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Changes in intermittent aeration regimes are effective tools to manage bio-granule size and microbial communities in partial nitritation-anammox SBRs

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Potential benefits of a spatially targeted regulation based on detailed N-reduction maps to decrease N-load from agriculture in groundwater dominated catchments

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Abstract

Denmark has since the late 1980ties significantly reduced the N-leaching from agriculture, but must further decrease the N-load to coastal waters from agriculture areas to comply with the Water Framework Directive. Farmers are, however, already fertilizing below economical optimum and new regulatory strategies are required. A new spatially targeted regulation, taking spatial variation in natural N-reduction in groundwater into account, is under development.

The objectives of this study were to analyse the potential benefits of a spatially targeted regulation based on detailed N-reduction maps and to analyse how uncertainty in the N-reduction maps affects the efficiency of such a regulation. Two ways of spatially targeting was examined: (i) Identification of target areas with low N-reduction where mitigation measures must be applied to reduce N-leaching to a defined level and (ii) redistribution of N-leaching on non-target areas according to the N-reduction maps, so that high leaching rates are relocated to areas with high N-reduction and vice versa. The study illustrates that there are potential benefits of implementing a spatially targeted regulation based on detailed groundwater N-reduction maps. The potential benefits are larger in Odense study catchment than in Norsminde catchment. The results show, that an increase in N-leaching can be allowed on non-target areas without increasing the N-load to surface water, if farmers at the same time implement a spatially targeted regulation. If spatially targeting is solely done by redistributing the present N-leaching a reduction of 8% in N-load can be obtained in Norsminde and 26% in Odense. Uncertainty on the N-reduction maps due to geological uncertainty is found to lower the efficiency of spatially targeted regulation since wrong target areas can be identified. The study shows that using the mean of an ensemble of N-reduction maps can lower this error. The uncertainty of the N-reduction maps decrease with increasing spatial resolution of the maps, but the study also shows that the spatial resolution greatly influences the efficiency of spatially targeted regulation.

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Hydrogeology and groundwater chemistry in riparian lowland – An investigation of nitrate transport and groundwater flow for an agricultural, riparian area with sandy aquifer located at a subglacial stream trench near Holtum Stream, Denmark

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A. Højberg, Geological Survey of Denmark and Greenland**

Abstract

This study investigates the hydrogeology and groundwater chemistry for an agricultural riparian area, EVI2, located at a subglacial stream trench with a sandy aquifer near Holtum stream, Denmark. The groundwater flow, nitrate transport and removal were explored in the riparian area in order to understand small-scale nitrate removal processes and parameters.

Different data were collected during field trips. Data investigations consisted of analysis of chemistry measurements, geology data as well as 1D PHREEQC modeling, 2D PHAST modeling and 3D MODFLOW modeling.

The results show that a 3D model at catchment scale can be used to examine the groundwater flow and origins of the water in the riparian area EVI2 at local scale. It was observed that nitrate is removed at the agricultural field and that nitrate-polluted water is presence in springs at the wetland area of the study site. Nitrate reduction appeared possible in presence of pyrite and organic material at the agricultural field. The analyses show that the processes controlling the water chemistry at the agricultural field with high probability are denitrification with pyrite and organic material as the electron donors, reductive dissolution of iron oxides and sulfate reduction with organic material.

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Current and future salinity patterns of groundwater in the southern part of the Danish Wadden Sea environment

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Abstract

This work investigates the saltwater-freshwater patterns of a part of the Danish Wadden Sea environment covering Rømø, the Wadden Sea lagoon and the Ballum marsh, located in the south-west part of Denmark. This area is composed of a typical Wadden Sea barrier island, lagoon and reclaimed salt marsh setting.

To investigate the system hydrogeological observations, geophysical mapping and chemical analyses have been performed. These results indicate that the Rømø system is in equilibrium and that a developed freshwater lens exists. Further they indicate that on the east coast of Rømø the aquifer is artesian and that freshwater flows from Rømø under the Wadden Sea seabed. In the Ballum marsh the results indicate that the system is in disequilibrium with an ongoing freshening tendency; the thickness of freshwater increases with distance east from the Wadden Sea shoreline.

To propose future evolution of the system, a numerical model was set up in FEFLOW 7.0. This model was based on a conceptual geological model of the area. Overall three layers were included in the numerical model. These layers were calibrated and validated with freshwater-head observations. Two layers were calibrated with uniform hydraulic conductivity values and one was calibrated with varying hydraulic-conductivity values using pilot points.

The model results indicate that the equilibrium on Rømø occurred within a time interval of 850 - 1125 years after the system was no longer dominated by the sea. Further the results indicate that the Wadden Sea lagoon is in equilibrium as model simulations indicate 4550 years of freshening to dilute the saltwater from the North Sea to salinity concentrations corresponding to the Wadden Sea. Finally the results indicate a freshening-time interval of the Ballum marsh area of 850 - 1575 years from present day conditions.

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Saltwater intrusions in the low lying coastal areas of South-Western Jutland

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Abstract

Saltwater intrusions are threatening fresh water resources especially in low-lying coastal areas worldwide. In this study we present a regional scale 3-dimensional density driven groundwater flow and transport model of seawater intruding the coastal aquifers in the transboundary region of Southern Jutland and Northern Germany. Here geophysical and geological mapping show saltwater intrusions up to 20 km inland from the present coast. The 1700km^2 large investigation area adjacent to the Wadden Sea was partly flooded before a dike was build approx. 200 years ago.

Based on a detailed heterogeneous geological voxel model spanning from Miocene through Quaternary deposits a large scale groundwater flow model was developed with MODFLOW. Hydraulic parameters were estimated during calibration against head, stream discharge and C-14 age observations using automated regularized inversion. Subsequently a density driven flow and transport model using SEAWAT was set up to simulate the development of the saltwater intrusion during the last ten thousand years. The SEAWAT model was compared to the saltwater extent delineated based on geophysical and geological data. Two features were found that impact the progression of seawater. The complex heterogeneous geology with features such as buried valleys forms preferential flow paths for the seawater in the deeper aquifers. The dike construction changed the conditions in the shallower aquifers from being seawater saturated during flooding (before the dike construction) to being dominated by refreshing (after the dike construction).

In this study hydrogeological, geophysical and geochemical data was complimentarily used together with groundwater flow and transport simulations to understand the development of the coastal groundwater system from the past to the future on a regional scale.

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Generating training images for multi-point statistics directly from data - a key step for effective use of geophysical data in groundwater models

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Abstract

The uncertainty of the input structure in groundwater models has long been recognized as a key contributor to the uncertainty of certain types of hydrological forecasts. However, this contribution to uncertainty is most often neglected by using a single model realization. Traditionally, defining the input structures to groundwater models is a manual task, where geological, geophysical and sometimes hydrological data is interpreted in a manual workflow. Most often the geologist setting up the models are well aware of the uncertainties related to the structure, but its contribution is not transferred through the groundwater model. A possible solution to this problematic aspect has been the emergence of effective algorithms for multi-point statistic [1]. An example of such an algorithm is SNESIM. Here, the manual interpretation of the structure can be used as a Training Image. However, for effective use of the algorithm, the probabilities must also be assessed for each lithological unit simulated in each cell of the model, which can be cumbersome. However, once these tasks have been completed, multiple structural realizations can be generated, and these can be assessed in a hydrological model [2].

We present an alternative and highly effective method for generating TI for structural realizations directly from geophysical and lithological data. We applied the concept for a survey area located around the Kasted well field north-west of Aarhus, Denmark. The training image was generated using the clay-fraction resistivity clustering method [3, 4]. An example of a data driven TI can be seen from the figure below The TI was generated as the mode model of a sequential indicator simulation using 200 model realizations. This type of modelling also allows for easy estimation of the probabilities of cluster distributions, which is important for stochastic structure generation using SNESIM. The main benefits of the proposed methodology is the transparent and objective workflow, and the time it takes for model development. The latter is thereby reduced to a few weeks going directly from geological and geophysical data to completed models.
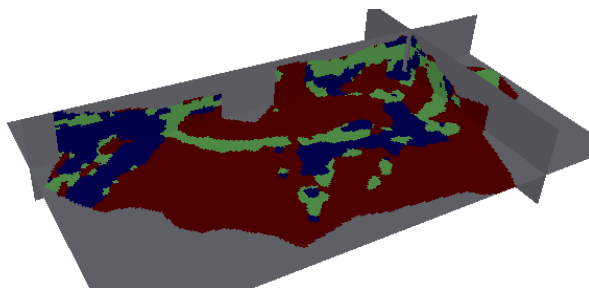
Figure: Example of 3D training image generated directly from geophysical and lithological data

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Quantifying and understanding runoff to an agricultural stream using geophysical, hydraulic and numerical methods

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Abstract

Quantifying and understanding stream-aquifer interaction is essential for the assessment of water, nutrient and contaminant exchange between land surface, soil, aquifers, and surface waters. In agricultural catchments it is of particular importance because of the risk of leaching of excess nutrients to streams and aquifers. In Denmark, 60 % of the land is agricultural and half of the agricultural land is tile drained. In this study, we investigate a small heavily tile drained agricultural catchment (Knivsbæk Catchment, 12 km^2) on Skovbjerg hill island in western Denmark. Our objective is to quantify and understand the runoff to the stream using geophysical, hydraulic and numerical methods.

We present the results of a geophysical mapping campaign. Here we mapped the shallow hydrogeological architecture in the study site using an ElectroMagnetic Induction (EMI) system (DUALEM-421S) which simultaneously obtains information about the electrical conductivity (m/Sm) of the soil in six different depth ranges. The variety of configurations with different sampling volumes makes the DUALEM-421S ideal for the investigation of the thickness and electromagnetic conductivity of layering in the top 5-10 metres of the subsurface.

Secondly, we present the results of hydraulic field measurements. We monitored stream stages continuously at two gauging stations: an upstream station representing approximately 1/3 of the catchment and a downstream station covering the catchment. We measured stream flow at the gauging stations regularly in order to transform stream stages to runoff hydrographs using Q-h relations. We used the hydrographs to analyse the runoff response to precipitation on different temporal and spatial scales. To complement the hydrographs, we measured stream flow in between the two stations a few times during the hydrological season.

Finally, we present the results of a transient 3D finite-difference groundwater flow model (MODFLOW-NWT). The NWT solver is designed to provide a solution to difficult unconfined groundwater-flow problems and surface-groundwater interactions making it ideal for this study. Water leaving the soil zone is calculated using the soil water balance code Evacrop. Tile drain nodes are simulated as head-dependent flux boundaries with the drainage (DRN) package. And the stream is represented as head-dependent flux boundary with the basic river (RIV) package. The model was calibrated to runoff data and hydraulic heads.

The results show that EMI data is able to map shallow hydrogeologically relevant architecture on catchment scale. The details revealed in the architecture reveals features on a smaller scale than even very dense borehole data (<250 m). The results of the hydraulic field measurements show that runoff hydrographs are event flow dominated. Hence, we expect the shallow hydrogeological architecture to control runoff. Finally, the results of the numerical modelling show that MODFLOW-NWT is able to simulate the runoff processes and to simulate measured runoff volumes and hydrograph dynamics.

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Multi-objective calibration of a highly parameterized coupled surface-subsurface model

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Abstract

In this study the physically-based coupled surface-subsurface model MIKE SHE is calibrated for the 4,700 km^2 area of central Jylland (Denmark) that is characterized by heterogeneous geology and considerable groundwater flow across topographical catchment boundaries. The calibration of the distributed conductivity fields is carried out with both a traditional zone based parameterization approach and a pilot point-based approach, implemented using the PEST parameter estimation tool.

Pilot Points as an alternative to classical parameterization approaches, introduce greater flexibility when calibrating heterogeneous systems without neglecting expert knowledge. However highly parameterized optimizations of complex distributed hydrological models at catchment scale are challenging due to the computational burden that comes with it. The high number of necessary model runs for calibration, which leads to impractical time spans, was overcome by using SVD-assist regularization technique and reduction of the model's complexity without unreasonable loss of the model's accuracy

The overall objectives of this project is to develop a new model calibration and evaluation framework by combining distributed model parameterization and regionalization with calibration techniques such as joint inversion and super-parameter optimization based on á priori spatial distributions.

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Joint treatment of rainfall uncertainties with support from days to years and point to catchment

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J.C. Refsgaard & T.O. Sonnenborg, Geological Survey of Denmark and Greenland[*]

Abstract

The importance of representing the spatial structure of rainfall accurately has been emphasized by various hydrological studies. Furthermore, it is widely acknowledged that there is a need to account for uncertainty in rainfall input. Common approaches generally account for only one source of uncertainty affecting rainfall estimation, e.g. either point measurement uncertainty or sampling uncertainty. This is likely to lead to an underestimation of overall rainfall input uncertainty. Hence, to obtain a more complete picture of rainfall input uncertainty, we present a statistical model that allows to jointly consider three different sources of uncertainty affecting the observation and estimation of rainfall: point measurement, sampling and locational uncertainty. Locational is an uncertainty that relates to unknown environmental factors that permanently alter the amount of rainfall received by ungauged locations; it is persistent in time. To our knowledge, locational uncertainty has not been included in any prior rainfall uncertainty analysis.

To assess rainfall input uncertainty, we generate an ensemble of 400 realizations of daily rainfall fields at a spatial resolution of 2 x 2 km for the Ahlergaarde catchment in Western Denmark (1055 km^2). Our method combines a stochastic simulation technique, sequential Gaussian simulation (SGS), with scaling factors (point measurement uncertainty) and an ensemble of scaling fields (locational uncertainty). Results indicate that our approach is able to reproduce key statistical features of the observed rainfall data and therefore can be considered valid. Moreover, we examine the impact of different spatial (grid and catchment) and temporal support scales (1 day, 31 days, 5-year period) on overall rainfall input uncertainty. We compare the effect of each of the three sources of uncertainty on the rainfall field ensemble and find that their relative importance for overall uncertainty varies with temporal and spatial support scale.

In conclusion, our approach results in rainfall uncertainty that is significantly higher than if only one source had been accounted for. However, comparison of the uncertainty obtained with that of a parallel expert elicitation study reveals that the expert elicitation resulted in even larger rainfall input uncertainty. This might indicate that rainfall uncertainty is still being underestimated and that further sources of rainfall uncertainty should be incorporated into our model.

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Mean transit time estimation based on stream Oxygen-18 in a humid low land catchment- What can we tell?

