3nd Annual meeting of the Danish Water Research Platform (DWRP, Forskningsplatformen - Vand)

Date: Thursday 29 January 2009, 8:30 a.m. – 6 p.m.

Venue: The Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10, 1350 København K. Auditorium Theodor Sorgenfrei.

ABSTRACTS

Session 1: EU FP6/FP7 projects with Danish participation

Degradation of NDMA in aquifer material from Wulpen.

Claus Jørgensen, DHI, Bjørn K. Jensen, GEUS, Arne Hein, Technical University of Berlin, Martin Krauss, Eawag Dübendorf, CH.

The study to be presented is part of RECLAIM WATER (www.reclaim-water.org) a research project under the 6th Framework Program. The overall aim of the project is to provide effective technologies to monitor and mitigate emerging risks posed by chemical contaminants and pathogens in reclaimed wastewater streams used for groundwater recharge. The project has 18 partners and includes 9 groundwater recharge demonstration sites in Europe, Israel, South Africa, Mexico, Singapore, Australia and China.

One of the European demonstration sites is situated in Wulpen, Belgium. The infiltration site receives treated waste water from an advanced waste water treatment plant. After infiltration and storage, the water is used as drinking water.

Nitrosodimethylamine (NDMA) is a disinfection-by-product. It is produced during chlorination of sewage and during chloramination of drinking water. NDMA is suspected to be carcinogenic. WHO has suggested a drinking water guideline value of 100 ng/l whereas California has set a provisional limit value of 3 ng/l. In the current revision of the European drinking water directive a limit value of 10 ng/l has been suggested. Hence, NDMA may be present in the reclaimed water and is a potential risk to public health.

The aim of this study was to investigate the degradation of NDMA during infiltration

In the presentation results of both batch studies and column studies using sediment from the Wulpen infiltration site are presented.

NoMiracle: Coping with chemical mixtures and combinations of chemicals and natural stressors.

Hans Løkke.

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In the FP6 project NoMiracle (Novel Methods for Risk Assessment of Cumulative Stressors in Europe), 38 partners work together 2004-2009. The project integrates environment and human health methods. Within the aquatic area, new methods will be available for assessing bioavailability, biodegradation and effect and risk assessment of chemicals and combinations of chemicals and natural stressors. A large database on mixture toxicity has been produced using an array of species and biological active compounds for toxicity testing. The classical models for independent action and for concentration addition have been improved and validated, and in parallel a new, effective tool has been developed based on the Dynamic Energy Budget theory. It has been demonstrated that the combination of chemicals and natural stressors such as temperature, salinity, and anoxia can be analysed by use of models

similar to those for chemical mixtures. No simple model could be derived for the interaction of chemicals and pathogens. Assessment of bioavailability of chemicals is markedly improved by introducing the concept of Chemical Activity.
http://nomiracle.jrc.ec.europa.eu

NeWater – Lessons learned from the experience of developing and piloting adaptive water management from seven case studies

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Abstract
The FP6 EU research project NeWater – New approaches to adaptive water management under uncertainty with 35 partners has done (action) research in seven case studies (Elbe, Rhine, Guadiana, Tisza, Amudarya, Nile and Orange). NeWater defines adaptive water management (AWM), *as a systematic process for improving management policies and practices by learning from the outcomes of implemented management strategies*. Within the context of IWRM a central contribution of AWM is that it provides added value through explicitly embracing *uncertainty*. AWM acknowledges the *complexity* of the systems to be managed, and the limits to predicting and controlling them. AWM adopt a *systemic learning perspective* rather than suggesting an approach for problems solving in isolation or based on top-down command and control.
Outputs can be defined as achievements of processes, as milestones and products. An example is training and awareness-raising workshops arranged to diffuse the principles of IWRM or AWM. Outcomes are accomplishments reached through a combination of outputs. What distinguishes outputs and outcomes is that the former are not an end in itself but a mean to achieve the latter. Of this reason it is also difficult simply to assess research or policy based on their eventual, long term outcomes, because other factors influence processes. The aim of sound natural resource management is an equitable, efficient and sustainable use of the resources (e.g. water). Governance systems should support processes that are open (transparent), inclusive, effective, coherent and accountable. A more mature governance is both an end in itself and a mean to the reach the above goals, therefore learning beyond reframing and transition also including developmental processes of the management regime is required. In this context AWM provides guidance to reach goals especially in the situations where our knowledge of the underlying system processes is limited and these processes therefore tend to get out of control due to the complexity. The ultimate long term outcome of adaptive management are more flexible institutions with a higher adaptive capacity, and more resilient societies ,ecosystems and water systems, which are better able to cope with occasional extremes and change processes (e.g. flooding, droughts, economic crises and profound demographic change processes).
In the four years, NeWater produced a number of outputs and short-term outcomes, of which some are accessible from synthesis products, journal papers, the project's web site (www.newater.info) and from the WISE-RTD portal (www.wise-rtd.info). Among the twelve synthesis products there are a guidebook, a training booklet, uncertainty guidelines, a management and transition framework, a special issue on public participation and many more products of value for practitioners and researchers who seek inspiration for new approaches for water management. Numerous training, dissemination activities, workshops etc. have engaged hundreds of end-users (water managers, authorities, consultants, scientists, interest groups and citizens) in the seven case studies. Some of the short-term outcomes have included better analysis and appreciation of uncertainty in the various policy contexts of the

