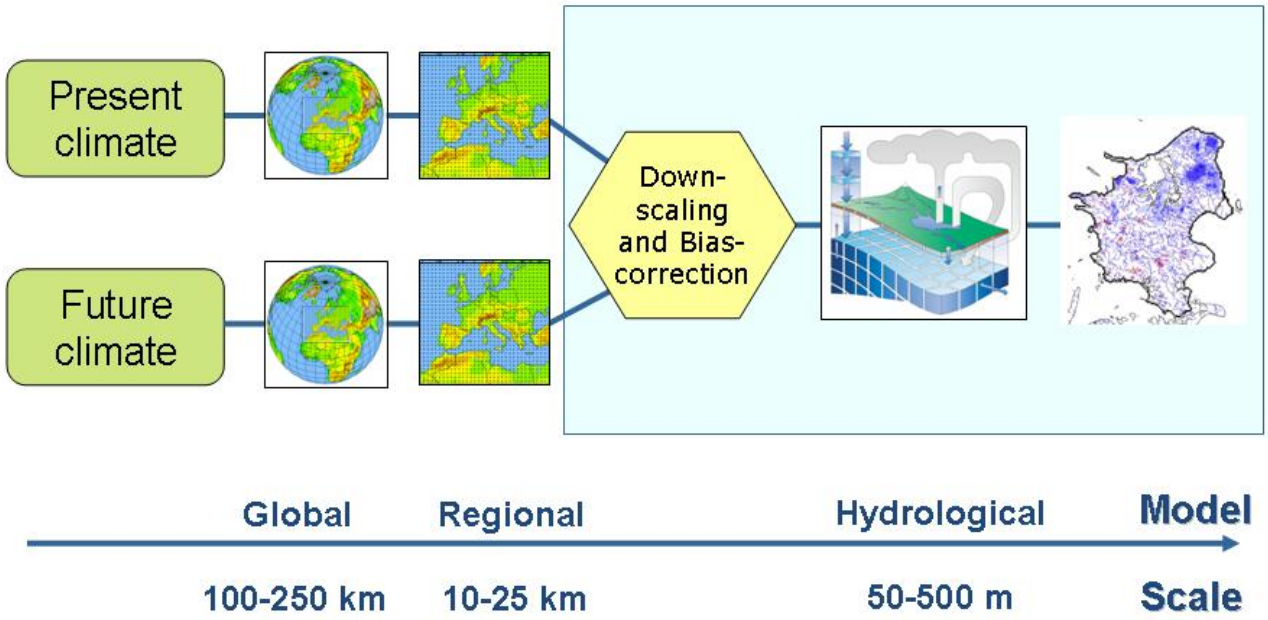
H. J. Henriksen, GEUS[1]

Abstract

The integrated, physical based and distributed groundwater/surface water model (MIKE SHE) for Denmark has recently been updated (2009) with improved geological data (100 x 100 m), horizontal discretization of grid (500 x 500 m), a two-layer root zone model, and more detailed topography and river setup (MIKE 11). The updated DK model (2009) has been subdivided into seven sub-models for Denmark, one covering Sjælland.

In 2010, the DK model for Sjælland was "water balance proofed" by introducing dynamic precipitation correction and a new set of assumptions for crop and forest evapotranspiration (crop coefficients and root depths). It has been evaluated that these are important for a valid description of the overall water balance on catchment scale, for simulating groundwater level and river runoff hydrographs dynamics and for obtaining realistic estimated parameters (e.g. root zone depth). The calibration was completed by use of dynamic inverse calibration (PEST) against time series of groundwater levels and river discharges.

Results from the two different (GCM/RCMs): ARPEGE-DMI and BCM-DMI (ENSEMBLE) and delta-change Bias-correction was used for a "pilot analysis" of climate change impacts (A1B) on groundwater level and recharge trends for Sjælland (2021-2050), compared to the control period 1990-2009. Results of the pilot runs will be presented and discussed.



Methodology for analysing climate change effects on groundwater levels and recharge for Denmark. Results from 16 different global and regional climate models and two different bias-correction methods ("delta change" and "direct, intensity based") are used as input for DK model for simulating present climate (1990-2009) and future climate (2021-2050). Uncertainties in GCM/RCM, Bias correction (delta change versus direct, intensity based) and hydrological model are evaluated, before data are released to the KFT portal (www.klimatilpasning.dk).

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Preparing for a coupled climate-hydrological model: The influence of domain characteristics on the HIRHAM regional climate model

M. A. D. Larsen, Copenhagen University[1], K. H.Jensen[1], J. C. Refsgaard, GEUS[2], J. H. Christensen, DMI [3], M. Butts, DHI[4]

Abstract

The study is a part of the HYACINTS project (http://hyacints.dk/index.shtml). As a part of the part the project a fully coupled climate-hydrological model will be developed for the entire Denmark consisting of the HIRHAM regional climate model (Danish Meteorological Institute) and the MIKE SHE hydrological model (DHI / Geological Survey of Denmark and Greenland). The coupled model is anticipated to provide improved hydrological predictions of the impact of climate change. In this study the impact of domain characteristics is analyzed by forcing the HIRHAM regional climate model by ERA-Interim reanalysis data. The results of eight different model runs are presented for varying domain size, domain location and grid resolution. The analysis was carried out as there are no strict guidelines in the choice of optimal domain characteristics.

Due to the hydrological focus of the project the model runs were mainly analyzed with respect to precipitation and temperature and validated against both point and spatial observations in the period 2008-2009. For spatial precipitation observations, both bias-corrected and uncorrected measurements were used since the current bias-correction method is considered to over-correct in the winter months. The actual observed winter precipitation must therefore be considered to be between the corrected and the uncorrected.