S. Müller, S. Jessen, & P. Engesgaard; all University of Copenhagen*

Abstract

A one year dataset of daily $\delta^{18}O$ stream observations at six stations across a Danish lowland catchment dominated by glaciofluvial sandy deposits was used to estimate catchment mean transit times (MTT). It was tried to evaluate the potential for $\delta^{18}O$ applications in a baseflow dominated, humid lowland headwater catchment. Different methods were used to compute MTT for each sub-catchment in order to compare the different methods against each other. Because baseflow dominates the catchment, we expected only minor variations in the $\delta^{18}O$ composition of the stream. Surprisingly, the stream $\delta^{18}O$ composition was varying by as much as 3.3‰ within a month, suggesting the existence of a faster runoff component. We explored the MTT and age distribution inferred by time-invariant models of the fast runoff component for each sub-catchment. Six approaches were compared: a simple transit time proxy (TTP), the analytical exponential model (A-EM), analytical combined exponential-piston flow model (A-EPM), and a lumped parameter model using a gamma distribution (GM), exponential distribution (EM) and exponential-piston flow distribution (EPM). Estimated mean transit times between all sub-catchments were rather diverse varying between 0.4 and 23.5 years. Within each sub-catchment the variations between the methods was on average 6.7 years. The analytical approaches yielded longest transit times on average 6.1 years, while the more sophisticated lumped parameter models estimated MTTs on average of 3 years. However, the lumped parameter models yielded poor fits and the time-invariant methods were therefore suspected not to capture actual flow conditions appropriately.

Nonetheless, CFC-11/12 analysis from earlier studies showed groundwater residence times, just beneath the stream, to be above 20 years. This suggests that the stream water in the lowland catchment receives a substantial amount of water of young ages (inferred from our study), likely from a reservoir of faster flow processes (surface runoff, saturation overland flow) which shows lower storage capacities (wetlands, near stream areas). As well as another component of much older water (deeper aquifers) inferred from earlier studies.

This study conclusively suggest to revise the flow-path conceptualization of the studied lowland catchment, where faster flows may be play a more important role in the catchment hydrology than what was prior expected, which consequently will impact, i.e. nutrient transport processes to the stream.

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Mapping shallow aquifers and groundwater discharge in a lake with combined offshore geophysical and thermal methods: Initial studies for assessing the potential for lake bank filtration

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Abstract

Water extraction from bank-filtration wells bordering rivers and lakes is common practice in water management as surface water bodies provide continuous supply of water, while the seepage of water through the sediment-water interface provides a physical, chemical and biological filtering of extracted water. Hence, bank filtration offers a potential for also reducing contaminants.

Due to the increasing demand for water resources Kalundborg Forsyning aims to raise the present extraction of 5 million m³/year surface water from Tissø by an additional 5-10 million m³/year. Tissø is the fourth largest lake in Denmark with a surface area of 12.3 km² and a water volume of approx. 100 million m³, which is continuously replenished by Halleby Å discharging to the lake in the north. To reduce water treatment costs, bank filtration could potentially be an additional optimal water extraction method around the lake provided that there are shallow aquifers in the area with good hydraulic connection to the lake. The aim of this study is therefore (i) to map the sediments under the lakebed to find shallow aquifers and their outcrops in the lake and (ii) to study if groundwater discharges from these aquifers to the lake indicating a good hydraulic connection.

A 5 km shoreline at the northern part of the lake was surveyed with offshore geophysical methods to locate shallow aquifers which could be used for water extraction. Electrical Resistivity Tomography (ERT) with floating electrodes was used to map the resistivity of shallow underwater sediments along the shoreline, while sediment properties perpendicular to the shoreline were mapped by a Ground Penetrating Radar (GPR). Synthesizing the results of the ERT and GPR surveys, airborne thermal imagery was used in a selected area to locate groundwater discharge locations in the lake. Finally, the Distributed Temperature Sensing (DTS) technology was used to map the spatial variability of groundwater discharge to the lake in detail.

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Groundwater modelling at the pore scale; a case study of groundwater remediation with ozone in limestone reservoirs

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Abstract

Fast characterization of rock microstructure has huge potential for the groundwater industries. We combined X-ray tomography experiments with reactive transport modelling to provide an accurate groundwater model that produced a quantitative framework for analyzing hydrogeological processes. A case study for groundwater remediation with ozone was performed to determine the radius of influence of ozone injected into a fractured rock contaminated by chlorinated organic compounds, i.e. tetrachloroethylene (PCE), trichloroethylene (TCE) and cis-dichloroethylene (cis-DCE). Injection of oxidizing compounds, such as ozone and chlorine, normally decontaminates the high permeability fractures while the matrix remains contaminated. The purpose of this case study was to estimate, at the pore scale, the decontamination time for PCE, TCE and cis-DCE using ozone in a fractured limestone where the pore structure was extracted from X-ray tomography data from real limestone samples. Hence this work was performed using both experimental and numerical methods. The X-ray tomography experiments were performed on a sample of limestone from Nykøbing Falster, Denmark. We collected 3D images of the limestone with 1 μm voxel resolution. We developed code to derive reactive transport models, which combined transport and chemical reactions at the pore scale. These were used to simulate transport of ozone through the fractures and the matrix while ozone was degrading PCE, TCE and cis-DCE. The combined method describes the flow field in the complete domain and estimates the decontamination time for all contaminants in a limestone with both fracture and matrix porosity (dual-porous medium) [1]. Results showed that higher pressure gradients in the domain causes larger differences between ozone transport in the fracture and in the matrix, i.e. there is larger delay between ozone transport in fracture and matrix. Degradation of cis-DCE is the fastest (50 seconds), then TCE (100 seconds) and finally PCE (>160 seconds), using 190 Pa pressure gradient over a 2D domain with 400*800 μm dimensions. We can conclude that reactive transport modelling using real, 3D images of pore and fracture microstructure provides valuable information that is important for accurate modelling of aquifers and their remediation in a time and resource effective way.
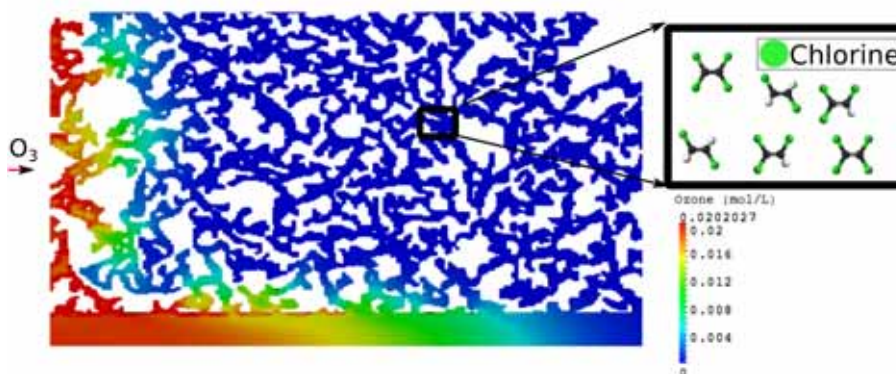
Figure: A 2-dimensional representation of the limestone matrix and a fracture (bottom of image) where ozone is injected from the left to decontaminate the chlorinated solvents. Ozone flow is from the left margin.

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Map-based screening to achieve cost-effective spatially targeted WFD river basin action programmes

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Abstract

Excess nitrate-nitrogen enters streams and rivers, as a result of intensive agriculture and the increasing use of fertilisers and fossil fuels, and is transported to our coastal waters leading to both eutrophication and low levels of dissolved oxygen. Denmark with its intensive agriculture and 7500 km long coastline with shallow estuaries and coastal waters is particularly vulnerable. Despite three decades of nitrate emission reduction, further reductions are needed to meet the requirements of the European Water Framework Directive and are associated with significant costs. Denmark's second-generation river basin management plans (RBMPs) are estimated to have a direct cost of 200 million euros when fully implemented. The Commission on Nature and Agriculture and the Danish Economic Councils recommend that the Danish Water Framework Directive (WFD) action programmes should be spatially targeted, cost-effective and holistic. Furthermore, in the 2nd and 3rd generation river basin management cycles (2015-2027) EU Member States are required to integrate climate change into these plans.

To address these challenges, we have developed a simple but powerful scenario tool to support the evaluation of nitrate management options. Building on earlier work this tool allows users to build and evaluate different nitrate management scenarios by assigning appropriate measures in a map-based environment from a pre-defined catalogue of measures. Adding new types of measures or defining new scenarios is straightforward. For each planning scenario, the nitrate reduction at specified target sites and cost-effectiveness are evaluated and more recently, the impacts on CO_2 emissions have been included. In this paper, we present the application of this tool in two Danish river basins, the Odense River and the Roskilde Fjord/Isefjord. We show how this new tool can be used to achieve important cost reductions, which meet environmental targets, by spatially targeting the application of measures. We also show how basin-scale management scenarios derived from this tool can be transferred efficiently to river basin scale models for more comprehensive assessment of the impacts. Finally, we present some recent work to show that by selecting appropriate measures, synergies can be achieved in reducing both nitrate and CO_2 emissions. The most important value of this tool however may well be the potential to support participatory water planning by non-model experts and stakeholders.

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Measuring water heights in rivers and lakes from lightweight unmanned aerial vehicles (UAVs)

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Abstract

A better quantitative understanding of hydrologic processes requires better observations of hydrological variables, such as surface water area, water surface level, its slope and its temporal change. However, ground-based measurements of water heights are restricted to the in-situ measuring stations. Hence, the objective of remote sensing hydrology is to retrieve these hydraulic variables from spaceborne and airborne platforms. Spaceborne missions will always face the limitations of: i) a low spatial resolution which makes it difficult to separate water from interfering surrounding areas and a tracking of the terrestrial water bodies not able to detect water heights in small rivers or lakes; ii) a limited temporal resolution which limits the ability to determine rapid temporal changes, especially during extremes. Unmanned Aerial Vehicles (UAVs) are one technology able to fill the gap between spaceborne and ground-based observations, ensuring 1) high spatial resolution; 2) tracking of the water bodies better than any satellite technology; 3) timing of the sampling which only depends on the operator 4) flexibility of the payload. Hence, this study focused on categorizing and testing sensors capable of measuring the range between the UAV and the water surface.

The height of the water surface is retrieved by subtracting the height above water measured by the sensors from the altitude above sea level retrieved by the onboard GPS.

The following sensors were tested: a) a radar, b) a sonar c) a laser digital-camera based prototype developed at Technical University of Denmark. The tested sensors comply with the weight constraint of small UAVs (around 1.5 kg). The sensors were evaluated in terms of accuracy, maximum ranging distance and beam divergence.
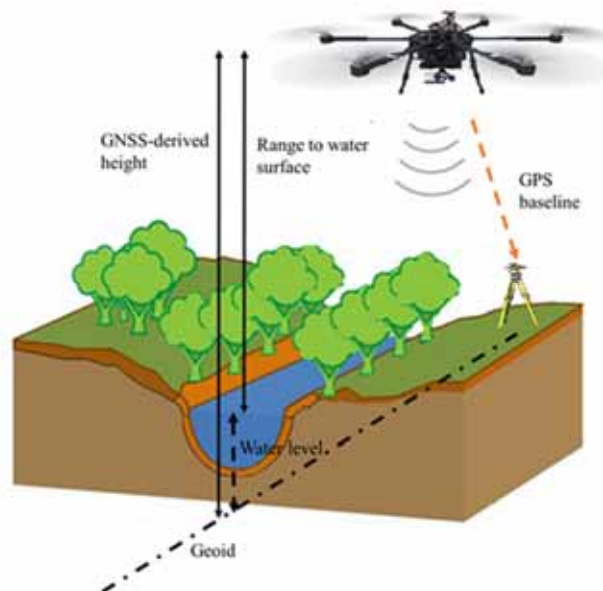
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Effluent from wastewater treatment plants: microbial quality measured by 16SrRNA amplicon sequencing

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Abstract

Incoming microorganisms to wastewater treatment plants (WWTPs) are usually considered to be removed in the treatment process. Analyses of the effluent generally show a very high degree of reduction of pathogens supporting this assumption. However, standard techniques for detecting bacteria in the effluent, particularly pathogens, are based on culture-dependent methods, which may give erroneous result by underestimating the type and number of bacteria in the WWTP effluent. The aim of this study was to determine which bacteria are discharged from WWTP together with the effluent. Culture-independent 16SrRNA gene amplicon sequencing was applied for the identification and quantification of the microorganisms. In total 84 effluent samples from 14 full-scale Danish wastewater treatment plants were investigated over a period of 3 months. The microbial community composition was investigated by 16S rRNA gene amplicon sequencing (V1 to V3 region) and MiDAS curated taxonomy (McIlroy *et al*. 2015). The microbial composition in the effluent from the WWTPs showed that among the 25 most abundant genera, there were many process-critical organisms for the treatment performance but also some genera which may contain pathogenic species. One of these was *Arcobacter* (Campylobacteraceae) which was found in up to 16% relative abundance. This indicates that *Arcobacter*, and perhaps other pathogenic genera, are not being removed efficiently in full-scale plants and may pose a potential health safety problem. Further investigations are needed to investigate in more detail the presence of specific pathogens.