case river basins. Others the needed assessment of feedback loops and public participation. Yet, in other cases the assessment of future changes to water cycle due to shifting climate, land use and new policies and their uncertainties have been explicitly assessed. Taken together, the outcomes of the seven case studies have improved knowledge about the practical implementation of AWM and initiated social learning, and relationships to IWRM. Even though the lessons learned from NeWater may be difficult to evaluate after only four years, a brief presentation of some outcomes and lessons learned from the seven NeWater case studies will be included from selected case studies, also compared to lessons learned from similar AWM case studies from the literature.
Important themes, when changing toward more mature and integrated AWM regimes, are focus on governance style, sectoral integration, scale of analysis and operation, information management, infrastructure, finances and risk. For supporting AWM tools and participatory learning processes are important especially: (a) Tools to be used to integrate across disciplines, scales, times, and knowledge domains (b) Tools that can help to engage stakeholders more effectively in the decision making processes and, (c) Tools to cope with science and policy uncertainty as part of scenario development and analysis.

Safe and High Quality Food Production using Low Quality Waters and Improved Irrigation Systems and Management, EU Project (SAFIR; www.SAFIR4EU.org).

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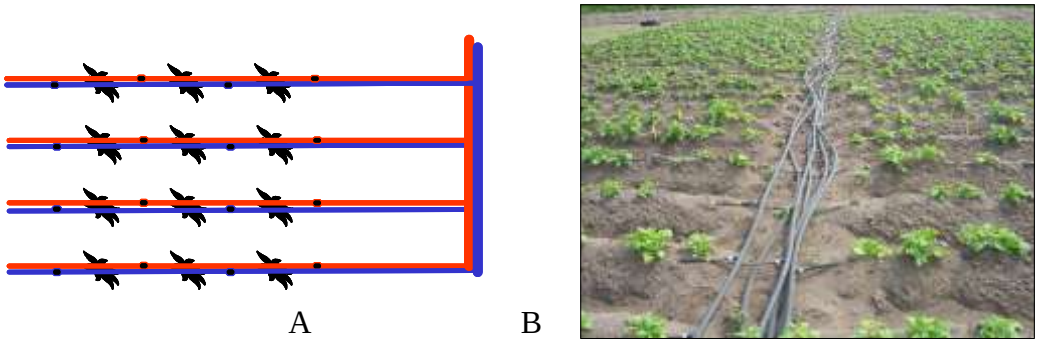
Globally, agricultural irrigation is the number one user of freshwater. Agriculture consumes about 70% of all water withdrawn worldwide, and up to 95% in some developing countries. The SAFIR project contributes to solving this challenge, addressing two major public concerns at the same time: the safety and quality of food products, and the increasing competition for clean freshwater. SAFIR is funded for the period 2005-2009 under the Food Quality and Safety thematic area of the EU 6th Framework Research Programme. The challenge for the next years will be to produce safe and high quality foods while at the same time reducing the use of natural resources and the impact on aquatic ecosystems that are frequently already polluted.
These problems are linked, since most of our vegetables are produced using irrigation water from the same ecosystems. To ensure food safety and quality, the innovative SAFIR irrigation systems combine state-of-the-art water-cleaning technology with high-efficiency irrigation systems. The water treatments consist of both high tech and low tech solutions supplying sub-surface and surface drip irrigation system with roughly treated waste water. SAFIR has assembled a multi-disciplinary
team, with food safety and quality experts, engineers, agronomists and economists from17 research institutes and private companies in Europe, Israel and China working together. The project assesses potential risks to farmers. Coupled with farm management and economic models, a new intelligent tool for efficient and safe use and re-use of low-quality water are being developed. Already published results indicate water saving in the order of 25-30% in agricultural crops as potatoes and tomatoes are possible without yield reduction. Slightly treated waste water can be used safely when irrigated as sub-surface drip irrigation.
KU-Life and AaU-DJF are the major partners in SAFIR of important work packages covering development of new irrigation strategies, use of waste water for irrigation, modelling, risk assessment and economy.