For precipitation there is a tendency for the HIRHAM model simulations to slightly overestimate in the winter period (DEC-FEB - 0-1mm/day) to slightly underestimate in summer and fall periods (JUN-AUG and SEP-NOV – both 0-1mm/day) and to be near the observations in the spring period (MAR-APR – overestimation app. 0-0.25mm/day) when validating against uncorrected observations. When validating against the corrected results overestimations prevail, strongest in the summer and fall periods (up to 1.5mm/day) and weakest in the spring (up to 0.75mm/day). For temperature, the fall and winter periods generally show slightly underestimated simulations, whereas the spring and summer periods are closer to the observed. The visual inspection of the error maps is somewhat subjective but in general the larger domains tend to predict the precipitation better than the smaller domains and for temperature the case is the same, except for the winter period. Comparing domains with the same extent there is no improvement in decreasing the grid size to 5.5km compared to 11km. Increasing domain size, but keeping the same resolution, does not show apparent differences in a spatial context whereas the point validation favors the smaller of the two domains. Altering the target area placement (Denmark) within the model domain keeping all other factors constant show slightly smaller errors for the domain having the biggest stretch to west.

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Session 5: Urban water management and water treatment

Integrated urban water management in Berlin with focus on natural water treatment in a partially closed water cycle

H. Schwarzmüller, Kompetenzzentrum Wasser Berlin[1], G. Grützmacher, Kompetenzzentrum Wasser Berlin[1], R. Gnirß, Berliner Wasserbetriebe AöR[2]

Abstract

With more than 150 years' experience, the Berliner Wasserbetriebe are supplying 3.5 million people with drinking water in Berlin (Germany) and surrounding areas and treating the sewage of 3.9 million people.

Traditionally, Berlin's water supply in the past has focused on sources within the city's limits. More than 40% of the territory of Berlin is covered by green areas and lakes or rivers. Added to these landscape and nature conservation areas, that in some cases overlap the water protection areas, in total around 1/3 of the total city area is protected. However, with a low average precipitation of 570 mm/a (average natural groundwater recharge: 152 mm/a) groundwater availability as traditional source of potable water is limited. For this reason the water supply has been designed to be replenished by surface water through bank filtration and aquifer recharge via infiltration ponds. Depending on the water works' location, between 10 % and 83 % of the drinking water originates from bank filtrate or artificially recharged groundwater (Zippel & Hannappel 2008).

On the other hand, natural discharge in Berlin's main rivers Havel and Spree is comparatively low with an average of 15 m³/s and 25 m³/s, respectively. Especially during summer, sewage treatment plant effluents (in average around 0.5 Mio m³/d) contribute a relevant share to the overall discharge, generating a partially closed water cycle. Maximum values of up to 40 % of treated sewage have been reported for some, heavily affected water bodies (SenSUT 1999).

In the past years, extensive research has been carried out by the Berliner Wasserbetriebe and Veolia Water on the processes that contribute to raw water quality and their efficiency. Limitations have been identified and strategies are being developed to cope with future challenges (Fritz et al. 2007).

For wastewater treatment, special focus is laid on high removal of nutrients in order to avoid cyanobacterial blooms that may affect drinking water production. For drinking water treatment, bank filtration and artificial recharge as main treatment steps ensure elimination of pathogens, algal toxins and many other unwanted substances.

Major impacts on Berlin's water system are expected in quality and quantity by lower flow in the River Spree and higher sulphate concentrations due to abandonment of mining activities. Together with climatic changes (hotter, dryer summers and warmer, wetter winters) this is expected to seasonally lead to a rise in waste water share as well as to rising sulfate concentrations in the rivers (Moeller & Burgschweiger, 2008). It is therefore recommended to enhance the buffer capacity of the system by additional aquifer recharge schemes during high flow periods. In addition, supplementary technical measures (e.g ozonation) for eliminating persistent trace organics and residual DOC are being investigated.

Keywords: *Partially closed water cycle, waste water treatment, drinking water, bank filtration, artificial recharge, indirect potable re-use*

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Urban Areas in Local Water Balance

M.B. Jensen, P.E. Holm, KU-LIFE/ViVa Life[1], U. Hindsberger, Danish Technological Institute TI[2]

Abstract

As a result of urbanization and economic growth freshwater is increasingly being withdrawn, used, and disposed off. Climate change escalates pressures on both water quantity and quality. Many places this ongoing degradation of the global freshwater resource already severely restricts water-related human activities and impairs human health as well as aquatic and terrestrial ecosystems. In order to reverse this unsustainable development the link between urban development and the freshwater cycle needs to be examined. Here, it is the aim of a new Danish Innovation Consortium, 'Urban Areas in Local Water Balance', to contribute, by addressing the following three global challenges:

(1) Adapt urban environments to an increasingly unstable climate, (2) Avoid overexploitation of groundwater and resultant drainage of fresh water streams, and (3) Enable recycling of polluted storm water runoff, including runoff from trafficked surfaces, to freshwater aquifers.

The consortium defines a city as being in full local water balance if (1) the supply of freshwater is based on precipitation resources within the boundary of the city, supplemented by technologies for water re-use, (2) the water quality is not impaired despite contact with city surfaces, use, and re-use, and (3) water management is linked to a robust green infrastructure in and around the city providing amenity values and supporting biodiversity.

As illustrated in Figure 1 the consortium aims at developing local water balance solutions that are appropriate in a Danish context and at the same time hold a potential for marketing abroad.

The consortium consists of three private enterprises: Per Aarsleff A/S, Wavin, and Orbicon, four water utilities including their respective municipalities: Copenhagen, Odense, Aarhus and Spildevandscenter Avedøre, and 5 knowledge institutions: Danish Technological Institute, KU-LIFE, GEUS, DTU and DHI. It runs from 2011 to 2014 and is based on a grant of DKR 16 million from The Danish Research Council for Technology and Innovation, and a similar contribution from the non-public consortium partners.