Genus	Bjergmarken	Ejby Moelle	Esbjerg V	Fredericia	Haderslev	Hirtshals	Hjoerring	Odense NE	Odense NW	Randers	Skive	Viborg	Aalborg East	Aalborg West
Arcobacter	5.3	4.4	4.2	8	4	1.8	3.8	2.1	2.3	13.2	3.8	10.5	3.9	16.8
Romboutsia	1.9	3.4	1.9	0.8	2.7	0.8	1.5	2.4	3.8	2.8	2	5.7	2.2	2.2
Rhodoferax	3.1	0.9	2.3	1.1	2.4	1.3	1.8	0.7	0.8	1.9	3.3	1.1	2.1	3.3
Clostridium sensu stricto 1	1.3	2.7	1	0.8	1.5	0.5	0.9	2.4	3.2	1.7	1.1	2.6	1.5	1
Bacteroides	1	1.7	0.8	0.9	1.9	0.4	0.9	1	0.5	1.7	1	3.9	1.1	2.5
Fodinicola	2.2	1.2	1	0	2.5	0.2	1.2	1	1.5	2.6	1.6	1.9	1	0.9
Tetrasphaera	2.6	0.5	4.2	1.5	0.9	1.4	3.4	0.3	0.1	0.5	0.6	0.2	1.6	0.1
Dechloromonas	1.1	0.1	1	0.3	0.6	5.3	4.3	0.1	0.1	1.1	0.9	0.4	1.1	0.9
Flavobacterium	0.4	0.5	0.2	0.8	1.1	1.6	0.5	0.7	0.6	0.4	5.9	1.1	1.7	0.9
Aquabacterium	1.2	0.4	0.5	1.2	1	0.3	0.3	0.5	0.4	1.2	1.3	0.6	1.4	3
Rickettsiella	0	10.9	0	0	0.1	0.2	0.2	0.1	0.2	0	0	0	0.1	0
Blautia	0.6	0.8	0.5	0.3	1	0.6	1.2	1.2	0.7	0.7	0.5	2.3	0.6	0.9
Acidovorax	0.6	0.3	0.3	0.4	0.9	0.6	0.8	0.4	0.3	0.9	2	0.8	2.1	0.9
Blastocatella	0.2	1	1	4.9	0.5	0.6	0.7	1.6	0.1	0.5	0.4	0.2	0.2	0.1
Streptococcus	0.3	0.4	0.3	2.3	0.3	0.1	0.2	0.5	0.8	0.3	0.4	0.5	0.4	3.7
Prevotella 9	0.4	0.5	0.3	2.7	0.8	0.2	0.6	0.2	0.1	0.6	0.5	1.5	0.5	1.1
Candidatus Microthrix	0.8	0.2	2.6	0.4	0.6	0.1	0.1	0.3	0.4	1.4	0.8	0.2	0.9	0.6
f__Neisseriaceae_OTU_64	0.8	0.2	0	0	2	0.1	0.7	3.9	0	0.3	0.7	0.6	0.3	0.1
SKagenfB0	0.4	0.6	3.7	0	0.2	0.6	2.5	0.1	0	0.3	0.1	0.3	0.1	0.6
Candidatus Amarilinum	6.5	0.4	0	0	0.4	0	0.1	0.3	0	0.4	0.4	0	0.1	0.5
c__Gracilibacteria_OTU_93	0.2	0.2	0	0	0.6	0	0	1.4	6.4	0	0	0	0	0
Defluviicoccus	0	0	0	3.6	0.1	0.6	0.1	4	0.1	0	0	0.9	0.8	0.1
Trichococcus	0.4	0.8	0.3	0.1	0.6	0.5	0.5	1.1	1.2	0.4	0.2	0.9	0.8	0.3
QEDR3BF09	0.2	0	2.1	0	0.3	0	0.7	0.2	0.2	0.8	0.7	0.1	1.3	0.3
Subdoligranulum	0.4	0.7	0.3	0.2	0.6	0.1	0.4	0.8	0.7	0.5	0.3	1.3	0.4	0.4

Figure: Heatmap of the 25 most abundant genera in effluent from 14 WWTPs. The numbers represent the average relative read abundance in the effluent calculated as the average abundance over 8 weeks (week 43 – 51, 2014). Some OTUs could only be classified to family level. Red represents high values, white low.

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Operational strategies for mitigation of nitrous oxide emissions from a phase isolated full-scale WWTP

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Abstract

Nitrous oxide (N2O) is a strong greenhouse gas (GHG) and ozone depleter, with a warming potential 300 times higher than carbon dioxide (CO2). Anthropogenic N2O emissions accounts for 6% of the total GHG emissions and 1.2% of the total N2O emissions are believed to originate from the wastewater treatment (WWT) sector. Conventional biological nutrient removal processes relying on nitrification and denitrification are known to produce N2O. The Intergovernmental Panel on Climate Change (IPCC) recommends an N2O emission factor of 0.0032 kg N2O-N person-1 year-1 or 0.035% of the influent nitrogen to estimate the N2O emissions from domestic wastewater treatment plants (WWTP). However full-scale N2O measurement campaigns have revealed that emissions can range from 0.1-11.2% of the influent nitrogen load. A recent long-term study at Lynetten, Denmark's largest WWTP, which uses the phase isolated BioDeniphoTM process, revealed a N2O emission factor 17% times higher than the IPCC factor. Clearly, the IPCC emission factors can strongly underestimate true emissions. Several studies have highlighted the importance of continuous, long-term studies, to improve quantification of emissions and to gain a better understanding of the underlying processes and the seasonal effects in N2O dynamics.

N2O emissions can be quantified either by direct off-gas measurements or based on liquid phase measurements followed by mass transfer estimations. The objectives of this study were therefore to; i) determine liquid/gas mass transfer behaviors to facilitate N2O emission estimation based on liquid phase measurements, ii) quantify N2O emissions and estimate the contribution to the yearly CO2 footprint, iii) correlate N2O production and emissions to varying process conditions.

A one year long-term study of N2O production and emissions was therefore performed at Lynetten, Denmark's largest WWTP. The WWTP is configured with phase isolated activated sludge reactors for biological removal of COD, phosphorous and nitrogen. Nitrification and denitrification takes place by alternating process conditions as well as influent and effluent flows in 20 pairs of interconnected and surface aerated reactors (total volume:147.000 m3). Quantification of N2O emissions were performed through N2O measurements in one of the phase isolated reactors. Electrode and flux-chamber techniques in combination with an infrared off-gas analyser were used to determine both liquid and gaseous phase N2O concentrations, in order to estimate the spatially varying N2O liquid/gas mass transfer coefficients in the biological reactors.

Devoted mass transfer measurements resulted in an estimate of the spatially varying reactor mass transfer coefficient, which was used to calculate the N2O emissions from the continuous liquid phase N2O measurements. The long-term data revealed that the N2O emissions contribute to as much as 30% of the total CO2 footprint from the WWTP. Examination of the N2O dynamics showed that high ammonium concentrations and long aeration phases, in the activated sludge process, lead to high N2O production and emissions rates. Nitrification phases were identified to produce and emit most of the N2O at this wastewater treatment facility. High production and emissions were also associated with the afternoon loading peaks at the WWTP. During denitrification phases N2O was produced initially but consumed consequently.

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Microplastic removal in Danish wastewater treatment plants

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Abstract

Wastewater is an important source of microplastic. However, rather few studies exist on microplastic in raw and treated wastewater especially when it comes to small sizes. This presentation deals with a screening of 10 Danish wastewater treatment plants for microplastic removal efficiency. Together these plants manage 26% of all Danish wastewater, hence giving a good estimate of the overall removal efficiencies of modern wastewater treatment. The size range addressed was 10-500 µm and the identification technology was a state-of-the-art FT-IR imaging system applying a focal plane array (FPA). FT-IR imaging is internationally recognized as the most reliable method for identifying small microplastic particles.

Method: Raw wastewater was collected flow-proportionally and pre-sieved to remove particles >500 µm. Wastewater is a challenging matrix for analysing microplastic, which is further complicated by the small size range targeted. The sample preparation and analysis was hence extensive. For raw wastewater, 1 L of sample was pre-treated by wet-sieving on a 500 µm sieve. A sub-sample was treated with cellulase, upon which it was oxidised by adding hydrogen peroxide and a catalyst. The initial enzymatic breakdown of cellulose was required because cellulose fibres (from toilet paper) otherwise limit FT-IR analysis as they tended to coat the plastic particles. The oxidised samples were wet sieved into 80-500 µm and < 80 µm intervals. The particles were removed from the sieves and gathered into demineralised water by ultrasonic treatment and filtered separately through a 10 µm stainless steel mesh. Particles were then collected in ethanol. A sub-sample of the ethanol was transferred to a transmission window (for particles ≤ 80 µm) or a reflection window (for 80-500 µm particles). For treated wastewater, varying sample volumes were collected as the content of suspended matter differed much between treatment plants. Known amounts of wastewater were filtered on-site onto 10 µm stainless steel filters until they clog. Filters were then treated enzymatic and oxidative. The ethanol particle suspension was transferred to a transmission window to quantify small particles (< 80 µm) and a reflection slide to quantify larger particles (> 80 µm). A fraction of a window/slide was scanned to create a mosaic with 5.5 µm pixel resolution on the FPA. The spectra of all particles in a scan were analysed to quantify their chemical composition and determine whether they were of plastic, and if so, of which plastic material. The size and shape of plastic particles was recorded.

Figure: The FT-IR imaging machine (left). Microplastic particles concentrated in ethanol

Results: The overall removal efficiency of the treatment plants was high in terms of both mass and particle number. Details on this removal as well as the found polymer materials will be disclosed at the conference. Unfortunately detailed results cannot be included in this abstract as the results are part of a report commissioned by the Danish Environmental Protection Agency and just now awaits final approval by the Ministry of Environment and Food. The approval is expected before Christmas 2016.

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Changes in intermittent aeration regimes are effective tools to manage bio-granule size and microbial communities in partial nitritation-anammox SBRs.

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Abstract

The use of bio-granules in wastewater applications is becoming increasingly popular due to their favourable properties like high settling velocity or their resilience to mechanical and environmental stress (Adav et al. 2008). Bio-granules host complex microbial communities, as they display varying redox conditions on a microscopic scale (Khan et al. 2013). During the partial nitritation-anammox (PN/A) process, NH_4^+ is partly oxidized to NO_2^- by ammonium oxidizing bacteria (AOB) in the presence of oxygen. Anaerobic ammonia oxidizing bacteria (AMX) metabolize NO_2^- and NH_4^+ to N_2 gas. The simultaneous aerobic and anaerobic conversion of nitrogen-species is possible in bio-granules, as oxygen is present at the surface of the granules, whereas anaerobic conditions prevail in deeper layers. The scope of the study was to investigate a simple strategy to manage the ratio between AOB and AMX in bio-granules to affect the ratio between their metabolic pathways. Differences in process performance were monitored in terms of conversion and accumulation of different nitrogen species. A special emphasis was laid on N_2O emissions from the process.

Two lab-scale SBRs were operated under two different intermittent aeration regimes. One SBR was operated at a high aeration frequency with short aeration phases ($R_{f=15}$), the other was operated at a low aeration frequency with longer aeration phases ($R_{f=10}$). As the length of the aeration phases was 15 minutes and 22.5 minutes, respectively, both reactors received the same total oxygen load. In both reactors the NO_2^- production rate was larger during aeration phases, than the NO_2^- consumption rate, so that NO_2^- accumulated during aeration phases to ~1 mg NO_2^- ($R_{f=15}$) and ~4 mg NO_2^- ($R_{f=10}$), respectively . It was hypothesized that NO_2^- would penetrate deeper into the bio-granules in $R_{f=10}$ allowing for growth of AMX at greater depth to extend the diameter of the granules. As a result a larger average granule size was expected in $R_{f=10}$, than in $R_{f=15}$. Indeed, the average granule sizes of $R_{f=10}$ and $R_{f=15}$ were measured to ~400 μm and 200 μm, respectively. The difference in the average granule size in both reactors was expected to trigger a shift in the microbial community, as the fractionation of redox zones in the granules would differ. Larger granules were expected to host relatively more AMX, than AOB, which was confirmed by qPCR results. While overall process performance was similar between $R_{f=10}$ and $R_{f=15}$, the emission of N_2O was different in both reactors. Less N_2O was emitted by the smaller granules at short aeration phases, than by larger granules under longer aeration phases. However, when larger granules were exposed to short aeration phases, less N_2O was emitted than by smaller granules under the same conditions.

The study shows that the size of bio-granules in the system is likely limited by the availability of NO_2^- in the core of the granules. The length of aeration phases appears as an effective tool to address the substrate limitation and to actively manage the fractionation between microorganisms in the microbial community. It was shown that a change in microbial community composition had an effect on the process performance and N_2O emissions from the system. The result helps researchers and operators to engineer microbial communities for their purposes. The controlled engineering of microbial communities in bio-granules may help to manage process performance and lower N_2O emissions from PN/A processes.

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Efficient pharmaceutical removal from (hospital) wastewater by staged-moving bed biofilm reactors (MBBRs) followed by ozonation

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Abstract

Hospitals are widely considered as large contributors to point source pollution of pharmaceuticals due to their discharge in wastewater. However, there are no recommendations as to what technology to use or where the hospital wastewater treatment should be conducted (selected sidestreams, main stream or at the municipality). The MERMISS project developed and optimized a new technology concept where the biological removal was biofilm-based, namely the Moving Bed Biofilm Reactors (MBBR), where the biofilm attached to plastic carrier material. However, not all pharmaceuticals can be removed biologically and therefore an ozonation step has been included in the MERMISS technology concept. Different test sites were examined ant at different scale.

A lab scale set up was tested on a toxic sidestream from the dept. of Oncology and the served as a prove of concept (Casas et al., 2015 a,b). Superior biological removal was observed for selected medium biodegradable compounds and hardly degradable compounds compared to conventional activated sludge, as shown in figure 1a. Both MBBR and a mixture of activated sludge and MBBR (HYBAS) configuration was tested. Based on these promising results, a pilot scale plant was build and tested during 11 months exclusively fed on main stream of hospital wastewater. The plant functioned as a conventional wastewater treatment plant (removal of C, N and possibility of P) beside a significantly enhanced removal of pharmaceuticals (Tang et al., in prep). The staged-MBBR showed a remarkable potential to remove 23 out of the 25 pharmaceuticals up to at least 30%. The aerobic steps (M2, M3a,b, M5) showed the highest removal capacity, as shown in figure 1b. Also, the anoxic steps contributed to the overall degradation of the persistent pharmaceuticals in denitrifying MBBRs such as venlafaxine and trimethoprim (M2 and M4).
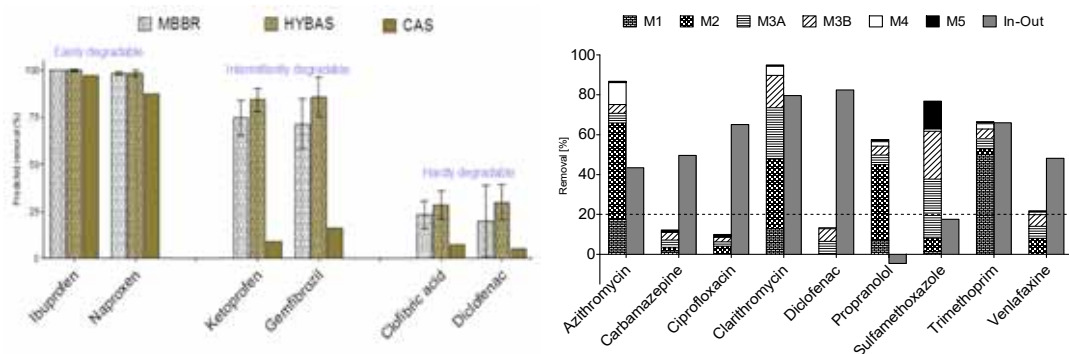

Figure: a) Removal percentage of pharmaceuticals in sidestream lab-scale experiment (left) and b) from main wastewater stream in pilot scale (right). M1-M5 refer to MBBR stage.

