16 April 2018
WATEC

ANNUAL MEETING 2018
## ANNUAL MEETING 2018

- Hot topics and trends in Water Technology Research

### SESSIONS:

**MONDAY APRIL 16**

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<th>Time</th>
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<td>8.30 - 9.10 a.m.</td>
<td>Registration and networking – have a cup of coffee</td>
<td></td>
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<tr>
<td>9.10 - 9.30 a.m.</td>
<td>A warm welcome – State of the Union</td>
<td>Niels Peter Revsbech.</td>
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<td>9.30 - 9.40 a.m.</td>
<td>Poul Due Jensen Foundation</td>
<td>Poul Toft Frederiksen</td>
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<td>9.40 - 10.05 a.m.</td>
<td>Looking into the subsurface for water, raw materials and geotechnical applications</td>
<td>Anders Vest Christiansen</td>
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<td>10.05 - 10.30 a.m.</td>
<td>Hydrological modelling with focus on N-retention with extensive structural input from 3D geophysical data</td>
<td>Troels Vilhelmsen</td>
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<td>10.30 - 10.45 a.m.</td>
<td>Short coffee break</td>
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<td>10.45 - 11.10 a.m.</td>
<td>Constructed wetlands for N and P removal from surface waters and drainage water</td>
<td>Finn Plauborg</td>
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<td>11.10 - 11.35 a.m.</td>
<td>Biofilters for N and P removal from drainage water</td>
<td>Carl Christian Hoffmann</td>
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<td>11.35 - 12.00 a.m.</td>
<td>Constructed wetlands for wastewater treatment; new developments and process intensifications</td>
<td>Carlos Alberto Arias</td>
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<td>12.00 - 12.15 p.m.</td>
<td>Walk, Lunch and networking</td>
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<tr>
<td>01.15 - 01.40 p.m.</td>
<td>Removal of micro-contaminants from wastewater</td>
<td>Kai Bester</td>
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<td>01.40 - 02.05 p.m.</td>
<td>Development of sensors for water analysis</td>
<td>Klaus Koren</td>
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<td>02.05 - 02.25 p.m.</td>
<td>Coffee break</td>
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<td>02.25 - 02.50 p.m.</td>
<td>Optimization of wastewater treatment for resource recovery</td>
<td>Lars Ditlev Mørk Ottosen</td>
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<td>02.50 - 03.15 p.m.</td>
<td>Lake and stream restoration – monitoring, experiments and modelling</td>
<td>Erik Jeppesen</td>
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<tr>
<td>03.15 - 3.30 p.m.</td>
<td>Discussion and interaction – spot your colleague</td>
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WELCOME TO ANNUAL MEETING 2018
AARHUS UNIVERSITY CENTRE FOR WATER TECHNOLOGY
WATEC – MEMBER DEPARTMENTS

- Department of Geoscience (Professor, Esben Auken)
- Department of Agroecology (Senior Scientist, Finn Plauborg)
- Department of Bioscience, Silkeborg (Professor, Erik Jeppesen)
- Department of Environmental Science (Professor, Kai Bester)
- Department of Engineering (Head of Section, Lars D.M. Ottosen)
- Department of Bioscience, Campus (Professor, Niels Peter Revsbech)
- iNANO
WATEC - RESEARCH AREAS

- **Groundwater** (Geoscience)
- **Constructed wetlands** (AGRO, Bioscience, Geoscience)
- **Techniques for lake and watershed restoration** (Bioscience, Agro)
- **Wastewater treatment** (ENVS, Bioscience, Engineering)
- **Energy/wastewater** (Engineering, Bioscience)
- **Micropollutants** (ENVS, Engineering)
- **Socioeconomy of the water cycle** (ENVS)
- **Sensor Technology** (Bioscience, Engineering, iNANO)
WATEC - FOUNDING GRANT

Aarhus University Faculty of Science and Technology

- A total of 15 Mkr for 5 years, on average 3 Mkr per year
- 1 Mkr is for 33% financing of PhD students
- 1 Mkr is for a new WATEC professor
- 1 Mkr is for initiatives in WATEC and salary for center manager
- 10% of WATEC participant grants will be allocated to WATEC -> more funds available for WATEC activities
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Apply for WATEC project support and PhD support by April 20!
OPENING OF WATEC

- Contract signed by July 1, 2017
- Official opening on October 6, 2017
- A total of 186 participants:
  - Universities
  - Sector-specific organizations,
  - Utilities
  - Private companies
HIRING OF WATEC PROFESSOR

Demand from Dean – “an area that is new to AU”.