The plan is to conduct a number of field experiments that can be grouped into two categories after objective:

- Improve the efficiency of stormwater infiltration in morrainic till by exploitation of natural or modified geo-morphological variability. Initial experiments with tap water infiltration followed by tests in Aarhus on shallow infiltration and possibly deep infiltration in Hvidovre of stormwater runoff.
- Improve the biodiversity and year-round water balance of near urban streams by stormwater management schemes based on detention and infiltration in the vicinity of the stream. infiltration and de

The expected output of the project are technologies for rapid infiltration of stormwater runoff in clayey soils, hydrological models of local water flows and balances in response to different stormwater infiltration practices, guidelines for control of storm water runoff quality, and guidelines for joint development of urban landscapes, biodiversity and stormwater management

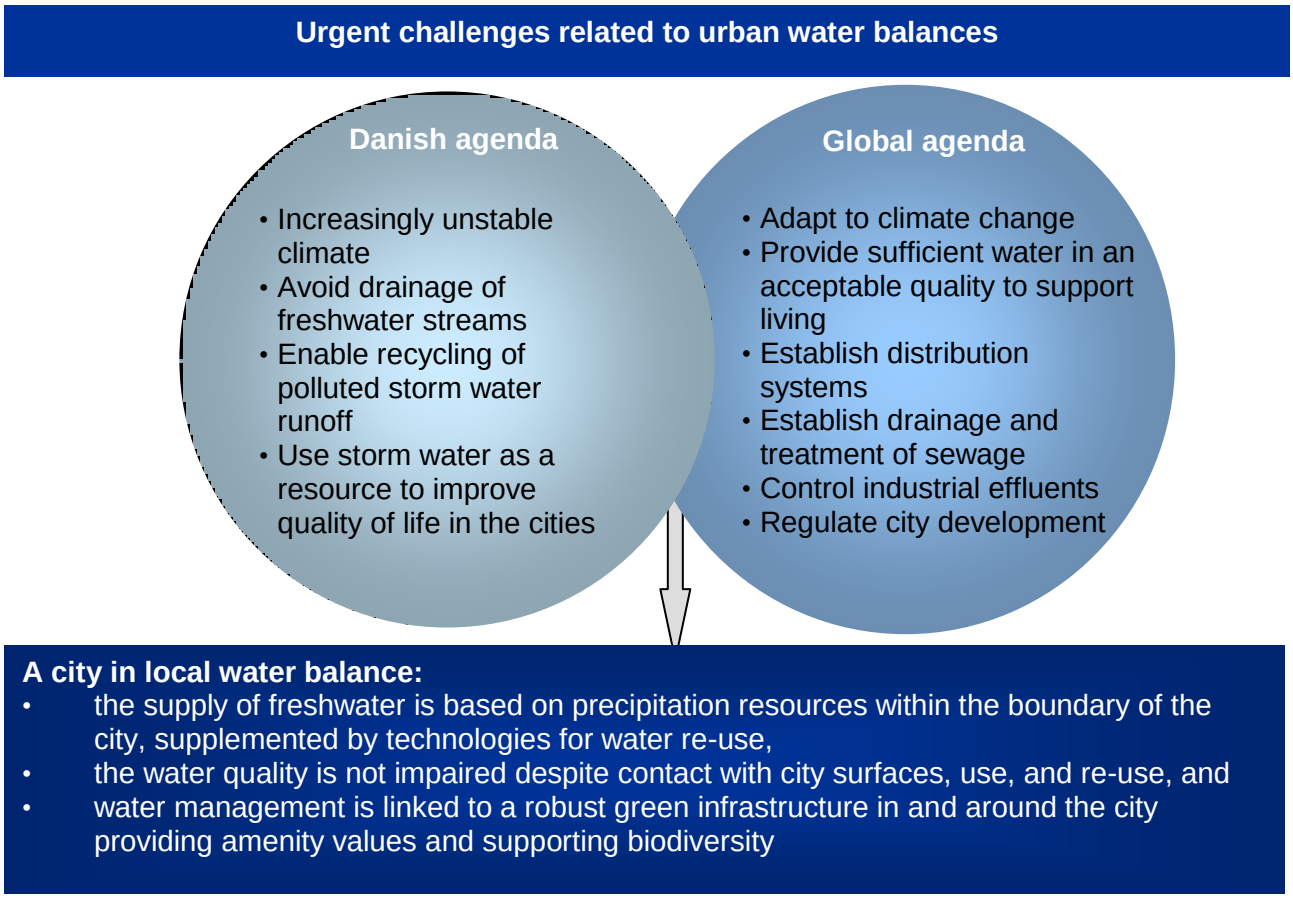

Figure 1. By aiming at freshwater challenges of relevance in a Danish (left) as well as in a global (right) context the ambition of the innovation consortium Urban Areas in Local Water Balance is to develop products and knowhow that can improve local freshwater balances - and be marketed - both nationally and abroad.

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PREPARED Enabling change: Adaptation of the water supply and sanitation sector to cope with the impacts of climate change

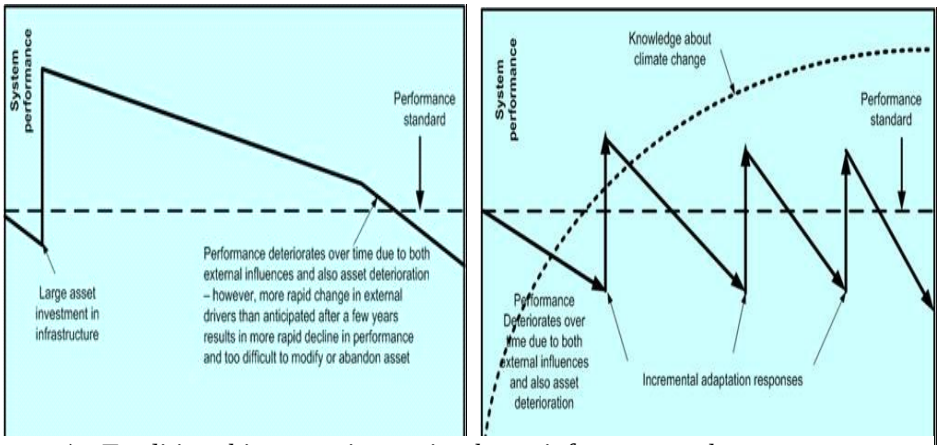
Adriana Hulsmann, KWR Watercycle Research[1], Gerard van den Berg[1], Anders Lynggaard Jensen, DHI[2], Yann Moreau- Le Golvan, Kompetenzzentrum Wasser Berlin[3]

Abstract

PREPARED aims to gather urban utilities in Europe and worldwide that (will) have an advanced adaptation strategy in meeting the upcoming challenges for water supply and sanitation brought about by climate change. The project provides a framework that links comprehensive research with development programmes in these utilities. The cities/utilities in PREPARED have been consulted and their major challenges are the basis for the research and development activities in the project. The cities/utilities are in return offering their systems and infrastructures for real scale demonstration and evaluation

of the project outcomes, after they have been developed and matured in the various supporting work areas. 12 European cities have been selected to best represent all the major climate zones in Europe, together with 2 cities outside Europe that will bring new aspects of how to manage drought and extreme rainfall in densely developed urban areas.