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Mònica Escolà Casas[1], Ravi Kumar Chhetri[2], Gordon Ooi[1], Kamilla M. S. Hansen[2], Klaus Litty[3], Magnus Christenson[4], Caroline Kragelund[3], Henrik R. Andersen[2] and Kai Bester[1*] (2015) Biodegradation of pharmaceuticals in hospital wastewater by a hybrid biofilm and activated sludge system (HYBAS). Science of the Total Environment (2015) 530-531, 383-392

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Microbial electrochemical technologies: an emerging alternative for wastewater treatment using constructed wetlands

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Abstract

Constructed Wetlands (CW) are biological engineering systems for the treatment of wastewaters widely used that are complex systems due to the interaction of physical, chemical and biological processes, that allow high removal efficiencies (Kadlec & Wallace, 2009). CW are characterized for being robust and cost-effective that require low operation and maintenance efforts but might require larger areas than conventional treatment systems. (Brix et al., 2007; Vymazal, 2007). Present CW wetland research and development aims at reducing the surface needs either by modifying the design such as fill and drain systems or by including technological improvements such as installing aeration systems to enhance the capacity of the systems. Exoelectrogens are microorganisms already present in wastewaters that are able to produce energy and transfer it. CW design has also benefitted from these microorganisms and new research has shown that Microbial Electrochemical Technologies (MET) is an alternative for improving their performance. The mechanism stimulates microorganism to generate and transfer electrons to an electro-conductive material that acts as an unlimited electron acceptor (Figure), maximizing substrate consumption (wastewaters), instead of leaving free electrons for methane generation and consequently to a decrease of microbial metabolism rates as in happens anaerobic system, due to the limited number of electron acceptors (Esteve-Núñez, 2015).
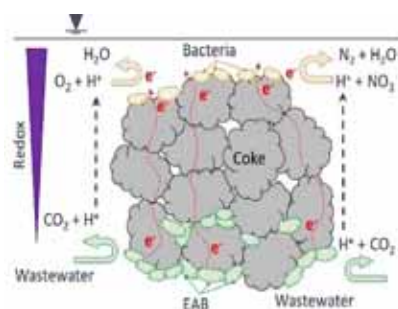
Figure: Conceptual model of MET processes in CW

Microbial Electrochemical-based Constructed Wetland (METland) concept has been tested for the removal of organic matter and nitrogen in horizontal subsurface flow biofilters filled with coke at laboratory scale and highly loaded. The systems showed removal rates as high as 97% COD, 96% for BOD_5, 97% for NH_4-N and 69% for TN (Aguirre-sierra et al., 2016), suggesting that METland system can enhance biodegradation rates, thus allowing the reduction of the area requirements.

A METland vertical flow mesocosm test to evaluate performance and removal rate kinetics of organic matter and nutrients has been established at Aarhus University. The set-up includes 16, Ø 160mm planted columns filled with coke as electron conductor to promote bioelectrogenesis reactions fed with sedimented wastewater. The systems has ran for over six months at different loading rates and has shown BOD_5 removals of up to 60 $gr.m^{-2}d^{-1}$ TN removal of 17 $gr.m^{-2}d^{-1}$, which if compared to traditional HFCW is around 10 times more effective. Additionally to the removal performance the columns are being investigated for electric potential production along the depth, the characterization of the microorganism population Fluorescense in situ Hybridization (FISH), DNA extraction and imaging of the surfaces of the tested material with Scanning Electron Microscopy (SEM) and CLPP.

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Bacteriological reduction of faecal contaminated lake water by a combination of electrochemical and filtering technology for emergency treatment of flooding water

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Abstract

Over 1/3 of the world population has temporary or permanent restrictions on access to clean drinking water. Clean drinking water resources can be limited, for example due to lack of wastewater treatment, poor sanitation, diffuse or point pollution, or in situations where the drinking water supply breaks down. Drinking water supply insufficiency can occur for example by leakage, unknown source of pollution or flooding. The solution to these limitations, both to economize and protect drinking water resources is to clean low quality water to drinking water quality in a cost effective manner. A mobile and inexpensive system based on electrochemical and filtering technology was constructed with the possibility to be installed where the need arises, e.g. in flooding situation where access to clean drinking water is often lacking. The aim of this study was to test the efficiency of this technology to reduce chemical and bacterial contaminants in faecal contaminated lake water.

The combined system included an iron-based flocculation unit to precipitate metal ions, phosphate, dissolved organic matter and certain organic contaminants, a flexible polymer filter to remove particles of 1µm -2 mm, e.g. algae, organic particles and colloids, and an electrolytic disinfection unit capable of generating active chlorine from chloride in the lake water, and to degrade certain organic contaminants. Lake water was spiked with 1 L and 10 L pig slurry to a final concentration of 0.1 ‰ and 1 ‰, respectively. Microbiological analyses parameters were selected and analyzed according standard methods and guidelines.

The result showed a concentration of 2.5×10^6 to 1.0×10^7 total viable bacteria per ml in lake water added slurry. Concentrations of the fecal indicator organisms *E. coli* and *Enterococcus* spp. as well as coliform bacteria were ranged from 2.4×10^6 to 1.4×10^7 CFU/100 ml in lake water with 0.1‰ slurry and 10 times higher in lake water with 1‰ slurry. After passage of the polymer filter, a 50% reduction in the particle concentration was observed while the bacterial concentration was unchanged. The electrochemical unit was capable of reducing fecal bacterial indicators with an approximately 8 log-units thereby fulfilling the requirement of drinking water legislation. The electrochemical unit reduced the concentration of total viable bacteria with 5 log-units but total viable bacteria were still detectable at in the concentration range of 4 CFU/ml to 1×10^2 CFU/ml. The identity of this bacterial population needs further characterization to reveal possible bacterial genus/species that showed increased resistance to chlorine treatment. The concentration of dissolved organic matter, heavy metal ions and phosphate was removed at variable extents. As the treated water appeared cloudy with a slightly yellowish ferrous color, improvement of the esthetical appearance of the produced drinking water is needed, e.g. increase of particle removal and flocculation adjustment.
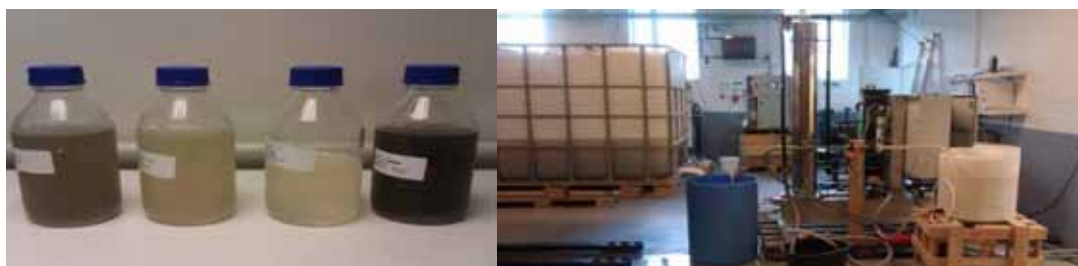
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Possibilities for reuse of calcium carbonate pellets from drinking water softening

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Abstract

Within the last decade the interest for central drinking water softening has increased in Denmark. The Copenhagen area utility HOFOR will implement central drinking water softening using the pellet technology starting in 2017, and other utilities are investigating the possibilities for softening or are planning to implement softening as well. Although it is generally agreed that central softening is associated with both socio-economic and environmental benefits, the softening process produces the by-product calcium carbonate pellets. If no reuse applications are identified, the expected annual pellet production of 14,000 t risks ending as a waste product which reduces the overall sustainability and economic feasibility of the softening process.

Potential reuse applications were identified through literature and a study trip to the Netherlands where pellet softening has been implemented since the 1970s and where solutions for pellet reuse already exist. The study shows that there are a number of potential reuses for pellets in Denmark including glass production, supplement to chicken feed, soil pH adjustment in agriculture and reuse in the softening process itself as seeding material.

In order for a reuse application to be technically feasible, the pellet quality must meet the demands from the industry in terms of e.g. chemical composition and color. 13 different pellet samples from Danish pilot-scale experiments have been analyzed in order to investigate the expected pellet quality from full scale softening. As a part of the project 'Future Water City' headed by VCS Denmark, their chemical composition has been analyzed in order to quantify the concentration of impurities such as iron and heavy metals. The results show that the chemical composition of pellets is highly dependent on the influent water quality and where in the waterworks treatment train softening is implemented. In addition to the previous analyses, the reactivity (i.e. the rate of dissolution) has been determined using the Sauerbeck & Rietz method, the specific surface area has been quantified and the mineralogy has been determined using Powder X-Ray Diffraction. The results show that the pellets all have very limited porosity resulting in a low specific surface area, < DL - 0.317 m^2/g, and reactivity, 7.39 - 25.7 %. The reactivity is low compared to commercial limestone products where it typically exceeds 70 %. This is a barrier for reuse in e.g. agriculture, which has been the main focus in Denmark as of yet.

This presentation will focus on possible reuse applications for calcium carbonate pellets, which pellet characteristics are important to consider, and how the quality of pellets can be optimized by integrating by-product reuse into the design of the softening process.

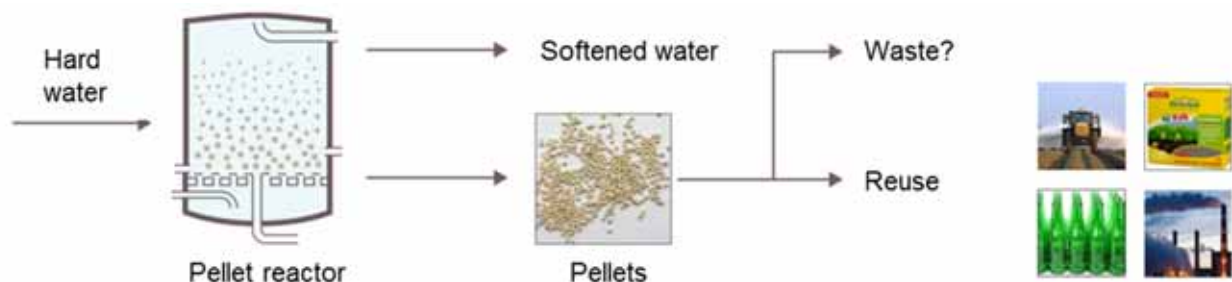**Figure:** Pellets are the main byproduct from central drinking water softening and will end as a waste stream if no reuse applications are identified.

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Exploring economic greywater treatment technology and possible high reuse

B. Prajapati*, N. O. G. Jørgensen, P. E. R. Bjerager, N. Bender Petersen & M. B. Jensen; University of Copenhagen

Abstract

Water recycling is a global topic. Water scarcity, both physical (scarcity due to no water availability) and economical (scarcity due to lack to finance) has forced humans to develop solutions that consume less fresh water. In spite of diminishing freshwater reserves and increased water consumptions, practice of reusing wastewater is not widespread due to users' attitude on recycled water and lack of reliable technology. This is also the case for reuse of greywater, despite the fact that it is produced on a regular daily basis. Apart from simple reuse of greywater for irrigation or toilet flush, this water source is not exploited to any significant extent. Quite a number of technologies for upgrading of greywater for upgrade reuse have flourished, but most of them are at pilot level only.

This research aim at developing an economic, eco-friendly greywater treatment plant that can be operated without trained human resources and is suitable for implementation at household level for upgrading purposes. A modified sequencing batch reactor concept was adapted to the principles in Dual Porous Filtration (DPF) technology. The gravity driven technology is based on sedimentation in combination with passively aerated biofilm for biological oxidation of organic matter.

The new technology was tested on greywater from a public bath in Copenhagen at a treatment rate of 1.5 m3 per day. Despite large variation in greywater pollutant load and production rate in a day, the treated greywater was clear and without smell. Both physical-chemical pollution parameters and biological parameters were significantly reduced, and stable outflow quality levels were obtained despite variations in inflow for most parameters. In combination with UV or ozonation the technology can show promising potential. By promoting the technology to relevant water scarce areas, the research could contribute to reduce the amount of freshwater diverted from sensitive ecosystems, reduce the amount of wastewater and the pollution it carries discharged to water ways.

Figure: Clarity of greywater from inlet to outlet of each box

Figure: Greywater treatment plant tower

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Converting wastewater into fertilizing irrigation

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Abstract

Fresh water is becoming a rare resource in many regions on earth. The Danish island called Samsø is a front-runner when it comes to establishing closed loops of all biological resources on the island, including water and the nutrients in wastewater. Fresh ground water for irrigation is a scarce resource on an island surrounded by seawater. Therefore, controlling the water circuits and utilizing the resources the water contains is crucial for creating a thriving circular bio-economy.

A consortium consisting of the local wastewater company on Samsø, water-tech companies and science institutions has embarked on developing and testing technical solutions for turning wastewater into fertilizing irrigation water for the energy crop production on the island. That will become the basis for biogas production for the island's ferry (project "Vandingssymbiosen" – local reuse of water for field irrigation, funded by the Danish Nature Agency – MUDP project).

The aim of the project is to develop and test wastewater treatment systems, which keep the nutrients nitrogen and phosphorus in the treated water during the summer growth phase, whereas those nutrients are eliminated from the water during the winter season. However, municipal wastewater also contains micro pollutants, which have to be removed to obtain a high water quality for irrigation of crops. Different treatment concepts for micro-pollutant removal have been published and their efficiency has been investigated.

With traditional sewage treatment methods it is difficult to achieve good removal of organic matter and micropollutants without nitrifying ammonia in the water. Ammonia is desired in irrigation water, as it is a better nitrogen source for plants than nitrate. A selection of technologies are applied for wastewater treatment (MBR – membrane bioreactor, SBR – sequencing batch reactor and SBBR – sequencing batch biofilm reactor) in semi-technical scale at Danish Technological Institute, using modified OECD-wastewater with addition of xenobiotics and heavy metals in typical concentrations found in municipal wastewater treatment plants. Different treatment concepts for additional removal of e.g. micro-pollutants are tested (iron-coated sand filter and reed bed). The technologies are evaluated based on removal rates using conventional parameters such as COD, T-N, NH_4-N and T-P, but also reduction of micro-pollutants are of importance. The preliminary results show that MBR has a high removal rate for COD and retains most nutrients in the effluent in the summer scenario.
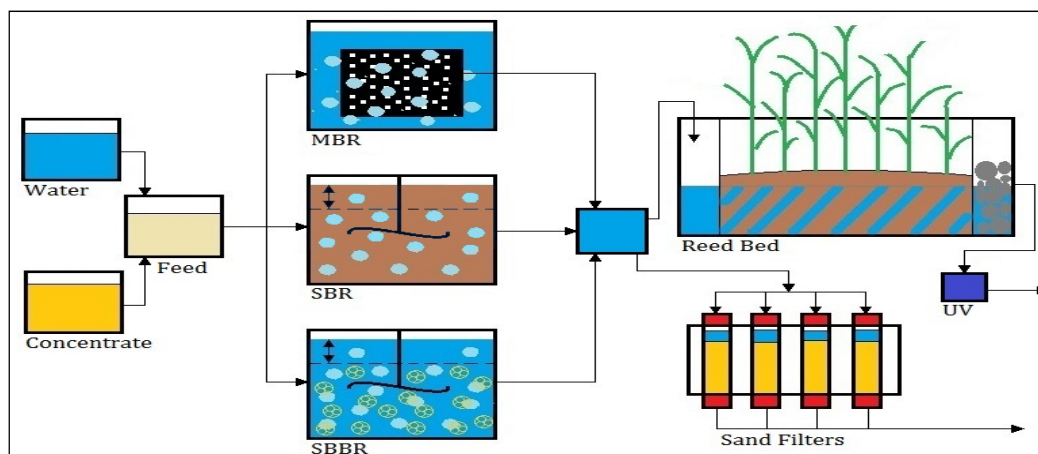
Figure: Experimental set-up for water treatment at Danish Technological Institute.