The Danish partners are now aiming at implementation of similar approaches in West Africa via capacity building at several levels for stimulating near urban vegetable based agro-business and livelihood.



A B

Figure. A: Shows the novel partial root zone drying principle tested in SAFIR in potatoes. B: Drip irrigation set up in potato ridges in the field. When slightly cleaned waste water was used in sub-surface drip irrigated potato crops no harmful organisms could be found in the produce.

ScorePP - Source Control options for Reducing Emissions of Priority Pollutants

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The SCOREPP project aims to develop comprehensive source control strategies that authorities and industry can use to reduce emissions of priority pollutants (PPs) from urban areas into receiving waters, focusing on priority substances (PSs) and priority hazardous substances (PHSs) identified in the European Water Framework Directive.

The primary scientific objectives of the ScorePP project are, in brief, to identify the sources of PPs in urban areas (WP3), identify appropriate strategies for limiting the release of PPs from their sources (WP4) and for their removal via treatment (WP5), connect and visualise pollution sources, paths and loads using GIS technology (WP6), develop dynamic source-and-flux models for quantifying the fate of PPs within the urban drainage and wastewater system and optimising monitoring programmes (WP7), and benchmark the different emission control strategies and determine their socio-economic impacts on a societal scale (WP8). Three further scientific objectives are additionally defined as follows: evaluate the usefulness of the developed approaches, technologies and emission control strategies in a number of case study cities (WP2), interact with the most important stakeholders and communicate the results of the project to a wide audience (WP1) and finally, integrate and condense the developed knowledge and experiences (WP9). Further information can be found at: http://www.scorepp.eu.

Acknowledgement
The presented results have been obtained within the framework of the project ScorePP - "Source Control Options for Reducing Emissions of Priority Pollutants", contract no. 037036, a project coordinated by Institute of Environment & Resources, Technical University of Denmark within the Energy, Environment and Sustainable Development section of the European Community's Sixth Framework Programme for Research, Technological Development and Demonstration.

FOOTPRINT
Creating Tools for Pesticide Risk Assessment and Management in Europe

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FOOTPRINT (Functional TOOls for Pesticide RIsk assessmeNt and managemenT) is a research project in the EU's 6th Framework Programme, which aims to develop a suite of pesticide risk prediction and management tools (the 'FOOT tools'), for use by three different end-user groups: policy makers/registration authorities at the national/EU scale, water managers at the catchment scale and farmers/advisors at the farm scale. The three tools allow stakeholders to make consistent and robust assessments of risk of contamination to water bodies at the scales relevant to management, mitigation and regulation (i.e. field/farm, catchment and national/EU), Fig 1. The FOOTPRINT tools allow users to i) assess whether pesticide application practices poses a contamination risk to local water bodies and, ii) provide site-specific mitigation recommendations. The three tools will share the same overall philosophy and underlying science and will therefore provide a coherent and integrated solution to pesticide risk assessment and risk reduction from farm scale to EU scale. The predictive capability and usability of the tools will be assessed, as part of the project, through a substantial programme of piloting and evaluation tests at the field, farm, catchment and national scales. More information about the project can be found at http://www.eu-footprint.org

	Farm 	Catchment 	Country 
Objectives	Minimisation of aquatic contamination by pesticides	Identification of pesticide contaminant hotspots	Identification of pesticide contaminant hotspots & assess the probability of exceeding thresholds
Stakeholders	Farmers & extension advisers	Water managers	Policy & decision makers
Provisions	Site-specific recommendations via a risk assessment	Definition & optimisation of action plans	Support for policy decisions
Tools	Standalone system & web portal	GIS	GIS

Figure 1. Schematic presentation of the intended objectives and application of the three tools developed in FOOTPRINT.

Session 2: Danish research projects

HOBE – a Hydrological Observatory

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Abstract

The Water Framework Directive of the European Union requires that water resources management strategies must be developed at catchment scale, the natural geographical and hydrological unit, instead of according to administrative or political bounds and that surface water and groundwater must be managed in an integrated and sustainable manner. In consequence there is a need to obtain a better scientific understanding of the hydrological processes at catchment scale. Recent assessments of the exploitable groundwater resource at the national scale based on integrated hydrological model simulations have documented that the knowledge of the in- and outgoing water fluxes and the exchange of water between the different hydrological compartments at catchment scale is insufficient. Even for the two most basic hydrological fluxes, precipitation and evapotranspiration, significant uncertainties are related to their estimation at larger scale. These uncertainties have among others been reflected in problems with closure of the water balance. To remedy these problems various empirical correction factors have been applied to the various fluxes in order close the water budget. As a result current assessments of the available groundwater resources for water supply in Denmark are inherently uncertain because of the uncertainty in the estimates of basic hydrological variables and processes at catchment scale.