Utilities have to plan their investments on the basis of climate change scenarios with a high level of uncertainty. Too low an investment might result in a high (and unacceptable) level of risk, too high an investment will lower the risk but might be a waste of community money. Therefore, PREPARED will work on both short-term and long-term adaptation solutions. Short term solutions are based on real-time control and management, which will result in better and more efficient use of existing systems and infrastructures. This will allow utilities to postpone investment decisions to a later date with more certain scenarios for climate change. The long-term solutions include new approaches towards more flexible and robust designs of infrastructure, as short-term solutions eventually will not be enough.



a) Traditional interventions using large infrastructural response,
b) Adaptive responses - staged interventions incl. new knowledge

As new adaptive approaches also requires a change in the mindset concerning urban infrastructure PREPARED will facilitate the implementation at the utilities through the creation of an environment that will enable change and transition. Adaptive water sensitive cities will be created with a framework of current best knowledge and practice about the physical and institutional characteristics. The focus will be on learning and action alliances and active learners. Virtual urban water system tools will be developed together with a socio-economic impact generator. This will make it possible to predict how climate change will affect urban water systems and how different scenarios will influence necessary investments.

The Danish Participants are: Aarhus Water, DHI and Krüger. See also http://www.prepared-fp7.eu/

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Design of microbial communities in membrane bioreactors: the next generation of environmental biotechnologies (EcoDesign-MBR)

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Abstract

The Research Center "Design of microbial communities in membrane bioreactors: the next generation of environmental biotechnologies" has recently been funded by the Strategic Research Council and is running in the period 2010-2016. The Centre applies a novel approach for the application of Membrane Bioreactors (MBR), which includes design of microbial communities to carry out specific biological processes

(ecosystem design). The approach includes determination of the identity, function and interactions of key microorganisms in mixed communities involved in selected environmental biotechnological processes. This understanding will be exploited to optimise the growth and activity of the microbes through process studies in the MBRs. MBR is a new technology in water and wastewater treatment – and other environmental and industrial biotechnologies - which is particularly well suited for ecosystem design. Three applications of the MBR technology are studied: 1) removal/recovery of phosphorus, 2) energy efficient nitrogen removal and 3) detoxification of organic micropollutants. The novel approach will be applied in each case to boost process performance by identifying selective factors for ecosystem design or by adding particular performance-enhancing bacteria. Studies into the membrane fouling in each system will be used to develop a model to predict fouling both as a function of operation and of microbial composition in order to develop novel approachs to mitigate fouling. The research projects are lead by researchers from Aalborg University and Danish Technical University and they are carried out in collaboration with foreign experts, DHI and DTI, several companies (Alfa Laval A/S, Grundfos Biobooster A/S, Krüger A/S, GIE Anjou Recherche, Novozymes A/S), and wastewater treatment utilities (Spildevandscenter Avedøre I/S, Aalborg Forsyning, Kloak A/S). The Danish industry partners are ideally positioned to rapidly implement these developments and thereby create export markets with spin off environmental and public health benefits. See also http://www.ecodesign.aau.dk.

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Investigation of fouling conditions in a high shear membrane bioreactor using the TMP-step method

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Abstract

Membrane BioReactor (MBR) is believed to be the dominating technology for treating both domestic and industrial waste water in the future. The technology is a combination of a conventional activated sludge wastewater treatment plant and membrane filtration. Therefore, an MBR plant consists of both a bioreactor and a membrane unit, either submerged into the bioreactor or sidestream configuration.

The advantage with MBR is the low footprint and high quality effluent. However, membrane fouling is a great limitation to the distribution of MBR technology. Fouling of membranes results in either a decline in flux for constant pressure operation or a higher trans-membrane-pressure (TMP) is required to maintain a flux. On the other hand, fouling can lead to better permeate quality, as the fouling layer on the membrane surface acts as a secondary membrane.

The decline in membrane performance place demands for an operational strategy to maintain a constant performance of a MBR plant and reduce operational costs. To do this, it is crucial to understand the mechanisms of membrane fouling. Membrane fouling in MBR is a complicated field of study, as there are several parameters to consider, e.g. aeration, shear at membrane, membrane characteristics (pore size and ζ-potential), transmembrane pressure (TMP) and sludge characteristics such as particle size and MLSS. The development in flux can be described by the above mentioned parameters, i.e. as a mass balance between the

amount of foulant transported to membrane by permeation drag and the transport of foulant away from membrane by shear. At equilibrium steady state is obtained.

The fouling conditions were investigated at different TMP by TMP-stepping, illustrated in Figure 1, on a membrane bioreactor setup inspired by the Grundfos BioBooster system. The effect of shear was studied from rotating the ceramic membranes at different speeds and, measuring the decline in flux. Between each TMP-step, there were two relaxation steps at 0.3 and 0 bar to restore permeability.

In Figure 2 the flux at the end of each step is plotted versus TMP. This figure show a development in end flux at TMP 0.3 -1.5 bar. However, at TMP above 1.5 bar, the end flux is constant, as a steady state in fouling is reached. This steady state flux increases with higher rotation speed. Therefore, the experiments show, that increasing shear gives higher flux and thereby less fouling, and that fouling makes it inefficient to operate at pressures above 1.5 bar. It is concluded, that TMP stepping gives information about how different parameters influence fouling and can be used to improve process efficiency.