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Increasing nitrification in biological rapid sand filters: Diagnosing and supplementing micronutrients needed for proper filter performance

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Abstract

In Denmark, drinking water is treated with biological rapid sand filters which are generally designed to treat groundwater for iron, manganese, and ammonium. Although this treatment technology has been widely used for decades, problems with ammonium removal can still persist in some water works. Nitrification is a biological process that oxidizes ammonium to nitrate and is responsible for ammonium removal in these filters. Because it is a biological process, carbon, nitrogen, phosphorus and other micronutrients, such as copper, are required. Recent research has shown that supplementing certain nutrients in full scale filters can substantially increase nitrification. Increasing nitrification is needed in filters that are unable to meet ammonium guideline values for drinking water. This can also be used to optimize filter performance by increasing water treatment capacity. One large obstacle in supplementing nutrients to filters is in determining if reduced nitrification of poorly performing filters is caused by a lack of nutrients. Therefore, there is a substantial need to accurately diagnose nutrient limitations in these filters to avoid the expense and time of dosing filters unnecessarily, and to overcome regulatory hurdles.

To determine nutrient limitations, full scale nitrification rates were determined and flow-through columns and batch assays were developed. Many different parameters were examined in the flow through columns and batch assays. A batch assay was developed that could accurately measure the nitrification rates found in full scale filters (Fig. 1). A trend of low ammonium removal rates was observed in filters having trouble with nitrification especially compared to properly performing filters (Fig. 1B). Rates were consistently much higher in properly functioning filters, which was also observed in both batch assays and flow through columns. These results have shown promise in determining nutrient limitations in problematic filters and could be useful in the future in determining if nitrification can be increased by supplementing nutrients.
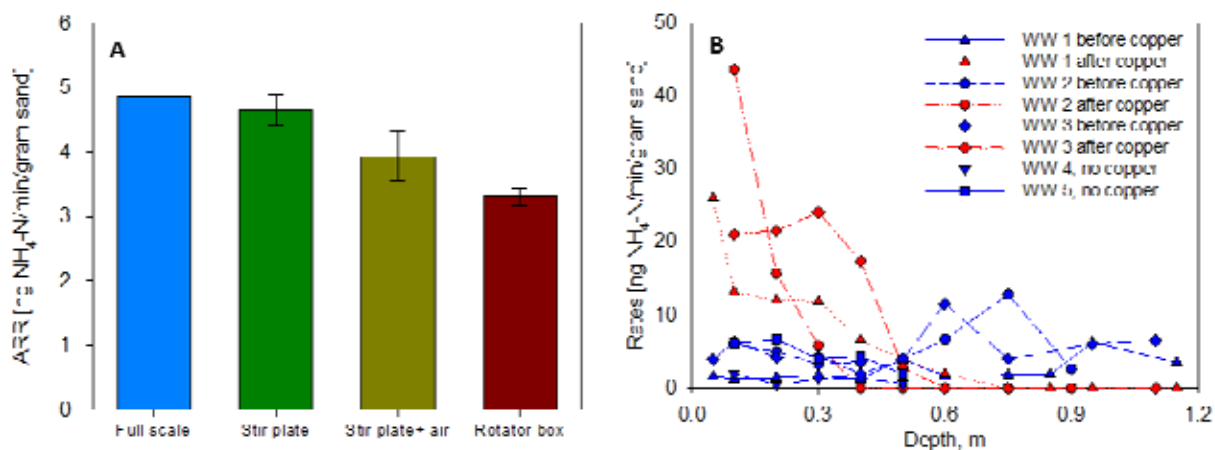
Figure: (A) Ammonium removal rates (ARR) measured in a full scale filter and with different batch assay configurations. (B) ARR with depth at different water works (WW) after copper addition, red, and with no copper addition, blue.

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The Trojan Horse - A new biotechnology for pesticide removal at drinking water sand filters

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Abstract

Rapid sand filtration is a widespread technology used to produce drinking water from groundwater in Denmark, EU and worldwide. In Denmark alone, more than 2.200 waterworks process groundwater into drinking water by rapid sand filtration (RSF), efficiently removing the natural pollutants (NH_4, Mn, Fe etc.) by a combination of chemical and biological (microbial) processes. Unfortunately, over the past few decades pesticides have appeared in groundwater as a direct result of intensive use of pesticides since 1950. The pesticide-pollutants in groundwater passing through RSF seriously challenge the future stable supply of clean and safe drinking water to consumers. The existence of natural microorganisms having the ability to degrade pesticides suggests that RSFs, containing over a billion bacterial cells per gram sand, represents a large microbial metabolic potential.

The Trojan Horse project aims to develop a novel biotechnological solution that will deal with pesticide in drinking water at rapid sand filters, via a direct improvement of the metabolic capabilities of existing natural microbial communities in sand filters. The Trojan Horse Concept is based on natural pesticide-degrading microbes carrying naturally occurring mobile genetic elements with pesticide degrading genes (MGE(P)). The Trojan Horse concept introduces bacterial isolates carrying pesticide degrading genes on a MGE(P) to RSFs, where after MGE(P) are delivered to the native bacteria on the sand. Sand from 10 Danish waterworks experiencing pesticides in groundwater was used in order to isolate pesticide-degrading microbes via traditional – and novel enriching methods. Microbial RSF communities were in the microcosms experiments tested for their ability to receive-, express- and maintain specific-labelled MGEs.
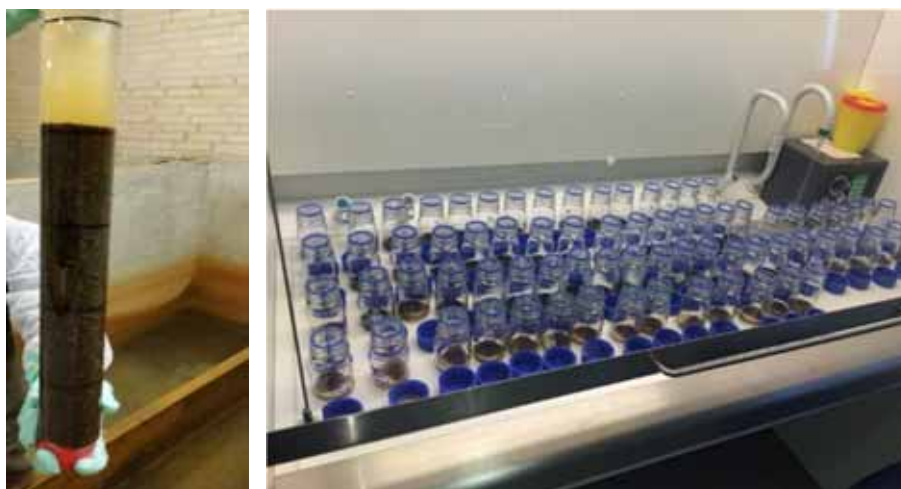
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A need for standardization in drinking water analysis – an investigation of DNA extraction procedure, primer choice and detection limit of 16S rRNA amplicon sequencing

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Abstract

Today 16S rRNA amplicon sequencing is a widely utilized technique for analyzing the bacterial community structure in drinking water. Concurrently with the prevalence of this method, the biases associated with 16S rRNA amplicon sequencing have been well-documented. However, no comprehensive attempts have been made to illuminate the effects specifically related to bacterial communities in drinking water. In this study, we investigated the impact of the DNA extraction and primer choice on the observed community structure, and we also estimated the detection limit of the 16S rRNA amplicon sequencing. The PowerWater DNA Isolation Kit resulted in significantly higher amounts of isolated DNA compared to the FastDNA SPIN Kit for Soil. Furthermore, extraction with the PowerWater kit lead to detection of a significantly higher number of OTUs. Likewise, the primer experiment revealed great discrepancies in OTU abundances between primers targeting the V1-3, V3-4 and V4 region of the 16S rRNA gene. Some of the primers proved unable to detect entire phyla. Estimations of the detection limit were based on bacteria free water samples (~1 L) spiked with *E. coli* cells in different concentrations [$10^1 – 10^6$ cells/mL]. *E. coli* could be detected in all samples. However, samples with 10^1 cells/mL had several contaminating OTUs, constituting approximately 8% of the read abundances. For 16S rRNA gene analysis in drinking water samples, we recommend using the PowerWater DNA Isolation Kit for DNA extraction in combination with PCR-amplification of the V3-4 region.
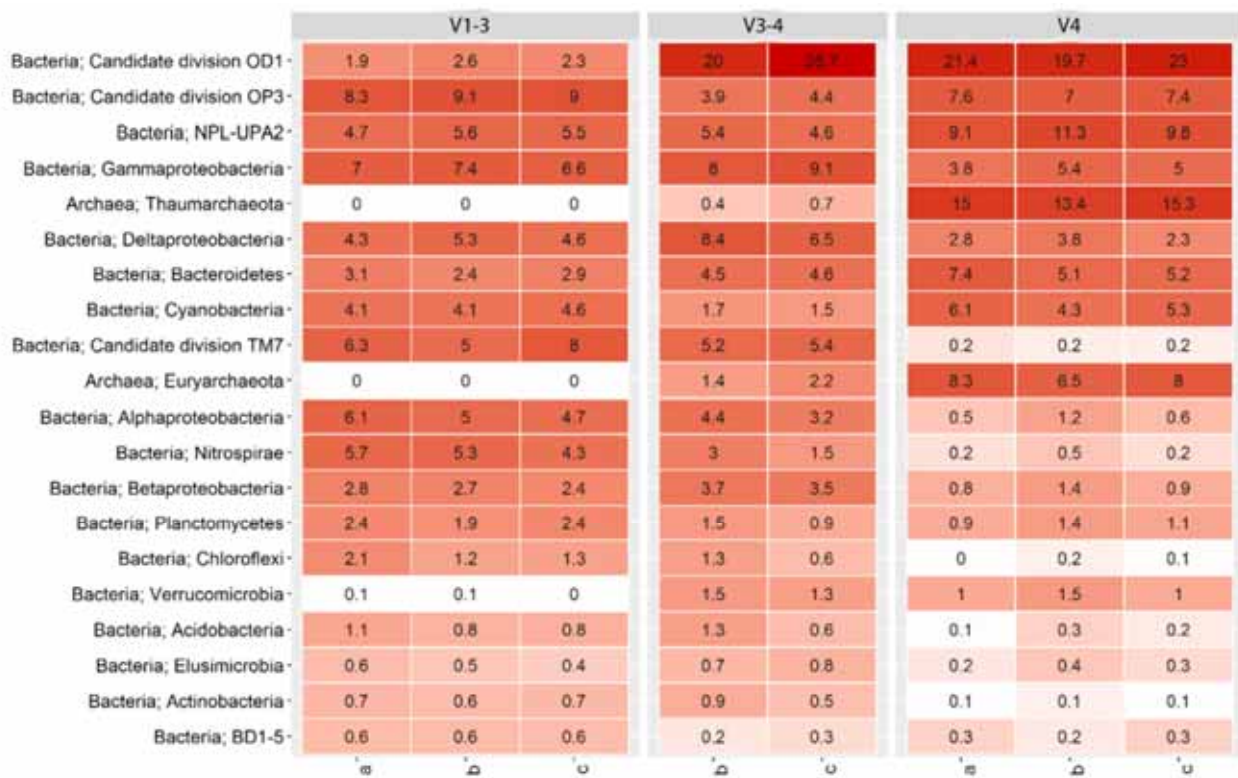
Figure: Heatmap of the primer test. The y-axis ranks the top 20 most abundant phyla across the samples, and each phylum is assigned with its kingdom. The columns along the x-axis represent each sample grouped by variable region targeted and denoted as replicate a, b or c. The numbers state the relative read abundance in percent.

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Storm water screening

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Abstract

Climate changes cause severe problems worldwide due to more frequent rain storms. Fortunately, several highly sophisticated models are available to model the floods and estimate the impacts. However, much information is required to run them so they become immense and time consuming to handle. Also, it is extremely computer demanding to process new generation of high-resolution elevation models if an application is based on raster tools, only. The consequences are that only a minority have such systems available. Especially, in schools of higher education only very few hydrogeologic departments have such setups causing other planners like geographers, landscape architects and surveyors never to get introduced to overall basic hydrologic modeling in practice. If merely a basic screening application could be available providing the bigger overview of rain storm impacts, more planners could enter the discussions when new site developments are considered and judge whether a location has obvious flood potentials or not.

An attempt to build a simple screening application modelling Horton flow conditions has been developed by combining the raster, vector and geometric network GIS data models. Assuming no soil infiltration is, of course, a rough generalization of the real world conditions. However, when rain intensities are very high and the sewer systems (if present) get out of control, almost all precipitation is turned into overland flow, anyway.

The initial screening steps are, still, based on basic raster tools to detect local landscape sinks, their capacities and local catchments within an overall drainage basin. Next, the sinks' pour points are located, converted to points and assigned the values for the sinks' capacities and the volumes entering the sinks from the local catchments during a rainstorm. Also, all streams carrying the downstream spillover are identified and converted to polylines. In a third step a geometric network is established from the pour points as junctions and the spillover streams as edges. In a fourth step a custom tracing tool is executed to calculate the nested spillover from sink to sink based on weights assigned to the network. Finally, the results for the accumulated flow and the volumes in the sinks after a specific rain event are visualized.

Currently, a terrain model is the only input. However, a buildings feature class may be added revealing if any house is located critically in a sink or along major water corridors. So far the method has been used to screen the Danish 0.4 m terrain model, but lower-resolution models have been processed successfully, too. The workflow will be shared as a resource for ArcGIS Desktop and Pro users in 2017, and the Danish Agency for Data Supply and Efficiency (SDFE) is currently sponsoring a conversion of all models into open source Python-plugins for QGIS.