To address these problems a hydrological observatory has been established in the 2500 km2 Skjern catchment based on a DKK 32.8 mill. donation from VILLUM KANN RASMUSSEN FONDEN. In the hydrological observatory integrated and interdisciplinary measurements and experiments at multiple spatial and temporal scales are carried to create a high density multi-scale data set that can provide a platform for interdisciplinary hydrological research. Emphasis is given to the investigation of the following components of the hydrological cycle: (1) precipitation, (2) evapotranspiration, (3) recharge, (4) surface water – groundwater interaction, and (5) groundwater seepage to the sea. In addition continuous measurements of greenhouse gasses over different vegetation types are carried out.

Classic state-of-the-art measurement techniques are used in combination with novel sensor techniques to measure and analyze the multi-scale spatial and temporal patterns of the land surface and subsurface systems including system parameters, state variables, and in- and outgoing water fluxes. In particular we will take advantage of the recent developments within ground-based, airborne and space-borne non-invasive sensors. The collected data will form the basis for further development of integrated and physically-based hydrological models and of techniques for integration and utilization of different types of data representing different scales.

The effects of hydrology and land use on water and nutrient budgets for seepage lakes: Lake restoration with a long perspective

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CLEAR project (Villum Kann Rasmussen Centre of Excellence, www.lake-restoration.net).

Lake Hampen in Jutland is one of the intensely studied lakes in the CLEAR project. The lake is 76 ha with a maximum depth of 13 m and is situated approximately 20 km southwest of the city, Silkeborg. The lake is surrounded by forest and agriculture. The lake has no major in-/outlet and is considered to be a flow-through lake. The lake is one of the few Lobelia lakes in Denmark, but is slowly changing its status as nutrient-poor to a nutrient-affected lake. In collaboration between hydrologists, hydrogeologists, and freshwater biologists the primary objectives are; (1) understand the spatio-temporal seepage of water and nutrients to and from the lake, (2) understand the effects of buffering of nutrients in near-lake aquifer systems and lake bed sediments, and (3) use this information to provide a water and nutrient balance for the lake. A suite of field methods have been employed to provide data and modelling is used to quantify the important physical and chemical processes.

Best Management of Stream Banks, Bufferzones and Floodplains for reducing Agricultural Phosphorus Losses (BUFFALO-P)

Brian Kronvang[1], Carl Christian Hoffmann[1], Hans E. Andersen[1], Annette Baatrup-Pedersen[1], Henning Jensen[2], Charlotte Kjærgaard[3], Goswin Heckrath[3] and Hans Christian Bruun Hansen[4]

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Background

Agriculture is today the main driving force for the phosphorus (P) pressure on the Danish aquatic environment (Kronvang et al., 2005a). The state of P in inland and coastal waters is in many cases so high that many rivers, lakes and estuaries are impacted to such an extent that a good ecological quality can not be obtained. Therefore, the objective of reaching a good ecological quality in water bodies as required by the EU Water Framework Directive will demand that the P-loss from agricultural areas is reduced. Consequently, responses in the form of introduction of general and targeted mitigation measures against agricultural P-losses in source areas and along the different P-pathways are needed (Kronvang et al., 2005b).

The content of the project

BUFFALO-P is developing and testing guidelines, methods and tools that can support stakeholders in implementing targeted mitigation measures in streams, buffer zones and floodplains for immediate reductions in the agricultural losses of phosphorus to the aquatic environment. The research strategy chosen is directed at increasing our understanding of the various mechanisms responsible for sorption, storage and loss of different phosphorus forms in the ca. 400,000 ha cultivated Danish low-lying soils and riparian areas along our ca. 65,000 km watercourses, these areas being currently responsible for more than half of the agricultural phosphorus loss to the aquatic environment. The establishment of uncultivated buffer zones along water courses or allowing former intensively farmed low-lying riparian

areas to become more wet by controlled irrigation with tile drain water from higher lying fields, temporarily inundated with stream water during winter or establishment of riparian wetlands can on relatively small areas give multiple advantages: 1) a reduction in the phosphorus loss to surface waters from soil and stream bank erosion; 2) an increase in particulate P storage; 3) an increase in the organic P storage through peat production. We hypothesize that such mitigation strategies will ensure a certain and immediate reduction in the losses and transport of particulate phosphorus forms from agricultural areas to streams, lakes and coastal waters. However, 'old' agricultural phosphorus stored in the low-lying soils may be released as the soils are becoming anaerobic and then the areas becomes a P-source for shorter or longer periods thus counteracting the net retention effect obtained from storage of particulate P.