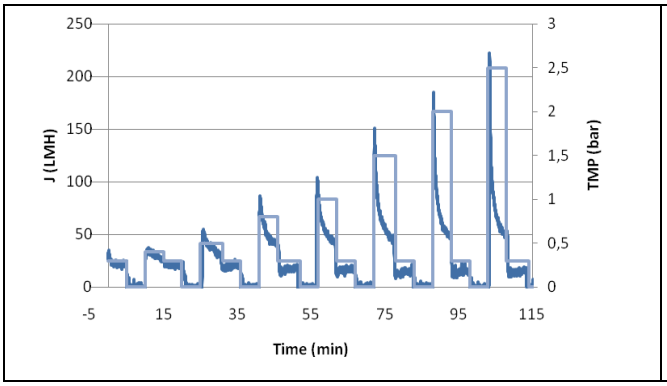

Figure 1. Method for TMP-step experiments

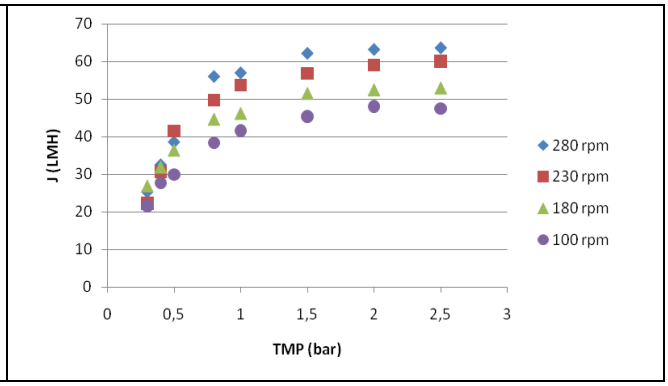

Figure 2. Flux at different TMP after 5 minutes

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Two cases of legionnaires´ disease associated with a newly build residential area - risk factors and remedial actions

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Abstract

At the end of 2008 / beginning of 2009, two men from the same newly built residential area were diagnosed with legionnaires´ disease, one of them died. The new residential area consists of 225 apartments (210 were inhabited) spread over 6 blocks. The deceased man (case I) had lived in the apartment for 2 months and had complained about low hot–water temperature. The other man (case II) only stayed in the residential area for a few days, in an apartment which had not been occupied before. The strain isolated from both patients was *Legionella pneumophila* serogroup (sg) 1 Philadelphia (Sequence Type (ST) 1) The same type along with *L. pneumophila* sg 3, was detected in high numbers in water samples from the apartment where the deceased man lived, especially in water samples from the shower hose, but also in samples from the hot-water circulating system for the whole residential area.

Several risk factors were identified during this small outbreak 1) water stagnation in the pipes in the apartments for longer periods before the residents moved in (case II) 2) stagnant water in the shower hoses (case I and II) 3) low flow in the water circulation system 4) low temperature in the hot water circulation

(46ºC, case I) and 5) presence of a virulent *L. pneumophila* strain in the water. Stagnant water in pipes seems to be a problem in new residencies since the water in the pipes are left at ambient temperature until people moves in During this period, a biofilm with *Legionella* can build up. . In order to prevent high levels of *Legionella* in water pipe systems in new buildings, standard procedures to clean the systems should be applied before people moves in.

To overcome the *Legionella* contamination from the water system, the water temperature was raised for longer or shorter periods (12 h-48 h), flow was increased, and shower hoses and heads where disinfected with chlorine. In an empty apartment, the effect of five minutes' flush with hot water was tested. Only heat treatment (48 hours, boiler adjusted to 70-80ºC, tap water 65ºC) was effective to reduce the presence of *Legionella.*

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Infiltration of stormwater runoff through special filter soil

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Abstract

The intensity of rain events has amplified the last couple of years, resulting in flooding of sewer systems in Denmark. To prevent future flooding on-site stormwater management is being considered as an alternative approach to the traditional sewer management of stormwater. On-site management means that stormwater is disconnected from the sewer systems and that the urban landscape structure is utilized for retention and infiltration of the water. However, the quality of urban runoff is often poor. As the water flows across impervious surfaces such as roads, parking lots and building materials it picks up a variety of potential pollutants, such as suspended solids, heavy metals, toxic organic compounds (e.g. PAHs), nutrients, and pathogens. In Denmark it is not allowed to infiltrate road runoff in urban areas, which in some areas can be a major barrier when planning for on-site stormwater management. The reason for such restrictions is the concern for polluting the groundwater which has an almost sacred state as the all-important source of drinking water in Denmark. However, in Germany, where groundwater is also an important source of drinking water, there are several examples of stormwater infiltration facilities for road runoff constructed during the last 10 to 15 years, namely swale-trench (Mulden-Rigolen) systems. These systems are placed alongside roads or parking areas and consist of a vegetated swale, an underlying trench and an engineered filter soil layer placed directly under the swale. This filter soil layer exists to ensure good infiltration and treatment capacity. There are specific requirements to this soil layer, i.e. in terms of thickness, hydraulic conductivity, texture, pH, organic matter content, as described by the German Association for Water, Wastewater and Waste (DWA) guidelines.

The objectives of this study are to evaluate the filter soil of German swale-trench infiltration systems that for more than a decade have received different kinds of urban runoff, including road runoff.

First of all on-site infiltration tests have been performed to assess the infiltration rate of the systems. Secondly, soil core samples were collected in the top soil layer (25-30 cm) below the swale and the samples have been analysed for pH, organic content, and texture as well as the content of phosphorus and heavy metals. Furthermore, eight intact soil columns containing the engineered filter soil were collected and brought to the laboratory for further testing of flow capacity, flow patterns and the treatment efficiency towards dissolved metals, phosphorus and fine particles.

To asses the treatment efficiency of the filter soil, the eight columns were exposed to a synthetic stormwater influent by a pump-driven irrigation system (Figure 1). The synthetic stormwater was composed of Cd (4 ug/L), Cr (50 ug/L), Cu (100 ug/L), Zn (400 ug/L) and P (0.2 mg/L). Each column was exposed to 4 events: two events corresponding to typical rain events (10 mm rain in 2 hours) and two corresponding to extreme

events (100 mm rain in 3 hours). Fractions of the effluent from each event were collected and is currently being analysed.

Figure 1. The treatment efficiency of an intact soil column from a German swale-trench is tested in the laboratory.