The presentation will demonstrate the setup and discuss the cons and pros of using such simplified non-dynamic models vs. dynamic raster models in storm water impact assessments.
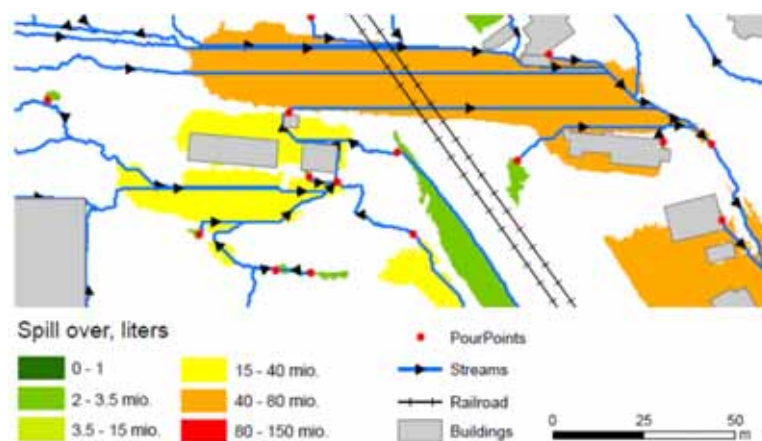
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GIS based urban surface runoff sub-model generation method

G. Zhao; T. Balstrøm; M. B. Jensen; all University of Copenhagen*

Abstract

Over the dramatically expansion of urbanization and population booming, the highly densified city is at great flood risk, especially under the circumstances of global warming. In cloudburst situation where huge run-off volumes are generated quickly, spill-over from the blue spots on higher elevations increase flooding vulnerability to the low lying urban spaces. To get a better understanding of the flooding hazard from upstream in urban, a network model needs to be organized to clarify this hydro-connectivity relation for surface runoff. In the research, a GIS based surface runoff sub-model generation method is proposed, constructing the different hydrological runoff network sub-model based on the high resolution DEM with specific customized modelling objectives.

The method is composed of a GIS and a SWMM component. For the GIS part, the main goal is aiming at achieving the screening and simplification of input data for SWMM through sub-model generation and blue spots classification. Additionally, all the input data are collected and assembled based on the hydrological distributed data model derived from the DEM. For the SWMM part, the main attempt is to realize the hydrodynamic quantification in each blue spot. Both 1D and 2D flooding representation approach are proposed to give different extents of detailed descriptions for water level variations inside the blue spots and water diffusion throughout the entire network.

Currently, the model is divided into 8 sub-modules. Three of them are adapted from the hydrologic screening method created by Thomas Balstrøm. Initially, it identifies the blue spots at the drainage basin level. Secondly, it locates the pour point inside each unit. Thirdly, it screens the blue spots according to a classification method. Fourthly, it dissolves the local watersheds and aggregates minor blue spots. Fifthly, a geometric network is generated with pour points and stream features. Sixthly, it identifies the urban flooding objects. Seventhly, it creates the sub-model by using customized trace tool. Finally, it aggregates and assembles the information based on a sub-model, then imports all the information into SWMM engine to expose the hydrodynamics in 1D and 2D.

This study shows a unique GIS approach to describe the urban overland runoff in an innovative way. Compared with traditional modelling, it prioritizes the surface runoff instead of pipe flow in cloudburst scenarios. Secondly, with maximum reservation of the DEMs accuracy at the basin level, the GIS screening method was used for many times to simplify the input data into a data load which SWMM is easily capable of. This suggests a high resolution modelling approach with power of simplification. Besides, the distributed data model creates a feasible data schema to subdivide the landscape information under basin from hydrology perceptions enabling it to fit into real hydrology conditions.

Urban heterogeneity is also integrated in the distributed model opening a gate to even wider coverage of hydro-modelling related datasets to be involved. Furthermore, unlike a 'one for all'- modelling strategy, the customized sub-model generation method makes it possible to produce diverse individual stormwater model depending on different customized target rainfall events and flooding objects. It provides a feasible modelling approach to adapt dynamic world. Also, multiple hydrology scale analysis was applied in the model. All the sub-models generated from the whole drainage basin is not only providing a trustworthy boundary for hydrology modelling but also achieve the hydrology downscale conversion, reaching a comprehensive flooding prevention understanding based on basin view. Automatic procedure in a GIS module with little manual inputs will reduce massive workloads for input hydraulic model.

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Dual porosity filtration (DPF) for treating an industrial effluent

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Abstract

Dual porosity filters are made up of stacks through which contaminated water flows and is purified while moving towards the end of the modules. Sedimentation occurs effectively, and if the layers are covered with a sorbent, adsorption may take place as well. According to the first proof of concept [1], the process is highly remarkable in terms of removing suspended solids and reducing Zn, Cu, Pb, Cr and P. Further advantages of the system are the simplicity of design and the capability of being self-operated. Additionally, since a large portion of DPF plant is installed underground, the footprint is miniature as compared to the conventional treatment plants. This feature is also of value with respect to aesthetic aspects of the used landscape. Today's commercial DPF units are manufactured in box forms and the cheapness of their fabrication is an eye-catching quality too.

While DPF has been initially developed for treatment of road runoff, the technology holds the potential of treating other types of wastewater. At heating plants, the thermal energy in the hot flue gas is often recovered from chimneys. As a result, the exhaust gases cool down and eventually liquefy. The liquid is called condensate and contains a high concentration of suspended solid (SS) and dissolved cadmium (Cd), a toxic heavy metal. The limit for Cd concentration prior to discharging to public sewer is typically 3 µg/L, which is difficult to meet by applying currently practiced processes such as sedimentation-membrane filtration and filtration through wood shavings. As DPF is robust in retaining both insoluble and soluble matter, the technology has been contemplated as an approach that may be able to control the Cd level by first removing the fine suspended solids, and then targeting the dissolved Cd. However, the SS covers the adsorbent materials and curtails adsorption. The present study is part of a project known as ReKoBi. Financed by the MUDP program, it aims to develop a system in which an initial DPF without sorbent is allocated for sedimentation and then an adsorption unit is incorporated; either as a DPF-box with sorbent or a separately added part.

There is a host of substances that could be used for sorption of cadmium from aqueous solutions under various conditions. Nevertheless, not all potential sorbents are appropriate for the described system because DPF is to be deployed in a cost-effective manner for long time. To put it in a nutshell, a few parameters have been considered for selecting proper materials; they include durability, availability, adsorption capacity, density and price. A literature survey has been conducted and based on the aforementioned criteria, following sorbents have been selected: sawdust, peat, eelgrass, limestone, olivine and lignite. Prior to employing the chosen items, their sorption properties for cadmium has to be known for the specific conditions of the proposed hybrid system. Therefore, adsorption experiments are in the pipeline to determine adsorption capacity, kinetics, isotherms and some other characteristics.

[1]: Jensen, M. B., Cederkvist, K., Bjerager P.E.R., and Holm P.E., 2011. Dual Porosity Filtration for treatment of stormwater runoff: first proof of concept from Copenhagen pilot plant. Water Sci. Technol. 67.4, 1547-1557.

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Improved input data and minimize uncertainties when designing SuDs solutions in urban development areas

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Abstract

Inhomogeneity of the topsoil often exceeds what can be verified by boreholes. Non-invasive geophysical investigations can efficiently increase our knowledge about the topsoil inhomogeneities and thereby minimize structural uncertainties in near surface hydraulic modelling.

High resolution geophysical multi coil Ground Conductivity Meter DualEM421 investigations have shown to be a successful tool for detailed mapping of the soil conductivity within the upper 5-7 m. Combined with shallow boreholes, hydraulic head measurement and simple infiltration tests, detailed description of the hydrogeological conditions of the near surface groundwater is obtained. Surveys can be scaled according to size of the area and needs for resolution.

Experiences show a strong relation between electrical conductivity measured with DualEM421 and geological conditions which again has shown to be strongly related to hydraulic conductivity obtained by infiltration test e.g. double-ring infiltrometer test. Site specific relation leads to significant improvement of data input for near surface 3D-geological and hydraulic modelling, and thereby optimizes the assessment of hydraulic consequences for specific SuDS and aquifer recharges solutions.

SuDS solutions for handling rainwater are often a necessity and an integrated part in the development of urban and suburban areas. Knowledge of the spatial distribution of high permeable sand layers and less permeable clay layers is crucial when pointing out the optimum location for artificial infiltration.

A concept of combining high resolution geophysics, boreholes and infiltrations tests is showcased by an executed project in an urban area in Aarhus. The project is a part of the Healthy Park Activities Rehabilitation and Climate project SPARK, which has the purpose of improving physical rehabilitation combined with climate adaptation. If possible rainwater within MarselisborgCentret and adjacent neighbourhood will be handled within the area, replacing present drainage through the sewage system. The combined survey significantly improved valuable knowledge employed in the planning of operational SuDs solution within the area.

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Plant toxins as groundwater contaminants - do we need to care?

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Abstract

Plants produce a large variety of bioactive natural compounds which may serve as "chemical weapons" to protect the plants against competitors, pests and diseases. Some are well known as food toxins, e.g. cyanogenic glucosides in cassava or sorghum, solanin and chaconin in potato, and lectins in beans. Also animals browsing on toxin producing plants can be severely intoxicated by e.g. pyrrolizidine alkaloids from ragworts and groundsels, ptaquiloside from Bracken, and cytisin from laburnum species. But can these plant toxins act as environmental pollutants in water reservoirs and eventually present a threat to the quality of drinking water? This presentation will provide examples of known common plant toxins, their sources, production and environmental fate, and it will identify and discuss the parameters most critical to exposure assessment for plant toxins.

Both crops and wild plants produce toxins often in amounts of up to kilograms per hectar. These are released from plant to soil via wash-off, or from roots and plant litter, thereby presenting continuous non-point sources. The highly water soluble toxins are readily leached to drains and groundwater. The rate of transfer of the toxin from plant to soil, the rates of abiotic and microbial degradation process along the path from source to recipient, and timing of events with climate are critical factors for the final toxin concentrations in water reservoirs.

Plant toxins comprise a wide range of chemical properties ranging from volatile low molecular weight compounds to high-molecular weight proteins. Within this group, low-molecular weight glycosides are of special interest due to their high aqueous solubility. Three examples of potentially problematic pollution sources from plants are given: Cyanogenic glucosides from clover, glucosinolates from rape, and ptaquiloside from bracken fern. All are glucosides, but while the first two groups of compounds are toxic due to their primary degradation products (hydrogencyanide and isothiocyanates), ptaquiloside is the direct toxin (carcinogen) after activation. While groundwater monitoring data for natural toxins are generally lacking, first measurements for ptaquiloside demonstrate its presence, with stabilities in groundwater of up to 6 months. Perspectives are made with respect to future monitoring, modelling and risk assessment of natural toxins as groundwater pollutants.

The potential impact of plant toxins on drinking water quality will be investigated in a new M. Curie ITN project (NaToxAq) during coming years where15 PhD students will be working with chemical analysis, distribution, fate, modelling and remediation of natural toxins in surface and groundwater within agricultural and forested catchments (www.natoxaq.eu).

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Towards impact based monitoring of estrogenic endocrine disrupting chemicals (eEDC). eEDC sources and behaviour in the Zenne river, Brussels

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Abstract

There is an increasing awareness regarding the exposure to endocrine disrupting chemicals (EDC) in water resources. Evidence of the high biological activity of EDCs resulted in some EDCs with pharmaceutical use and of emerging concern to be included in the Watch List (2013/39/EU) of the European Water Framework Directive (WFD) where EU member states are urged to monitor these substanstances. Current deterministic water quality modelling methods are not sufficient to calculate the transport of estrogenic endocrine disrupting chemicals (eEDC) concentrations in a river. This is because eEDCs are present in very low concentrations and are very costly to analyse, its present and acts in a mixture of chemicals and little are understood regarding the interactions and transformation processes between eEDCs and its environment.

During this study, eEDC activity and its transport along the Zenne river in Brussels was investigated. The estrogenic equivalent concentrations (BEQ) were determined with Estrogen responsive elements - Chemical Activated Luciferase Gene Expression (ERE-CALUX) analysis at four samplings sites in the Zenne river. The samples were collected over a period of one year. Samples were also collected at a hospital wastewater outlet and at the inlet and outlets of the wastewater treatment plants which discharges into the Zenner river. A water mass budget and BEQ load budget was calculated by using the sampling sites as flux boxes boundaries in the study area of the Zenne River.

BEQ measured along the Zenne River were comparable to ranges measured in literature and were higher than EQS (environmental quality standard) standards for EE2 (17α-ethynylestradiol) and E2 (17β-estradiol). 4 Sampling events that met the eligibility criteria (<25% error in water fluxes due to uncertainty, spatial variation in rainfall, CSO events…) were selected for BEQ load calculations. Although the waste water treatment plants removed 93-98% of the BEQ received at the inlet, it was still identified as the major eEDC contributors to Zenne River. 9-57% of the total BEQ load could be attributed to the contribution of wastewater treatment works. A clear upstream (Z3) – downstream (Z11) gradient of the BEQ loads were visible.

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Microplastic particles in sediments of Lagoon of Venice, Italy: first observations on occurrence, spatial patterns and identification

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Abstract

In order to improve knowledge of the identification, distribution and abundances of small microplastics (SMPs ≤ 1mm) in the coastal area of the Mediterranean region, a monitoring survey (2012) was carried out in a transitional environment along the north-eastern Italian coasts, the Lagoon of Venice (Vianello et al., 2013). SMPs were evaluated in sediments collected from 10 sites chosen in shallow areas variously affected by natural conditions and anthropogenic influences (landward stations influenced by freshwater inputs, seaward areas near sea inlets, and sites influenced by the presence of aquaculture farms, industry and city centers). SMPs, extracted from bulk sediments by flotation and filtered on GF-F fiberglass filters, were counted and identified by Fourier-Transform Infrared Micro-spectroscopy (μFT-IR), using a semi-automatic surface chemical mapping of 12 sub-areas of the filter surface. The identification of the acquired spectra was performed using both peak to peak identification and references infrared library database to assess potential MP contamination. SMPs were recovered from all samples. This fact emphasizes their extensive distribution throughout the Lagoon. Total abundances ranged from 672 to 2175 SMPs kg^{-1} d.w., and the higher concentration was generally observed in landward sites, usually affected by less hydrodynamics. The most abundant, among the ten polymer types identified (accounting for more than 82% of total identified MPs) were, despite their original buoyancy, polyethylene (PE) and polypropylene (PP), suggesting these particles were heavily weathered, probably changing in density. The most frequent size (93% of MP) was in the range 30-500 μm. Total SMPPs values were significantly correlated with the finer sediment fraction.
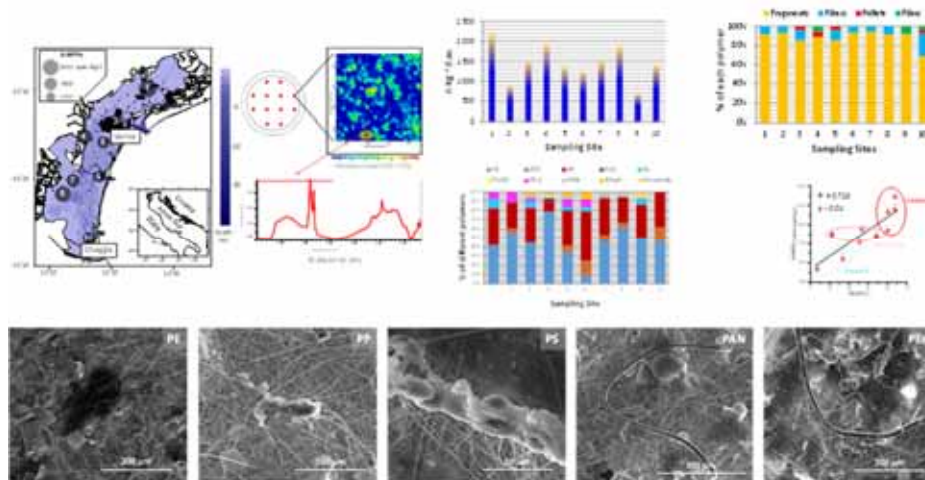
Figure. Sampling sites, μFT-IR map, MPs abundance, % of polymers, shapes, correlation MP - %Mud, MPs SEM images.