References

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Survival of indicator organisms and pathogens in drinking water distribution networks

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Abstract. The aim of the project was to investigate the survival of indicator organisms and pathogens in drinking water and the effect of different pipe materials on their survival. Seven strains of E. coli, seven strains of K. pneumoniae and six strains of C. jejuni were investigated with respect to survival in the water phase and biofilm on PE material. E. coli and K. pneumoniae were quantified on MacConkey agar and Colilert-18 and C. jejuni on Abeyta Hunt Bark agar. Pipe segments were added to the batch set-up with non-disinfected drinking water produced from groundwater inoculated with the three organisms at initial concentrations in the range of 102 to 103 cells/mL. The experiments were conducted at 10 °C or 15 °C for a period of approx one month. Six E. coli strains and all seven K. pneumoniae strains were detected on day 30 - E. coli concentrations were in the range of 0.2-10 CFU/mL and 1-20 CFU/mL for K. pneumoniae. Three of the E. coli strains and two strains of K. pneumoniae had a faster decay rate compared to the other strains. The PE-material inhibited the survival of all strains. Both E. coli and K. pneumoniae were detected in the biofilm on PE pipe segments, but generally to a much lower extent compared to the concentration in the water phase. All C. jejuni strains survived for a much shorter period compared to the two indicator organisms. Three C. jejuni strains were detected on day 5 in concentrations of 0.03-0.5 CFU/mL, while the other strains were detected until day 3 in concentrations of 1-48 CFU/mL. In contradiction to the two indicator organisms none of the investigated C. jejuni strains colonized the biofilm. The effect of PE, PEX and silicone was investigated with regard to the survival of E. coli ATCC 25922 and K. pneumoniae M&R No.1 in the water phase. Silicone and PE caused a faster decay compared to PEX, i.e. PEX had the least impact on the survival of the two bacteria. Experiments showed that the two investigated indicator organisms can survive for a long period in oligotrophic environments such as drinking water systems while the pathogen – C. jejuni – proved to have a poor survival under such conditions.

Results are output of the project "Overlevelse af indikatorbakterier og patogener i ledningsnet" (InPaNet) carried out in collaboration with Gentofte Vandforsyning. The project is financed by By- og Landskabsstyrelsen.

Microbial ecology of wastewater treatment

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The overall research topic of the Environmental Biotechnology Group is concerned about the use of mixed microbial populations in environmental biotechnology. The aim is to study, apply and manage microbial populations for treatment of primarily wastewater by combining microbial ecology and engineering approaches. Specific research topics are the microbial ecology of wastewater treatment in relation to:

- Biological phosphorus removal
- Nitrification and denitrification
- Detection and survival of pathogens
- Transformation of micropollutants
- Control of filamentous bacteria (bulking and foam control)
- Conversion of wastewater to bioplastic (PHA) by mixed cultures
- Biofilms and flocs – structure and function of extracellular matrix.
- Bacterial influence on sludge drainage and dewatering
- The Danish Microbiological Database – refers to microbial communities in 50 full-scale wastewater treatment plants

Other research areas include

- Biofilters in aquaculture
- Odour control by biofilters
- Detection and control of biofouling and biocorrosion in technical systems.

The studies are based on development and application of new in situ techniques in microbial ecology and single cell microbiology (molecular methods, isotope methods, e.g. FISH, microautoradiography, isotope array, confocal laser scanning microscopy). Recently, also methods for "Systems Biology" are included (genomics, transcriptomics and proteomics).

The projects are funded or co-funded by different research councils, Lundbeck foundation, Århus and Esbjerg Kommuner, Danish wastewater treatment plants, and companies such as Kemira Water, Viborg Energy, Krüger A/S, and Limnotech.

The Environmental Biotechnology Group organizes the next IWA international Specialised Conference on "Microbial Population Dynamics in Biological Wastewater Treatment" in Aalborg, May 2009. Visit www.aspd5.com

SENSOWAQ – Immunosensors for detection of pesticides

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Due to their very high sensitivity, immunological methods have long been used in biological science for analysing a large variety of organic structures but have only recently been introduced to environmental analysis. The benefit of such assays is primarily their high sensitivity, which allows the analysis to be undertaken without the need to concentrate the samples, but also the facility of dealing with large numbers of samples.

New immunological assays have been developed for the pesticide metabolite BAM and several triazine herbicides including their degradation products. All assays have a very low detection limit in the range of 0.01-0.02 µg/l, making them ideal for monitoring specific pesticide residues in ground- and drinking water. For routine, the analysis is carried out in 96 wells micro titre plates, but we have also transferred the micro titre plate format to a biochip allowing the analysis of several compounds simultaneously. The principle of the biochip analysis is the same as for the micro titre plates, but the reagents are added as micro spots (in the nanoliter range) on a glass surface. The new pesticide biochip enables the analysis of pesticides in a single drop of water in concentrations as low as 10 ng/l.