Three themes are proposed:

1. Professor in water distribution systems
2. Professor in effects of Climate change on the hydrological cycle
3. Professor in advanced water treatment/removal of micropollutants
POUL DUE JENSEN FOUNDATION
A GENEROUS KICK-START OF MIO 40 DKK.

**Sensor laboratory including infrastructure: 16.2 Mkr. + 6 Mkr.**
- 1 professor
- 1 assistant professor
- 1 technician to the sensor laboratory for a period of 5 years
- 8 postdoc years

**WATEC junior researchers: The talent and the innovative ideas: 7 Mkr.**
- 8 postdocs/assistant professor years

**Wastewater laboratory including Infrastructure: 11 Mkr.**
- 1 professor
- 8 postdoc years
POUL DUE JENSEN FOUNDATION
STATUS OVERVIEW

• Assistant professor Klaus Koren started on January 1, 2018

• Technician for the sensor laboratory - started today – welcome on board to Claus Madsen

• Two WATEC postdoc positions – deadline yesterday

• Postdoc position for the sensor laboratory – deadline yesterday

• Professorship for the sensor lab - deadline on June 1

• Professorship in water treatment technology - deadline on Aug. 1
WATEC - DOES IT MATTER?

Creation of WATEC has resulted in several invitations:

- Collaboration with Danish utilities and companies
- Participation in meetings – talks, discussions, dialogue
  - Participation in meetings on implementation of the Danish Water Vision
  - Danish-Chinese Business Forum last Thursday on export of water tech
  - Water Summer School – August 2019 - leading Danish Companies
  - "Folkemødet”/ People Meeting – Bornholm 2018
WATEC; A POTENTIAL FOR AU COLLABORATION

Example: Alliance of water modelling - The perfect match:

- Department of Geoscience: Geophysics, subsurface geological mapping, groundwater hydrology.
- Department of Agroecology: Transport of water through the root-zone
- Supported by WATEC with 300.000 Dkr. Pitch of joint project at Innovation Fund DK
- One PhD student working on the joint project
NEW ENGAGEMENTS AND COLLABORATIONS

- Rural water resources in China (AGRO) with GEUS
- Anammox in wastewater treatment (ENG, BIOS) with Aarhus Water
- Water resource mapping (GEO) with USGS, Stanford, iGIS etc.
- Degradation of xenobiotics (ENVS) with BFG, KWB, SYKE etc.
- Lake and water reservoir management (BIOS) with Orbicon, Envidan, res. org. US, Ghana
- Student Water Summer School (WATEC) with AKV, Grundfos, Danfos, Niras, iGIS, etc.
ADVISORY BOARD

• We are grateful that you are willing to participate!

• The advisory board will participate all day today – and convene tonight and tomorrow morning

• The advisory board is composed of external specialists on most WATEC fields

• The advisory board will help us to focus our efforts on the most promising areas
HOT TOPICS AND TRENDS IN WATER TECHNOLOGY RESEARCH
Wellcome to
WATEC ANNUAL MEETING 2018
WATEC and PDJF

Who, what and why?

Poul Toft Frederiksen, Programme Manager, Research
April 16, 2018
PDJF was founded on May 18, 1975 with a dual purpose:

Active ownership

Philanthropy: Water Research Inclusion
“There are obligations that go beyond those derived from legislation and tax payments”

Poul Due Jensen
Three donation areas

**Water**
Our philanthropic work directly supports UN Sustainable Goal #6.1 through providing sustainable and affordable access to safe drinking water to the world's poorest.

**Research**
In collaboration with selected universities, the Foundation wants to build and strengthen research environments within selected technical research disciplines and natural sciences.

**Inclusion**
The Foundation works to promote labour market inclusion in the Central Denmark Region. We believe that having a connection to the labour market is important in order to safeguard and develop social cohesion, individual well-being and creating value for society.
We intend to create changes

Our donations finance concrete outputs – lab equipment or academic hires

The delivery of the output leads to results – a laboratory, a research team etc.