Vianello, A., Boldrin, A., Guerriero, P., Moschino, V., Rella, R., Sturaro, A., & Da Ros, L. (2013). Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification. Estuarine, Coastal. *Estuarine, Coastal and Shelf Science*, *130*(0272–7714), 54–61. https://doi.org/http://dx.doi.org/10.1016/j.ecss.2013.03.022

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The Europe - China Water Innovation Balance – Findings from the PIANO project's mapping exercise

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Abstract

The objective of the EU funded **PIANO Project (Policies, Innovations and Networks for enhancing Opportunities for China Europe Water Cooperation)**, is to identify opportunities for the joint EU - Chinese development of technological solutions in the water area. A core analysis in the PIANO project has been the identification and prioritization of European technological water innovations (TWI) that have potential for application in China. We present in this paper some of the core analysis undertaken in PIANO work package 2 (WP2) consisting of an extensive mapping, classification, scoring, categorization and ranking of European as well as Chinese Technological Water Innovations (TWI) with the purpose of identifying and comparing innovative water technologies in both regions. The methodology used has been an expert 'Delphi survey' in both Europe and China, but with most analysis taking place in Europe [1].

The analysis has been carried out within five core water domains and has resulted in a gross list of European and Chinese TWIs within each of these. A succeeding scoring has resulted in an Inventory I containing up to 20 European TWIs per domain, and a targeted Inventory II containing up to 10 European TWIs per domain, belonging to the core category 'innovative TWIs available in Europe but not China'.

The focus in this paper is to provide some first analysis on the Europe - China water innovation balance from the PIANO data. That is, we seek to analyze the respective innovative performance of Europe and China and the degree of possible green catching-up of China to Europe in the water area. We do this by using our scoring and categorization analysis of each TWI. We hence analyse the distribution of the European and Chinese TWIs within the following five categories:

Category 1 - established (conventional) technology solutions (TS) available in both the EU and China,

Category 2 - established technology solutions in Europe, but not in China,

Category 3 - similar/joint innovative (i.e. TWI) solutions available in both the EU and China,

Category 4 - innovative (TWI) solutions available in Europe but not China,

Category 5 - innovative (TWI) solutions available in China but not the EU.

While we find discrepancies in the European and Chinese mapping, scoring and categorizations the main picture is quite clear. Most TWIs are found in category 3 and 4, with the Chinese experts emphasizing category 3 more than 4 as compared to the European experts. The high level of category 3 TWIs is an indication of quite a high level of Chinese catching up with European water innovation. Further in-depth analysis across as well as within the specific water domains is needed to clarify and elaborate these first results.

1. An online survey was sent out first to the project partners with water domain-specific expertise, and subsequently to relevant European and Chinese water experts (e.g. European Innovation Partnership Water and its working groups, International Water Association). This was supplemented by relevant searches in water innovation project specific databases (e.g. ECOWEB, EUREKA) by PIANO participants

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Conventional soil P test methods versus diffusive gradient in thin film (DGT) technique to assess the potential risk of P mobilization

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Abstract

Rapid growth of greenhouse vegetable production in China along with inputs of large quantities of P have led to excessive P accumulation in the soils and eventually P leaching to surface waters. This study examined the potential risk of P losses to fresh waters based on conventional soil P test methods, P as measured by diffusive gradient in thin film (DGT), and the degree of P saturation (DPS). To do so, a broad range of 75 soil samples, including 31 acidic and 44 alkaline soils, were chosen from five different greenhouse vegetable locations in China contrasting in soil properties and cultivation history. Three different conventional soil P test methods including Olsen, MehlichIII, and ammonium oxalate were applied to measure soil labile P. After DGT deployment soil samples were centrifuged to obtain soil solution, and the supernatant was filtered to measure soluble P of pore water. Moreover, 14 sampling sites different in labile P content were selected for column leaching experiment by taking intact soil cores (20 cm depth and 15 cm diam) and leaching with water in a laboratory setup providing measures of leachate P.

Results showed that total P varied between 260 and 11,220 mg P kg^{-1} while Olsen P varied from 5 to 740 mg P kg^{-1} with a mean 157 mg P kg^{-1}. This huge difference witnessed the significance ($P<0.01$) of vegetation history along with intense fertilization on excessive accumulation of labile P.

High to very high risk of P mobilization was found for course-textured alkaline greenhouse soils. Dissolved reactive P (DRP) concentrations in the leachates of these soils ranged between 0.8 and 13 mg L^{-1} exceeding 8 to 130 fold the environmental eutrophication threshold P concentration of 0.1 mg L^{-1}. In contrast, a low risk of P losses was found for acidic soils. None of the tested DPS measures were found successful to assess P losses. Overall, the DGT assay provided the best single measure of P mobilization from greenhouse soils in China as the DGT estimated P showed the highest correlation with both soluble P of pore water ($r^2=0.88$) and DRP in the leachates from column studies ($r^2=0.87$). Hence, the DGT method developed to assay plant available P, also is a powerful measure of the leachability of P from soils.

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Site suitability analysis for sustainable urban drainage systems in Denmark and China

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Abstract

Sustainable Urban Drainage Systems (SUDS) are increasing in popularity due to their demonstrated ability to promote infiltration, reduce stormwater runoff and improve receiving water quality. However finding sufficient space for this additional infrastructure in the already congested urban landscape remains a challenge.

This presentation will outline GIS based methodologies for the identification of suitable areas for various SUDS types based on their specific physical site requirements and demonstrate these approaches using three cases studies:

1) A simple vector based 'yes/no' site suitability analysis covering the greater Copenhagen area for a vegetated road barrier that serves to reduce noise and air pollution from traffic while simultaneously storing and evapotranspirating the stormwater runoff from the roofs of adjacent buildings.

2) A raster based weighted multi-criteria analysis for both lined and unlined permeable pavement in a 9 km^2 catchment in Frederiksberg, Denmark.

3) A city wide scale satellite based study (still in progress), for two of China's 'Sponge Cities' considering a variety of SUDS practices and taking into account the predevelopment water balance target of the significantly different geographies and climates.

Figure: Site suitability scores for permeable pavement placement in Frederiksberg, Denmark

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Qatar rainfall and runoff study

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Abstract

The objective of the Qatar Rainfall and Runoff study is to provide an improved design basis for investment of storm water infrastructure in Qatar. The combined efforts of data collection, site-specific investigations, statistical and climate analyses have expanded understanding of Qatari rainfall-runoff characteristics. These efforts will be incorporated into updates of existing drainage design standards and lead to better protection of Qatar's urban and natural environments from rainfall related impacts.

The study has collected rainfall data in multiple temporal resolutions from rain gauges in Qatar and adjacent Arabian Peninsula countries. The data was used to derive not only Intensity-Duration-Frequency (IDF) relationships, but also temporal and spatial distributions of rainfall for Qatar. Furthermore, the study evaluated climate changes impacts based on the Intergovernmental Panel on Climate Change (IPCC) predictions. The study also undertook a micro-scale catchment study of rainfall-runoff using a custom built rainfall simulator.

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Study of pollution transported by combined sewer system during wet-weather for the city of Murcia

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Abstract

Urban drainage is a very important problem for sustainable development in heavily anthropized areas. During a rainfall event, flushing on urban catchment areas and sewer systems involves an increase in the pollution load in waste water. In these situations, Combined Sewer Overflows (CSOs) can transport important volumes of pollution to receiving water bodies.

For stormwater pollution monitoring, traditional sampling and analysis techniques are not appropriate. In order to replace these methods, turbidimeters can be used to estimate continuously Total Suspended Solids (TSS) concentration through empirical equations. (Bersinger *et al*., 2013; Bertrand-Krajewski, 2004).

Pollution flows during storms have been studied at two locations of Murcia's (Southern Spain) sewer system. Information of precipitation, turbidity and flow are available. From this data, hyetographs, hydrographs and "pollutographs" (time evolution of TSS concentration) have been obtained for storms occurred in years 2014, 2015 and 2016.

Once hydraulic, hydrologic and pollution parameters of the rainfall are known, relationships between these variables can be studied with the objective of developing prediction indexes which can be useful to improve the management of the network (Gupta *et al*., 1996).

At this paper, two prediction indexes are defined: pollutograph time to peak index (I_{TPP}) and maximum concentration index (I_{CMAX}). Hydraulic time to peak, total rainfall and the antecedent dry weather period were found to be the most important parameters influencing the mobilization of suspend solids. For this reason, these parameters are involved in these equations.

The results of this study provide a methodology for calculating pollutographs based on hydraulic and hydrologic parameters that are readily available on urban catchments.

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Building water resilient green cities in Africa

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Abstract

Since 2013 the University of Copenhagen has collaborated with universities and communities in Addis Ababa (Ethiopia) and Dar es Salaam (Tanzania) on the framing of water resilient cities in Africa. See www.watergreenafrica.dk. Current funding from Danida will terminate by mid-2017 and a follow-up project is underway. This paper will present key findings from the initial project, expand on the research needs emerging from our work during the past four years and present the draft research proposal for a new four-year research and development project in East Africa. The paper aims to spark a discussion on ways to involve companies from the Danish water sector in an international development project on nature-based water management in emerging cities in the Global South.

The initial project has explored if a robust green infrastructure in combination with multi-level stakeholder engagement can be the key to water resilient green cities in Ethiopia and Tanzania. A green infrastructure for flood control and water supply is expected to provide urban water infrastructure in a more timely, cost-effective and holistic manner than the 'business-as-usual' approach. Further, it is expected to support sustainable urban development in a wider context including environmental protection, social equity and economic viability. Over the past four years, a range of technological concepts for landscape based stormwater management at site and catchment level have been developed along with new knowledge on inclusive water governance and planning .

Yet, there is a critical need for 1:1 full scale demonstration projects that can lead by example and serve as precedent-setting business cases for the upscaling of nature-based urban water management systems. Denmark has a track record of successful triple-helix networks that have fostered collaboration and innovation, Vand i Byer being the most prominent example. Experiences from Denmark show the relevance of involving end-users, companies and research institutions in the process of developing, demonstrating and upscaling good solutions, which in turn strengthen the capacity of all partners. Demonstration projects are critical to drive this process of change and to facilitate knowledge diffusion in society at large.

In the proposed follow-up project we hope to utilize existing networks in Denmark to support holistic water management, capacity building, business development and international trade in a mutually beneficial partnership for the development of sustainable cities in the Global South and in the Global North.

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WISE – Water Innovation SmE's – Innovative solutions with in the water field.

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Abstract

The WISE project has the purpose of bringing innovation in to small medium sized enterprises (SME's) within the water field in the capital region and thereby increase the development of new innovative concepts. The total budget of the project is DKK 15 m handed out over a 3-year period starting August 2015. In the project, SMEs are matched with a researcher from Technical University of Denmark and the project is carried out as a collaboration since the researchers' hours are financed through the WISE project and the SME's must co-finance a corresponding number of in-kind hours. The goal is to make 24 matches in the WISE project and each match (project) should include minimum one SME and researchers from one or preferably more departments. Other stakeholders from the water sector are welcome in the group. There is still room for more matches with SME's and researchers.

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Integration of natural microorganisms at drinking water sand filters with micronutrient composition of groundwater

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Abstract

Rapid sand filters (RSF) are commonly used for drinking water production at thousands of waterworks across Denmark, Europe and worldwide. Groundwater pollutants (e.g. ammonium, iron, manganese etc.) from groundwater are effectively removed through sand filters by a combination of chemical and biological processes. Rapid sand filter is a microbial rich environment, where well-known microbial groups catalyze pollutant removal. The activity of these microbial group also dependents on the presence of essential micronutrients in the surrounding. This project investigates the physiological need of the main microbial groups at RSFs toward micronutrients, with the intention to optimize their performance and activity. The obtained results will allow waterworks to blend the ground waters from different water-wells, often having different chemical properties, Creating of a well-defined inlet-water blend with a specific concentration of micronutrients could ultimately improve RSF`s capacity up to 30 percent.