So far only first break through curves with bromide are available. These results indicate that the infiltration pattern approximates an ideal plug flow. The results of this study will provide important knowledge for the future implementation of swale-trench systems to infiltrate road runoff in Denmark. In a German context the results will be valuable for an approaching national project aiming at evaluating the existing swale-trench systems.

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An integrated model for management of stormwater micropollutants

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Abstract

Urban water management has moved towards a holistic approach that boosts the use of integrated models as essential elements in the assessment of strategies aiming to achieve the desired water quality standards. Diffuse pollution loads deriving from separate system and stormwater treatment have received little attention from modellers, as the existing integrated models mainly focus on traditional water quality parameters (total suspended solids- TSS, nutrients, general organic matter) with limited examples dealing with stormwater micropollutants (MP - heavy metals, organic compounds).

This study presents an example of an integrated dynamic model for estimating micropollutant fluxes through separate stormwater systems. The integrated model is composed of submodels that represent the elements of the stormwater system (catchment, drainage network and treatment unit). The various submodels have been developed in order to maximize the use of existing information (e.g. GIS data, substance inherent property data) and to exploit easily measurable data (flow, TSS). The release of MP is estimated according to a catchment classification based on land usage. Transport through the sewer system is simulated by an accumulation-washoff approach. MP removal in stormwater treatment units is modelled by using a multi-compartmental approach, which estimates MP fate based on the pollutant's inherent properties. Given the high level of uncertainty affecting stormwater quality models and monitoring of stormwater MP, the estimation of uncertainty bounds is essential to allow a wide application of the integrated model. The model uncertainty bounds are thus estimated by using the Generalized Likelihood Uncertainty Estimation technique (GLUE).

The model was applied in an industrial-residential catchment in Albertslund (Denmark) in order to (i) quantify the MP loads released from the catchment and subsequently (ii) released to the aquatic environment after treatment in a retention pond. Furthermore, the model can be used to assess (iii) compliance with

discharge regulations (e.g. Figure 1 – left), and (iv) the relative efficiency of different pollution control strategies, based both on source control and end-of-pipe treatment (e.g. Figure 1 – right). The model was applied to simulate heavy metals (e.g. copper – Figure 1) and polycyclic aromatic hydrocarbons (PAH). The results of this study represent the first application of an integrated stormwater quality model for these pollutants, and it can provide an important support in the evaluation of stormwater pollution control strategies.

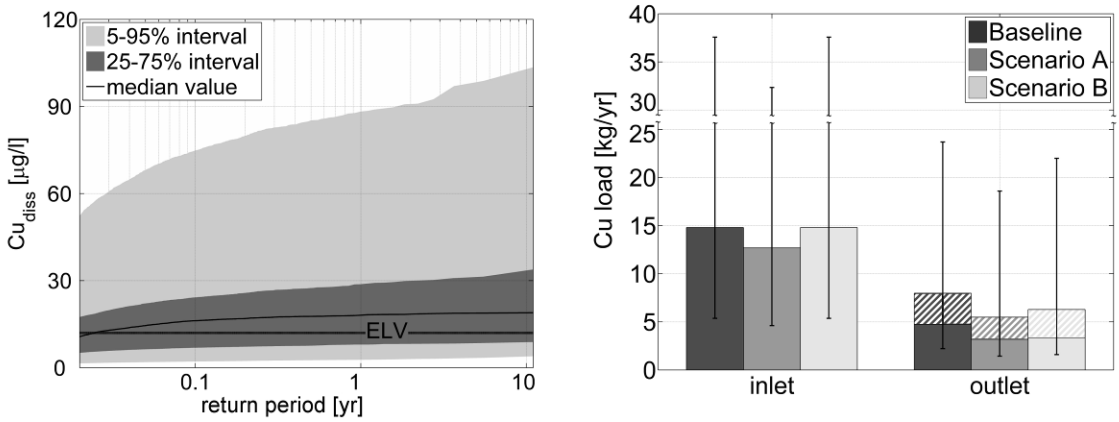

Figure 1. Example of outputs from the integrated model. Left: outlet dissolved copper concentrations a retention pond and comparison with an Emission Limit Value (ELV). Right: comparison of Cu loads at the pond inlet and outlet for different scenarios involving source control (Scenario A) and improvement of existing treatments (Scenario B). Hatched areas represent the dissolved fraction.

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Poster session

Hydro-geochemical properties and retention of phosphorus in drainage filters and constructed wetlands

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Abstract

Excessive nutrient inputs to surface waters degrade water quality through the process of accelerated eutrophication. In many watersheds, phosphorus (P) from agricultural sources is an important pollutant. At the same time, P is an essential nutrient for crop growth (as for all forms of life) and should therefore be recycled, especially since raw materials from manufacturing P fertilizers are limited and non-renewable. Due to decades of P additions with manure and fertilizers, the source of today´s P losses is accumulated soil P, which becomes a problem when connected to the aquatic environment by subsurface pipes and ditches.

The strategic research project SUPREME-TECH (www.supremetech.dk) aims at developing innovative technologies such as flow-through drainage filter structures and subsurface flow constructed wetlands (SSF-CW) to be implemented as part of the drainage structures to reduce nutrient loads (P and N) to the aquatic environment. The main challenges for drainage filters are to meet the requirements of both filter hydrology and the nutrient retention properties. The filters should allow drainage water to pass but still allow sufficient time and contact volume for the nutrients to be removed. The aim of the present PhD project is to study the hydraulic properties of different types of filter substrates and their dynamic processes that influence a sustainable P removal from agricultural drainage water. The main mechanisms of P removal in drainage filters is retention of P in the filter substrate, as a consequence of adsorption and precipitation reactions with calcium (Ca), aluminium (Al) and iron (Fe). The P removal efficiency is a complex interaction between the concentration and form of P in the drainage water, the hydro-physical properties of the filter substrate and the nature of the drainage discharge. The active flow volume (contact area) and the hydraulic retention time (contact time) is the potential limiting factor for the adsorption and precipitation reactions, and it depends by the type of substratum, grain size, grain-size distribution, porosity, etc. Therefore studying the hydraulic properties of the filter can help to select filters with certain hydro-geochemical characteristics, which can improve P removal efficiency. Experimental laboratory column studies and successively field measurements are included. The tasks include: i) measurement of saturated hydraulic conductivity (Ksat) (see equipment in the picture) and hydro-physical parameters, ii) column studies for both *tracer* to investigate active flow-volume and *P-retention* as a function of P-concentrations under variable flow regimes of drainage waters, iii) investigation of environmental variables on P retention efficiency. The results are expected to contribute in scientific systematic knowledge regarding hydraulic properties and phosphorus retention in a broad range of filter substrates including filtralite-P, damolin, granulated lime, crushed sea shell, granulated concrete, iron sludge, CFH-sorbents, and mixtures of filter substrates.