With the aim to develop stand-alone on-line immunological sensors for groundwater and drinking water analysis we have established a laboratory flow system where a BAM immunoassay is coupled to electrochemical detection. Preliminary results have shown a detection limit of 0.1 µg/l using this flow system.

The research is affiliated to the SENSOWAQ project (WWW.SENSOWAQ.DK) financed by the Danish council for Strategic Research

Economic assessment of water quality

Martin Rygaard, Hans-Jørgen Albrechtsen, Erik Arvin & Philip J. Binning, DTU Environment

Copenhagen City exemplifies the vast number of cities around the world that are challenged to find new drinking water resources. Polluted groundwater and the implementation of the EU Water Framework Directive increase the challenges for Copenhagen Energy (KE) to renew contracts for water abstraction around Copenhagen. In a collaboration project between DTU Environment and KE a number of alternative water resources that can increase the water self-sufficiency of a city has been identified. Alternatives like wastewater reuse, rainwater harvesting, and desalination are increasingly used in all regions of the world. Enormous technological development has occurred over the last 20 years, and research continues on improving the efficiency of the techniques involved. However, integrated assessments of the consequences of combining multiple sources and manipulating water quality are not yet fully developed. Water suppliers can optimally blend multiple water resources to meet one or more goals. In practice, the blend ratio often reflects the available water resources rather than an integrated assessment of the resource, its quality and the application of the water. Desalination can provide product water that is dramatically different

from water obtained using conventional treatment methods. This is especially true in water supply systems delivering water of high salinity and hardness.

In a PhD-project at DTU Environment we have developed a method for assessing the economic impact of changes in water quality. To illustrate the method, it is applied to Copenhagen City (Denmark, 0.5 mill. inhabitants) which is currently supplied with relatively saline (TDS around 560 mg/l) and hard water (around 370 mg/l as CaCO3). The consequences of diluting water supplied to Copenhagen City, Denmark, with desalinated water are described.

The results showed that changes to water quality may cause significant impacts on health, lifetime of consumer goods (e.g. clothes washers) and soap consumption. With a mineral content at 50 % of current levels, dental caries and cardiovascular diseases are expected to increase by 34 and 20 % respectively, representing increased hospitalization costs equal to €0.10 and €0.51 per m3 water delivered. Meanwhile, the number of dish and clothes washer replacements is expected to decrease by 6 % which is equivalent to a cost of €0.04/m3. These impacts are equal to 10-150 % of water production costs in 2005. Some of these costs could be off-set by remineralisation adding specific minerals to the water at a much lower cost (e.g. by fluoridation ~1 ¢/m3). The calculations indicate that the economic impact of changes to water quality can be at least as significant as the change in operating costs involved in changing from fresh water based to desalinated water supply. This highlights the importance of developing assessment methods that include indirect effects on public health, corrosion and chemical consumption (e.g. detergents) from changes to the water quality and integrate it with resource availability and treatment costs.

The KE-DTU collaboration is funded by KE and the PhD-project is funded by DTU.

Further reading:

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Arsenic in groundwater of the Red River floodplain, Vietnam: controlling geochemical processes and reactive transport modeling.

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An outcome of the Danida/ENRECA project "Water Resources Research in Vietnam"

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The mobilization of arsenic (As) to the groundwater was studied in a shallow Holocene aquifer on the Red River flood plain near Hanoi, Vietnam. The groundwater chemistry was investigated in a transect of 100 piezometers. Results show an anoxic aquifer featuring organic carbon decomposition with redox zonation dominated by the reduction of Fe-oxides and methanogenesis. Enhanced PCO2 pressure causes carbonate dissolution to take place but mainly in the soil and unsaturated zone. The concentration of As increases over depth to a concentration of up to 550 µg/L. Most As is present as As(III) but some As(V) is always found. Arsenic correlates well with NH4, relating its release to organic matter decomposition and the source of As appears to be the Fe-oxides being reduced. Part of the produced Fe(II) is apparently reprecipitated as siderite containing less As. Results from sediment extraction indicate most As to be related to the Fe-oxide fractions. The measured amount of sorbed As is low. In agreement, speciation calculations for a Fe-oxide surface suggest As(III) to constitute only 3% of the surface sites while the remainder is occupied by carbonate and silica species. The evolution in water chemistry over depth is homogeneous and a reactive transport model was constructed to quantify the geochemical processes along the vertical groundwater flow component. A redox zonation model was constructed using the partial equilibrium approach with organic carbon degradation in the sediment as the only rate controlling parameter. Apart from the upper meter a constant degradation rate of 0.15 C mmol/L/yr could explain the redox zonation throughout the aquifer. Modeling also indicates that the Fe-oxide being reduced is of a stable type like goethite or hematite. Arsenic is contained in the Fe-oxides and is first released during their dissolution. Our model further suggests that part of the released As is adsorbed on the surface of the remaining Fe-oxides and in this way may be retarded.