The effect of micronutrients (copper, nickel, zink etc) on bacteria responsible for ammonium and nitrite oxidation was monitored in laboratory microcosms using sand filter material from two Danish waterworks. The molecular PCR-based approach revealed that investigated microbial groups had similar distribution-patterns between replicate RSFs, yet the microbial distribution as a function of RSF`s depth was different between investigated microbial groups. Copper seemed to have a stimulation effect on ammonium oxidation, also at low concentrations found in groundwater. Presence of nickel at low (1ug/L) and high (10ug/L) concentrations revealed the respective stimulating and inhibiting effect on nitrification, suggesting its potential co-factor role in enzymes involved in nitrification.
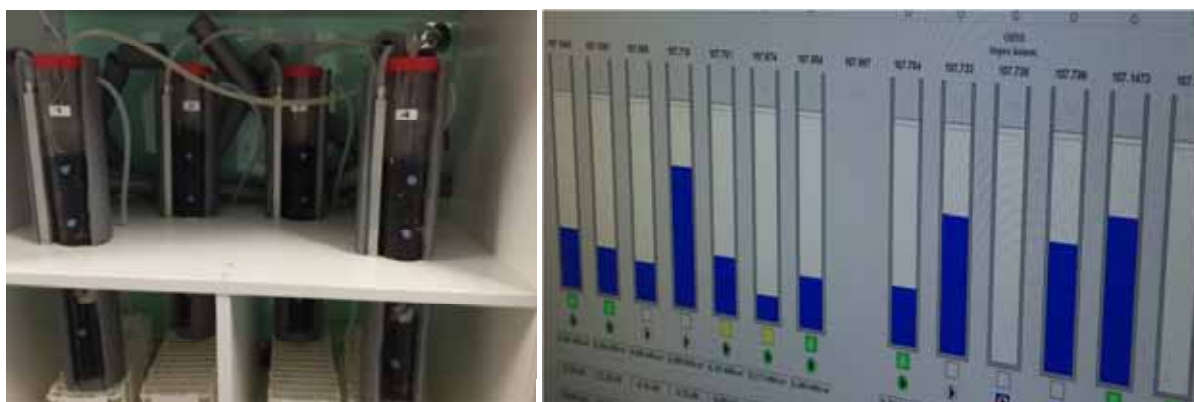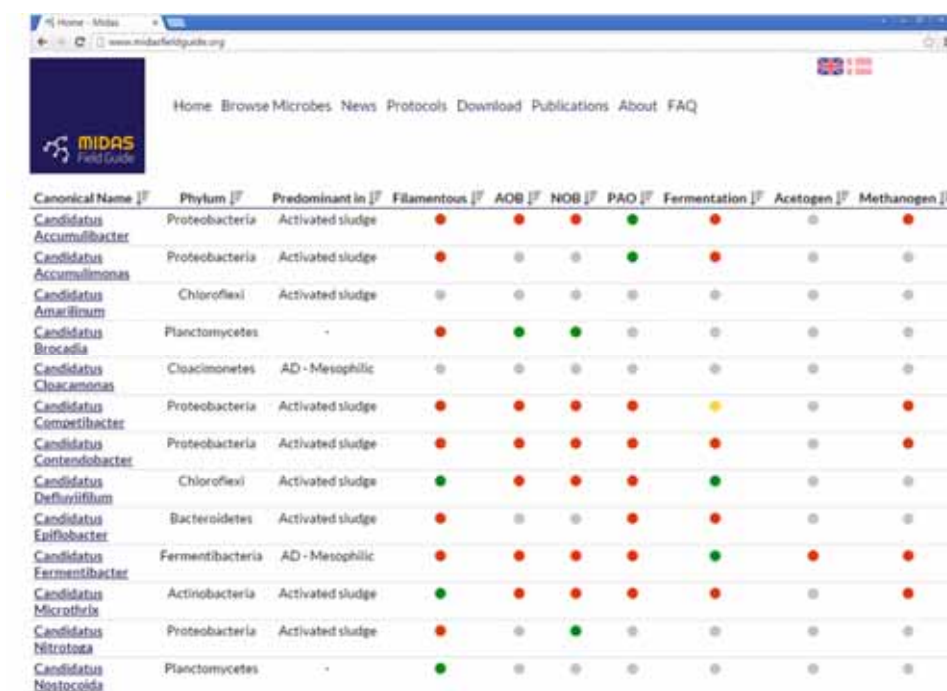
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MiDAS: The site-specific curated database of microorganisms in activated sludge and anaerobic digesters

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Abstract

An understanding of the microbial communities and dynamics in wastewater treatment systems is a powerful tool for process optimization and design. The advent of amplicon sequencing of the 16S rRNA gene now allows the diversity within the microbial communities to be sampled sufficiently to describe the composition and dynamics of the most abundant organisms. However, to understand the relationship between the population dynamics and operational parameters of the system, a functional role must be attributed to each organism. The Microbial Database for Activated Sludge (MiDAS) and Anaerobic Digesters (AD) presented here provides a curated taxonomy for abundant and important microorganisms in these systems and in the incoming wastewater and integrates it into a community knowledge web platform about the microbes present therein. The MiDAS taxonomy, a manual curation of the SILVA taxonomy, proposes putative names for all the abundant genus-level microorganisms in AS and AD systems. The online database covers >250 genera found in biological nutrient removal treatment plants, based on extensive in-house surveys with 16S rRNA gene amplicon sequencing, including full-scale AS (20 plants, 8 years) and AD systems (36 reactors, 18 plants, 4 years). Surveys also include the Archaea. The MiDAS field guide is available as a web resource (www.midasfieldguide.org). The website provides a searchable database of information about each abundant and/or important genus present in the influent, AS and AD systems. Information is referenced, with the database acting as a central, on-line repository for current knowledge about activated sludge organisms. Information includes morphology (e.g. filamentous), metabolic guilds relevant to the AS and AD environments (e.g. polyphosphate accumulating organisms, ammonia oxidizing bacteria, methanogens), abundance information and many others. The MiDAS genus names proposed can provide a common vocabulary for all researchers in the field, facilitating the exchange of data and benefit studies into the ecology of these industrially important ecosystems.

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A software tool for ecosystem services assessmenst

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Abstract

The EU FP7 DESSIN project is developing methods and tools for assessment of ecosystem services (ESS) and associated economic values, with a focus on cost-benefit analysis in urban settings. As part of the project, DHI is developing a software tool to support users implementing the DESSIN ESS evaluation framework.

The DESSIN ESS evaluation framework is a structured approach to measuring changes in ecosystem services. The main purpose of the framework is to facilitate the application of the ESS approach in the appraisal of projects that have impacts on freshwater ecosystems and their services.

The DESSIN framework helps users evaluate changes in ESS by linking biophysical, economic, and sustainability assessments sequentially. It was developed using the Common International Classification of Ecosystem Services (CICES) and the DPSIR (Drivers, Pressures, States, Impacts, Responses) adaptive management cycle. The former is a standardized system for the classification of ESS developed by the European Union to enhance the consistency and comparability of ESS assessments. The latter is a well-known concept to disentangle the biophysical and social aspects of a system under study. As part of its analytical component, the DESSIN framework also integrates elements of the Final Ecosystem Goods and Services-Classification System (FEGS-CS) of the US Environmental Protection Agency (USEPA).

As implemented in the software tool, the DESSIN framework consists of five parts:

- In part I of the evaluation, the ecosystem is defined and described and the local stakeholders are identified. In addition, administrative details and objectives of the assessment are defined.
- In part II, drivers and pressures are identified. Once these first two elements of the DPSIR scheme have been characterized, the claimed/expected capabilities of a proposed project can be estimated to determine whether the project affects drivers, pressures, states or a combination of these.
- In part III, information about impacts on drivers, pressures, and states is used to identify ESS impacted by a proposed project. Potential beneficiaries of impacted ESS are also identified.
- In part IV, changes in ESS are estimated. These estimates include changes in the provision of ESS, the use of ESS, and the value of ESS.
- A sustainability assessment in Part V estimates the broader impact of a proposed project according to social, environmental, governance and other criteria.

The ESS evaluation software tool is designed to assist an evaluation or study leader carrying out an ESS assessment. The tool helps users move through the logic of the ESS evaluation and make sense of relationships between elements of the DPSIR framework, the CICES classification scheme, and the FEGS approach. The tool also provides links to useful indicators and assessment methods in order to help users quantify changes in ESS and ESS values.

The software tool is developed by DHI in collaboration with the DESSIN user group, who will use the software to estimate changes in ESS resulting from the implementation of green technologies. Although the software is targeted to this user group, it is intended for continued use in ecosystem service assessment after the conclusion of the DESSSIN project.

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Evaluation of leakages effects in the water supply system of Moratalla (Spain)

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Abstract

One of the risk management requirements is the assessment of the effect of each kind of possible failure. In water supply systems, the most common failures are the pipe leakages. Most leakages can be modelled as orifices in a pipe [1]. In this paper, a leakage pattern is defined for each of the 300 pipes in Moratalla's water supply system. That leakage pattern is defined as an orifice whose diameter length is 1/10 of the pipe diameter.

Epanet-Octave is a GNU Octave wrapper that makes easy and vector oriented the use of EPANET ToolKit. Epanet-Octave library has been used to carry out a simulation for each pipe which may have a leakage. Each simulation lasts a whole simulated day to include leakage effects for the different pressures and demands that happen during the day. Then, the results are summarised by using an index which weights the negative effect of the leakages. Usually leakages are evaluated mainly by the energy waste in pumping that water [2-3]. In this case, the suggested index accounts for leakage flow rates, water quality deterioration and service deterioration.

Leakage flow rates effects are included through the maximum leakage flow rate (in time) and its average value, which in this case is proportional to the energy cost used in other works as the system distributes the water from the reservoirs to customers by gravity. Water quality deterioration is evaluated by the presence of negative pressures around the orifice. Finally, service deterioration is measured through the water that would be supplied below the regulated minimum pressure.

This weighted index, which is shown in the figure below, can be used, together with other non-hydraulic factors like pipe-age or pipe-material, to prioritise the maintenance and even the replacement of pipes according to a risk management strategy.
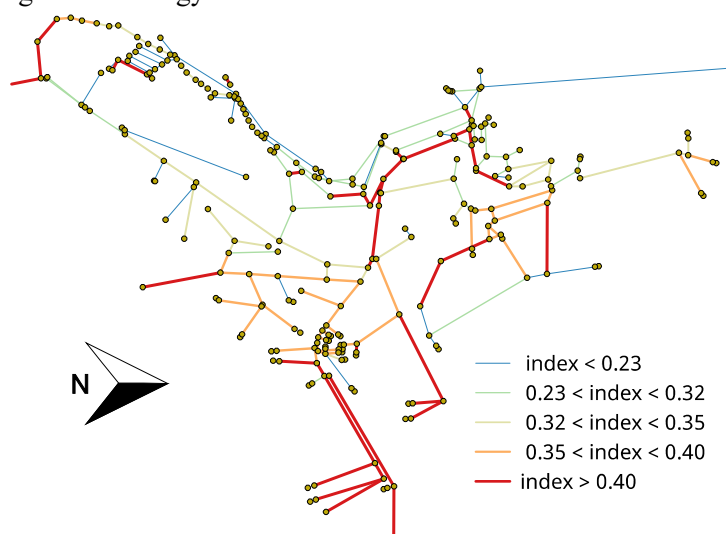
Figure: Distribution of the leakage effect index in the Water Supply System of Moratalla.

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Fertilizer driven forward osmosis as a low energy technology for sodium removal in greenhouse applications

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Abstract

With the increasing pressure on the limited fresh water resources, good quality irrigation water is often not available for greenhouse growers that increasingly are forced to use water with high sodium content. Sodium concentration particularly affects the quality of fertigation water, often decreasing yield and quality of the growing crops. Membrane technologies could play an important role in solving the water scarcity and quality issue. Among them, forward osmosis technology has recently emerged for its low fouling and low energy consumption. The concept of Fertilizer Driven Forward Osmosis (FDFO) has been investigated due to advantages of avoiding draw solution recovery. If successful, FDFO technology could be introduced as a low energy solution in the for water treatment in the greenhouse industry.

The objective was to investigate if FDFO has the potential to be a viable low energy solution for the removal of sodium in the fertigation water of the greenhouse industry. A proof-of-concept of the FDFO technology was conducted together with a feasibility study to test the hypothesis.

The results show that FDFO, as a standalone technology, has insufficient driving force to provide enough dilution of the fertilizer to meet the greenhouses requirements. Especially when high water recovery is targeted. Assisting the process with additional hydraulic pressure (PA-FDFO) has been deemed necessary to fulfil the water treatment targets. Pressure assistance, of up to 6 bar, was found necessary to overcome the expected range of osmotic pressure in the feed water. Moreover, positive effects on the membrane footprint and losses of fertilizer have been found by applying the additional hydraulic pressure. The FDFO set-up with Aquaporin Inside™ biomimetic hollow fibers membrane have shown 99% sodium rejection. Significantly lower specific reverse salt flux has been observed compared to published data on other commercial membranes. The outcomes of the feasibility study show that the PA-FDFO technology fulfils the requirements of the greenhouses, while at the same time being economically viable by offers significant energy savings ranging up to 75%.

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Characterizing the hydrogen and oxygen isotopic compositions of different waters at reclaimed water irrigated district in a Southeastern suburb of Beijing

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Abstract

Characteristics of hydrogen and oxygen isotope of reclaimed water, surface water and groundwater are essential to recognize hydraulic connections in the regional hydrologic cycle. In order to obtain stable isotope (δ^{18}O, δD) characteristics and to detect causes of differences among different water bodies (precipitation, reclaimed water, surface water and groundwater in different depths), field investigation and water samples collection were conducted separately in 2014 and 2015 in a district southeast of Beijing irrigated with reclaimed water.

The results showed that: Local Meteoric Water Line of Beijing was expressed with the function of δD=7.27 δ^{18}O+2.43 (R^2=0.93 n=198) which was used as isotopic baseline. Reclaimed water and surface water carried larger isotope content than groundwater, with declining order of surface water> reclaimed water> groundwater with respect to δ^{18}O and reclaimed water> surface water> groundwater with respect to δD. Reclaimed water was enriched in hydrogen and oxygen isotopes due to evaporation fractination. Generally, the heavy isotope content in the river are gradually enriched along the river flow, while the sudden drop could be ascribed to entrance of isotope depleted groundwater. On account of slow water circulating in wetland recharged by Han River, the wetland water has undergone strongest evaporation which was heaviest isotopic concentration in all samples. Generally, the isotopic content of deep groundwater (depth >80m) was lower than that of shallow groundwater (depth <80m). The lowest isotopic value of groundwater at 300m and 150m depth were influenced by the infiltration of precipitation occurring in a colder paleoclimate rather than modern climate, with no influence from reclaimed water. Shallow groundwater from monitoring wells located 10 m away from the river was dramatically recharged by river and canal water nearby; however lateral flow of depleted groundwater penetrating to some wells adjacent to the river channel was observed. This indicated that vertical infiltration of reclaimed water, precipitation and irrigation water into the groundwater plays vital roles in the shallow groundwater isotope composition in this district irrigated by at reclaimed water.
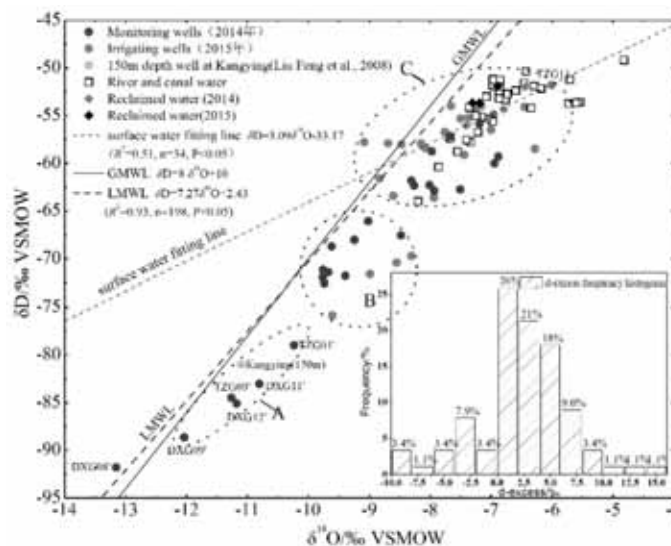
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