Keywords: agricultural drainage; filter media; phosphorus; saturated hydraulic conductivity, water treatment

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Hydrobiogeochemical cycling of phosphorus in restored wetlands

D. M. Forsmann and C. Kjærgaard, Aarhus University[1]

Abstract

Restoration of riparian wetlands was presented as one of the main means in Water Action Plan II (1998) due to the documented nitrogen removal in wetlands. In recent years focus has not only been nitrogen removal from wetlands but also wetlands effect in relation to phosphorus removal from the aquatic environment.

During the winter semester where wetlands are flooded they contribute to phosphorus removal due to deposition of particle-bound phosphorus on the wetland. Some of the deposited phosphorus can be taken up by plants and removed from the wetland by haying during summer. Many lowland soils have been drained and used for agricultural purposes. Thus there is a large amount of phosphorus in theses soils. New research indicates that there is a potential risk for phosphorus release from restored wetlands.

One of the interesting pools of phosphorus in the soil is the ironbound phosphorus, where phosphorus is bound to iron(III)oxides under aerobic conditions. During flooding of former drained lowlands the condition in the soil is changed from aerobic to anaerobic. This change in environment results in reduction of ferri iron (Fe^{3+}) to ferrous iron (Fe^{2+}) causing a risk of release of ironbound phosphorus. Release of ironbound phosphorus will happen in the soil matrix under anaerobic conditions, but phosphorus can be readsorbed under aerobic conditions where ferrous iron is oxidised to ferri iron. This change in redox conditions happens at the sediment-water interface, where the anaerobic soil matrix meets the often aerobic water phase. The risk of phosphorus release from restored wetlands will be reduced in case of readsorption of phosphorus to ferri iron at the sediment-water interface despite the possible release within the soil matrix.

The overall hypothesis for the project is that the redox gradient over the sediment-water interface can function as precipitation layer for phosphorus mobilised within the soil matrix. The effect of this precipitation layer is depending on (i) phosphorus saturation of the iron pool expressed as the molar ratio between iron and phosphorus (Fe:P), (ii) hydrology and (iii) hydrochemistry E.G. occurrence of sulphate. Experiments based on the hypothesis are setup under controlled conditions in the laboratory and as field experiments. Focus in these experiments is on the processes at the sediment-water interface, and it is investigated whether readsorption happens at the interface as a function of the mentioned parameters. A new DET-method will be used to monitor the content of phosphorus in the soil matrix, across the sediment-water interface and in the water phase. This method will be used both in laboratory and field experiments.

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Electrochemical oxidation of PAHs in water from harbor sediment purification

J.Muff and E.G. Søgaard, Aalborg University, Campus Esbjerg, Denmark[1]

Abstract

Sediments of harbors are regularly dredged for various reasons: maintenance of navigational depths, recovery of recreational locations, and even environmental recovery. In the past, the harbor sediment have been dumped at sea, however, environmental regulations now, in many cases, prohibit this due to contamination by PAH, heavy metals, TBT etc. In Denmark, contaminated harbor sediment is pumped ashore to inland lakes or upland sites where treatment of the runoff water is required before discharge to the recipient. In this study, electrochemical oxidation (EO) has been investigated as a method for treatment of the discharge water addressing primarily polycyclic aromatic hydrocarbons (PAHs). PAHs are by-products of incomplete combustion of organic materials with recalcitrant and strong mutagenic/carcinogenic properties, due to their benzene analogue structures. PAHs are hydrophobic compounds and their persistence in the environment is mainly due to their low water solubility.

The experimental study was performed in laboratory scale with volumes of water from 3 to 10 L in a batch recirculation experimental setup at constant temperature with a commercial one-compartment cell of tubular design with Ti/Pt_{90}-Ir_{10} anode (60 cm^2) and SS 316 cathode operated at galvanostatic conditions. The EO of naphthalene, fluoranthene, and pyrene was investigated in model solutions, in order to study the reaction kinetics and the influence of variations in experimental parameters such as current density, electrolyte composition, and electrolyte concentrations on the rate of oxidation, followed by a proof-of-concept study with the actual discharge water from a dump of contaminated sediment.

In the model solutions, all three of the subjected PAHs were degraded during the electrochemical treatment, and all of the conducted experiments confirmed that the removal rate of the two-ring structured naphthalene was significantly faster compared to the four-ring structured compounds fluoranthene and pyrene. In a Na_2SO_4 inert electrolyte, all three PAHs were degraded by direct electrochemical oxidation at the anode surface, but the removal rates where significantly enhanced in NaCl, where indirect oxidation by hypochlorite, formed by the electrolysis of chloride, increased the apparent reaction rate constants of the PAHs by a factor of two to six. The oxidation rate of naphthalene was in all experiments showed to follow second order dependence on the naphthalene concentration, whereas the oxidation rate of fluoranthene and pyrene followed the expected first order reaction kinetics with comparable values of the rate constants. Reducing the NaCl electrolyte concentration at constants current density decreased the removal rate of all three PAHs providing evidence for the importance of the indirect oxidation mechanism in the degradation of the PAHs.

The proof-of-concept study was conducted both by a direct treatment approach and an intermixing-with-oxidant approach, where the contaminated water was intermixed in different ratios with an electrochemically generated oxidant solution with a free chlorine concentration of 2 gL^{-1}. Both strategies resulted in a successful degradation of 5 PAHs to fulfil the discharge limit on 0.010 μgL^{-1}. The intermixing-with-oxidant approach can also be applied as a method to address the actual sediment matrix.