Temperature models for key processes in nutrient cycling

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CONWOY (Consequences of weather and climate changes for marine and freshwater ecosystems)

The influence of temperature on nitrification and denitrification rates in lake sediments was experimentally studied by aerobic and anaerobic incubation of sediment surface samples in a temperature gradient block generating a gradient with 30 equidistant intervals with 4 replicates over the range 0 – 60oC. The temperature dependences for nitrification and denitrification were fitted to a number of temperature models ranging from traditional Arrhenius-models to thermodynamically based optimum models identifying the latter to give the best fit. Also the acclimatisation was studied and after incubations at 8 different temperatures in 7 – 83 days there were no significant changes in optimum temperature for

nitrification but for denitrification an increase of 0.15 oC per degree increase in acclimatisation temperature was observed independent of incubation length. The resulting models for temperature dependencies were successfully validated on sediments from monthly sampling over a year in an experimental pond system with 4 replicates of 3 climate scenarios representing ambient and predicted climate changes. The importance of choice of model was illustrated for annual rates of potential nitrification and denitrification and showed no influence of model choice for nitrification but double as high denitrification if an Arrhenius-model was used compared to the thermodynamically based model.

Session 3: Danish PhD projects

Sorption and desorption of arsenate and arsenite on calcite

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The adsorption and desorption of arsenate (As(V)) and arsenite (As(III)) on calcite was investigated in a series of batch experiments in calcite-equilibrated solutions. The solutions covered a broad range of pH, alkalinity, calcium concentration and ionic strength. The initial arsenic concentrations were kept low (<33 µM) to avoid surface precipitation. The results show that little or no arsenite sorbs on calcite within 24 h at an initial As concentration of 0.67 µM. In contrast, arsenate sorbs readily and quickly on calcite. Likewise, desorption of arsenate from calcite is fast and complete within hours, indicating that arsenate is not readily incorporated into the calcite crystal lattice. The degree of arsenate sorption depends on the solution chemistry. Sorption increases with decreasing alkalinity, indicating a competition for sorption sites between arsenate and (bi)carbonate. pH also affects the sorption behaviour, likely in response to changes in arsenate speciation or protonation/deprotonation of the adsorbing arsenate ion. Finally, sorption is influenced by the ionic strength, possibly due to electrostatic effects. The sorption of arsenate on calcite was modelled successfully using a surface complexation model comprising strong and weak sites. In the model, the adsorbing arsenate species were H2AsO4- and CaHAsO40. The model was able to correctly predict the adsorption of arsenate in the wide range of calcite-equilibrated solutions used in the batch experiments and to describe the non-linear shape of the sorption isotherms. Extrapolation of the experimental results to calcite bearing aquifers suggests a large variability in the mobility of arsenic. Under reduced conditions, arsenite, which does not sorb on calcite, will dominate and, hence, As will be highly mobile. In contrast, when conditions are oxidizing, arsenate is the predominant species and, because arsenate adsorbs strongly on calcite, As mobility will be significantly retarded. The estimated retardation factors for arsenate in carbonate aquifers range from 25 to 200. Preliminary results from a field investigation in carbonate aquifers on Sjælland have supported the laboratory results, as As(III) species are almost exclusively present where elevated concentrations of arsenic are present in this type of aquifers

Small animals in water distribution networks

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The presence of invertebrate animals has been reported from drinking water distribution systems worldwide. The reports indicate that only few water distribution systems are completely free of animals. In tropical and subtropical countries, some species of invertebrate animals can act as secondary hosts for parasites and thereby pose a serious health risk to consumers. In temperate areas, the animals are largely regarded as an aesthetic problem, however some animals can harbour bacterial pathogens and may play a role in the survival of these organisms in drinking water systems.

The Danish drinking water supply system is very special in the sense that it is based solely on ground water, and generally without the use of chlorination. The major aim of this study was to investigate the abundance of invertebrates in a Danish drinking water supply system. Other aims of the study were to develop sampling methods and to identify parameters influencing the abundance of invertebrates.

Water samples from pipes were taken by flushing from fire hydrants while clean water tanks were emptied prior to sampling. The floor and flush channels of the tanks were carefully inspected. The water louse, Asellus, was found at the majority of sampling points and the abundance was correlated to placement in the distribution system and pipe material. In addition to Asellus, oligochaetes (worms) and microscopic crustaceans were found.