The realisation of the results leads to the desired changes - research with academic and/or social impact
WATEC and PDJF
The What (and the Why)

The sensor laboratory
- Serious laboratory upgrade
- 5 years full professor salary (will be taken over by AU)
- 8 man-years of junior researcher salary

Water treatment
- 5 years full professor salary (will be taken over by AU)
- 8 man-years of junior researcher salary
- Intention of supporting an ambitious laboratory construction

The firecrackers
- 8 man-years of junior researcher salary—with the field defined by junior herself—plus associated costs
Looking into the subsurface for water, raw materials, and geotechnical applications

Anders V. Christiansen and Esben Auken

Hydrogeophysics Group
Department of Geoscience, Aarhus University
Why geophysics?
The Hydrogeophysics Group (HGG)
The geophysical toolbox

- Electrical - *contact*
- Electromagnetic – *no contact*
The geophysical toolbox

- **Electrical – contact**
  - Resistivity of the subsurface
  - Lithology (clay or sand?)
- **Chargeability**
  - Pore-space properties (links to hydraulic behavior)

- **Electromagnetic – no contact**
  - Resistivity of the subsurface
  - Lithology (clay or sand?)
- **Magnetic resonance**
  - Water content and pore-space properties
What do we measure?

Resistivity depends on:
- Sediment type – sand or clay
- Ion content of the pore-water
- Porosity

Resistivity of different geological units:
- Paleogen clay
- Marine clay
- Till
- Saturated sand with clay/silt
- Saturated sand or gravel
- Unsaturated sand or gravel
Innovative instruments built in-house

• tTEM
**tTEM method**

**Technical details**
- Measurement takes a few milliseconds resulting in 3-10 meters lateral resolution
- Depth of investigation 0-70 meters
- High-resolution in upper 30 meters

**Mapping details**
- 10-20 km/hour ~ 3-5 m/s
- Line distance is typically 10-20 meters (driving tracks distance)
- Coverage is 50-115 hectares per day

Auken et al., 2018, *A new towed groundbased TEM system for 3D imaging of the top 70 meter of the subsurface*, SAGEEP annual conference.
tTEM method - in the field..
tTEM – the vision😊
Results, Javngyde

- 1000 hectare area, ID15
Results, Javngeyde

- 1000 hectare area, ID15
- Between 60-120 hectares per day
- Glacial sediments overlying tertiary clays and sands

Total mapped area = 509 ha
Results, Javngyde
Mean Resistivity maps 0 – 5 m
Mean Resistivity maps 5 – 10 m
Mean Resistivity maps 10 – 15 m
Mean Resistivity maps 15 – 20 m
Mean Resistivity maps 20 – 25 m
Mean Resistivity maps 25 – 30 m
Mean Resistivity maps 30 – 35 m
Mean Resistivity maps 35 – 40 m
Mean Resistivity maps 40 – 45 m
Mean Resistivity maps 45 – 50 m
Profiles
P3
Geological interpretation

- Heavily affected by man-made interference
Geological interpretation

• Heavily affected by man-made interference
• Glacial thrust structures
Geological interpretation

- Heavily affected by man-made interference
- Glacial thrust structures
Geological interpretation

- Heavily affected by couplings
- Glacial thrust structures

[Diagram showing geological layers and ice push]
Summary

• Large-scale mapping as well as pore-scale
• New and innovative mapping tools
• Applications → instruments → mapping → software
HYDROLOGICAL MODELLING WITH FOCUS ON N-RETENTION WITH EXTENSIVE STRUCTURAL INPUT FROM 3D GEOPHYSICAL DATA
OUTLINE

• The rOpen research project
• Why groundwater modeling for N-retention?
• Why does the subsurface structures plays an important role
rOpen - Open landscape nitrate retention mapping

“Our Vision is that more effective targeting can be achieved using innovative geophysical mapping in combination with hydrogeological, and geochemical modeling. This higher resolution will improve the forecast of nitrate transport in the open landscape at field scale (a few hectares). Furthermore, it will lead to a transparent, data-driven decision support tool that will be cost effective on the national scale. Such improved management can lead to targeted regulation and more efficient fertilizer utilization benefiting both the agricultural sector and the environment.”
rOpen - Open landscape nitrate retention mapping