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Bench scale thermal treatment of contaminants from a complex pharmaceutical waste mega site

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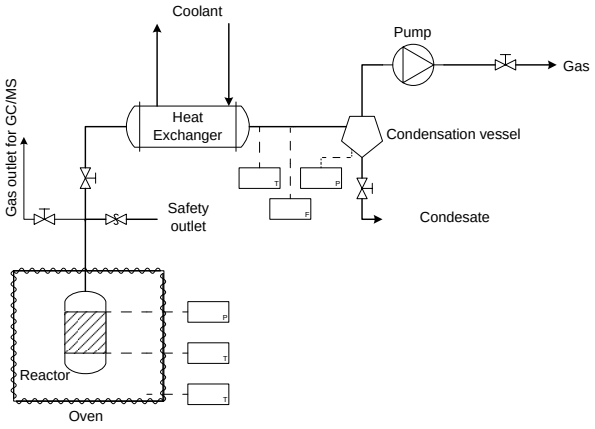
Abstract

This research is based on studies carried out with highly contaminated soil and groundwater from the Kærgård Plantage megasite in Denmark. In order to determine the best remediation technique, biological, chemical, and thermal techniques are tested and compared in bench scale before pilot studies are performed in 2010.

The paper will contain detailed results of the thermal treatment tests as well as a thorough description of the laboratory setup used for the experiments and analytical methods. Several contaminants are present at the site, including DNAPL's, BTEX's, sulphonamides, barbiturates, aniline, pyridine as well as mercury and cyanide. It is the aim to examine the mobilization and eventually partly degradation of these compounds by thermal treatment of the contaminated soil as well as identification of major existing decomposition products.

A sketch of the experimental setup for the bench scale testing is given in the figure below, detailing a heated reactor, sample outlets for both online sampling of gasses as well as collection of condensate and gas phases at specified temperatures.



Measurements of the contaminants mobilized are performed by GC/MS analysis, which will also allow for identification of major degradation and reaction components. Samples may be measured during the thermal treatment as well as following the treatment, allowing for a time resolved evaluation of the effect of the thermal treatment.

The bench scale tests will determine the effect of temperature on the contaminants, including mobilization and degradation products. An optimized time-temperature setup may subsequently be used to determine how large a fraction of the contaminants may be removed by this method.

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Reactor for the elimination of arsenic from drinking water system

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Abstract

One of the natural pollutants that cause troubles and risk to health in several countries in the world is Arsenic. Also in Denmark, elevated concentration of arsenic is found. Since the nineteen seventies, a lot of research has taken place partly to find out about the origin of the problem and also how to solve the problem by the help of a special water treatment method. In Denmark the normal water treatment way of oxidizing and precipitating Fe(II) compounds by catalytic chemical methods in sand filters will partly solve the problem for low values of arsenic substances in groundwater treated for drinking water.[1]

Co-precipitation and adsorption onto iron oxides could remove amounts of arsenic down to levels accepted by W.H.O for drinkable water. However, after this limit was lowered to 10 µg/L. Danish EPA decided to lower that limit to 5µg/L at exit from the water work and below 10 µg/L at exits from household installations.[2]

One of the most promising methods to solve the problems of As in ground water is to involve co-precipitation and adsorption to iron oxides. Rather small amounts of iron oxides can solve the problem and a new plant with biological iron precipitation followed by extremely good aeration by help of the creation of micro drops can solve a big part of the problem.[3]

A couple of pilot plants based on this microdrop principle were used to investigate the method in greater detail. (Please see figure 1 below). The results showed that biological iron precipitation could enhance the method by oxidising and precipitate Fe (II). Arsenic (III) is slower to oxidize to arsenic (V) but an oxidation is necessary to enhance the co-precipitation / adsorption affinity to iron oxides. The microdrop system helped by aerating the water to above 95% saturation. Finally catalytic chemical oxidation / precipitation of the un-oxidised Fe (II) did the rest of the job so that the water at inlet to the water work was below 5µg/L. In most cases arsenic was reduced from more than 30µg/L and on the other hand, an inlet value of arsenic, which was above 100µg/L, was reduced to below 40µg/L. If the iron in the anaerobic wells is insufficient, then the iron tray with iron coils placed just before the microdrop system could increase the amount of iron to a sufficient level.

Based on improved principles and knowledge from the work above, this on-going research work will reveal more details when a new pilot plant reactor positioned next to Department of Chemical Engineering, Aalborg University, Esbjerg, Denmark is started-up.

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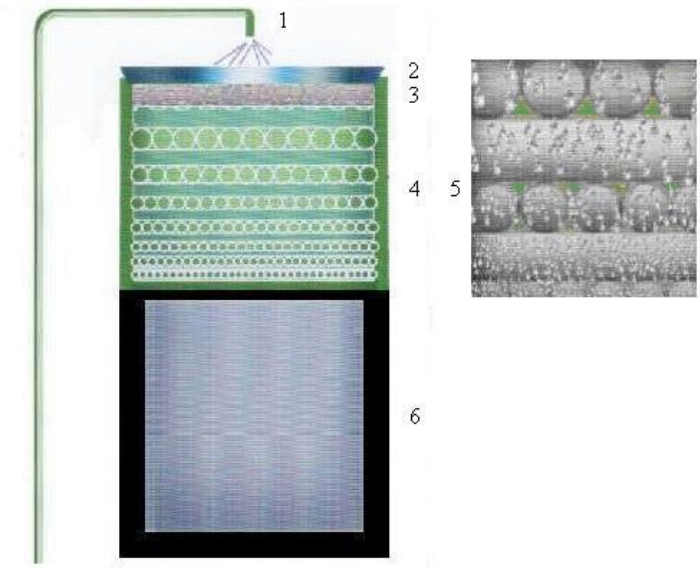

Figure 1. The microdrop system with inlet of groundwater (1), distribution tray (2), iron coil filtration tray (3), polymer grid pipe oxidation unit (4 and 5) and and buffer tank (6).

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