The project was partly funded by the Urban Water Technology Graduate School.

Climate change impacts on groundwater and stream discharge in Denmark

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This study investigates how future climate change is likely to affect groundwater recharge and discharge to streams in Denmark. Estimating possible climate change effects on groundwater resources is highly relevant because the water supply in Denmark is entirely based on groundwater. A physically-based, distributed hydrological model is used to simulate the changes in hydrology for two geologically and climatologically different catchments and for two climate scenarios (2071–2100). The use of climate data for climate change impact studies is not straightforward, due to the discrepancies in scale and because biases occur for key climate variables. Therefore the regional climate model output for the present-day climate is compared to observations and also to the output from seven other climate models. Precipitation, temperature, and evapotranspiration increased for both scenarios, resulting in higher mean groundwater heads and stream discharges. However, during summer decreased values were found, thus amplifying the seasonal dynamics significantly. Due to drier summers irrigation volumes increased by up to 90% compared to current values. Changing the land use from grass to forest had a minor effect on groundwater recharge, whereas CO2-effects on transpiration resulted in a relatively large increase in recharge. This study shows the added value of studying different climate scenarios and hydrological systems, so that the simulated effects can be compared both qualitatively and quantitatively.

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Urban versus climatic impacts on the water cycle of the Copenhagen area 1850-2003

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Research project: Black, Blue & Green – Integrated infrastructure planning as key to sustainable urban water systems (www.2BG.dk). Partners: Faculty of Life Science at Copenhagen University, Danish Technical University, Odense Water Ltd., DHI water and environment, Grontmij|Carl Bro, Alectia A/S, Department of Earth Science at University of Aarhus, The Danish Road Directorate, Copenhagen Energy, Danish Town Planning Institute, Danish Water and Wastewater Association, Municipality of Greve, Municipality of Odense, Municipality of Aarhus, and Municipality of Copenhagen.

The research project *Black, Blue & Green – Integrated infrastructure planning as key to sustainable urban water systems (2BG)* explores the possibility for a paradigm shift within urban water systems towards (1) local treatment, detention, and infiltration, (2) with link to freshwater production, and (3) integrated in the green infrastructure planning.

In order to significantly reduce the contribution of storm water to existing sewer systems, massive storm water infiltration to the groundwater system might be a key solution. Whether or not this is possible depends on the levels and dynamics of groundwater. A product of the 2BG project is therefore a model capable of quantifying the total urban water cycle with emphasis on interactions regarding the groundwater system on catchment scale. The urban water cycle is described in terms of root zone water balance, water supply, waste water, storm water, groundwater flow between geological layers, and the interactions between these systems. Application of the model is demonstrated for the Copenhagen area for the period 1850-2003, whereby the complete history of groundwater abstraction and major city development in the region is covered. In order to minimize uncertainty on simulated urban water flows different observation types are used for model calibration and validation. These observations include historical piezometric head data, stream discharge, and inflow to sewage works.

Model simulations indicate that the subsurface leaky water service network underneath Copenhagen acts as a groundwater sink rather than a source, and definitely so since the 1970s where leakage from water mains has been reduced to diminishing levels (current rates of mains leakage is 3-4 % of water supply). The major controls on groundwater recharge in Copenhagen are thereby the climate and the sealed areas, whereas contributions from the water service network are insignificant. This finding is contrary to the results reported for many other city-studies.

In connection with groundwater recharge in the Copenhagen area, it is interesting to note that the simulations show a 20 mm (14 %) increase in annual recharge from 1850 to 2003. This has happened thanks to a 20% increase in precipitation during the past 150 years. The increase in precipitation has thus more than counterbalanced the decrease in recharge caused by the city development of impervious areas

Future work includes the development and implementation of a module capable of describing soak-aways (or infiltration trenches) and related interactions with groundwater. Thereafter, long-term future climate change scenarios (several decades) will be analyzed by the model, which enables a full description of the consequences on the urban groundwater

system from storm water infiltration, increasing sea-level, and increasing winter-precipitation.

Transportation and distribution of *Salmonella enterica* serovar Typhimurium in loamy and sandy soil monoliths with applied liquid manure

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Salmonella Typhimurium (tet^+) DSM554 was applied to the soil surface of undisturbed soil monoliths (0.6 m diameter, 1 m long). Leaching through loamy clay and sandy soil was investigated following swine manure application. S. Typhimurium was detected in concentrations up to 1.3×10^5 CFU/ml - the highest detected concentrations originated from loamy monoliths. After the leaching experiment the distribution of the test strain was measured down through the soil profile at five depths.
CFU data were validated using Real-time PCR targeting *inv*A DNA and showed a clear correspondence between total and culturable number of cells leached through the soil.

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