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INTRODUCTION

- 3133 ID 15 Catchments in Denmark
- Regulatory basins for agricultural management
INTRODUCTION

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• Regulatory basins for agricultural management
• Currently a single retention value for each catchment
INTRODUCTION

- 3133 ID 15 Catchments in Denmark
- Regulatory basins for agricultural management
- Currently a single retention value for each catchment
- rOpen field sites
INTRODUCTION

• Javngyde field site
• App. 10.5 km²
• Agriculture constitutes 79% of area
INTRODUCTION

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- App. 10.5 km²
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- App. 10.5 km²
- Agriculture constitutes 79% of area
THE GOAL OF ROPEN

Identification of management areas
THE GOAL OF ROPEN

Mapping and modeling the shallow subsurface
THE GOAL OF ROPEN

Analysis and management

- Tile drain mapping
- Surface discharge
- Subsurface structures
- Groundwater flow paths
- On field practices and near surface characterizations
- Geochemical characterization
Geophysical mapping and modelling

Dynamic model update with new data collection

N-transport
Vulnerability, streams and groundwater
Nitrate degradation
Identification of sensitive areas

GIS, land use, lithology, etc.

Soil – crop modelling

+ N-LES₄

Kristian Kristensen, Jesper Waagepetersen, Christen Duus Børgesen, Finn Pilgaard Vinther, Ruth Grant and Gitte Blicher-Mathiesen (2008), Reestimation and further development in the model N-LES - N-LES₃ to N-LES₄.

Groundwater modelling


Dynamic model
Decision support


N-transport
Vulnerability, streams and groundwater
Nitrate degradation
Identification of sensitive areas

Geoscientific mapping

Soil – crop modelling

+ N-LES₄

Geophysical mapping and modelling

Dynamic model update with new data collection

N-transport
Vulnerability, streams and groundwater
Nitrate degradation
Identification of sensitive areas

GIS, land use, lithology, etc.
IMPORTANCE OF SCALE AND STRUCTURE

Homogeneous: 1945

- > 0.1 N (mg/l)
- > 1.0
- > 10 --MCL--
- > 100

Heterogeneous: 1945

Carle et al., 2006, Geosphere; June 2006; v. 2; no. 4; p. 195–209; doi: 10.1130/GES00032.1;
IMPORTANCE OF SCALE AND STRUCTURE

Homogeneous: 1945

Heterogeneous: 1945

Carle et al., 2006, Geosphere; June 2006; v. 2; no. 4; p. 195–209; doi: 10.1130/GES00032.1;
IMPORTANCE OF THE SUBSURFACE

Geology
IMPORTANCE OF THE SUBSURFACE
IMPORTANCE OF THE SUBSURFACE
Water can only leave the system through **the drains**

Water can leave the system through **the drains or the groundwater system**
IMPORTANCE OF THE SUBSURFACE

https://wi.water.usgs.gov/glpf/imagessfig23_sustainability.jpg
IMPORTANCE OF THE SUBSURFACE

3 cluster mode model

Clusters:
- Cluster 0
- Cluster 1
- Cluster 2

Map details:
- Borehole > 100m
- Borehole 50 - 100 m
- Borehole 20 - 50 m
- Borehole 10 - 20 m
- SkyTEM data
- Forecast wells
- Model area outline
- Cross sections

Geographic areas:
- Ristrup
- Kasted

Dimensions:
- W: 9 km
- E: 97.5 m
- A: 97.5 m
IMPORTANCE OF THE SUBSURFACE
IMPORTANCE OF THE SUBSURFACE

3 cluster mode model

3 cluster model with unc.

Cross section Ristrup

3 cluster mode model A

3 cluster model with unc. B

Cluster 0
Cluster 1
Cluster 2
IMPORTANCE OF THE SUBSURFACE
IMPORTANCE OF THE SUBSURFACE
CONCLUSIONS

• The complexity of the subsurface in former glaciated areas can be very high
• 3D models of the subsurface are needed for modelling of the groundwater system
• These models (must) be able to represent the uncertainty of the structures if they are needed to make informed decisions
• 3D geophysical data is the only effective mean to estimate and reduce this uncertainty
CONSTRUCTED WETLANDS FOR N AND P REMOVAL FROM SURFACE WATERS AND DRAINAGE WATER

WATEC ANNUAL MEETING April, 2018
Hot topics and trends in Water Technology Research
SURFACE FLOW CONSTRUCTED WETLANDS (SF-CW)

Layout of this talk with focus on the Danish experience

- Background (short version)
- Latest political interventions and various MAPS
  - N retention map
  - Potential areas for SF-CW
- Sketch of a SF-CW design
- Performance of SF-CW
BACKGROUND – SHORT VERSION

Regulations imposed on agriculture to reduce losses of N and P to the aquatic environment

With the **NPO report in 1984**, a survey was made for the first time, where agricultural use of nitrogen and phosphorus fertilizers was associated with the eutrophication of the aquatic environment.

1985. **NPO Action Plan**: Focus on husbandry manure

1987. **Water Environmental Plan I**: Action Plan against pollution of the Danish aquatic environment with nutrient salts both from municipalities, industries and agriculture


BACKGROUND – SHORT VERSION

Regulations imposed on agriculture to reduce losses of N and P to the aquatic environment

In 2000 the EU adopted the Water Framework Directive (Directive 2000/60 / EC of 23 October 2000). The directive establishes a binding framework for water management in EU member states, and the overall objective of the Directive is that all water, surface water and groundwater must have at least by the end of 2015 at least "good condition" or "good ecological potential".

2004. Water Environment Plan III:

▶ Farmers’ surplus of phosphorus must be halved - reduction of approx. 25% up to 2009 and 25% more by 2015
▶ The emission of phosphorus must be reduced - 50,000 ha of marginal zones will be established along streams and lakes
▶ The leaching of nitrogen from agriculture must be reduced - by a minimum of 13% by 2015
▶ Vulnerable nature protected - Stop for livestock expansion within 180,000 ha new protection zones
In April 2013, the Nature and Agriculture Commission published its recommendations for a reform of the existing environmental regulation of Danish agriculture. Central to the report was the recommendation of a paradigm shift in the regulation of agricultural nutrient emissions from general to targeted rules.

So far, commitments to Danish agriculture’s reduction of nutrient discharges have been formulated as general rules for cover crops, reduced fertilizer use, etc. This means that the diversity of Danish nature and the major geographic differences in the vulnerability of the environment are not taken into account.

The need for environmental efforts is typically larger around closed fjords than in areas that drain into open sea areas with high throughput. The targeted regulation creates room for continued growth and development of Danish agriculture in areas where the environment is robust while protecting the environment, the fjord and groundwater where the environment is vulnerable.
With the Growth Plan for Food of April 2, 2014 and the Food and Agriculture Package Agreement of December 22, 2015, the first basic principles were formulated.

Targeted measures and regulation

By 2021, nitrogen emissions must be reduced to 6,900 tonnes. Around half 3,400 tonnes must be achieved through collective measures. The other half 3,500 tonnes - the targeted regulation - must be achieved by means that the individual farmer should establish.

Collective measures:

The collective measures include the establishment of constructed wetlands, wetland projects and afforestation. The actions are paid by the state and solves problems for a larger area (sub-catchment) and benefits farmers in that given sub-catchment.
Targeted measures are defined by the Water Area Plans (2009-2015), (2015-2021) and (2021-2027) set the targets to meet the requirements of the Water Framework Directive.

### Expected effects of the nitrogen measures 2015 – 2021

<table>
<thead>
<tr>
<th>Water Area Plans 2015-2021 Coastal waters</th>
<th>Measures to reach the WFD goals</th>
<th>Nitrogen</th>
<th>Tons/year</th>
<th>Restored wetlands</th>
<th>Lowland projects</th>
<th>Constructed wetlands receiving drainage water</th>
<th>Afforestation</th>
<th>Environmental focus areas (MFO)</th>
<th>Target regulation</th>
<th>Wastewater</th>
<th>Total effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postponed (after 2021)</td>
<td></td>
<td></td>
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<tr>
<td>Danmark</td>
<td></td>
<td>13160.1</td>
<td>1252.7</td>
<td>150</td>
<td>900.3</td>
<td>149.6</td>
<td>866.4</td>
<td>3513</td>
<td>44.3</td>
<td>6960.4</td>
<td>6199.7</td>
</tr>
</tbody>
</table>

Targeted measures are defined by the Water Area Plans (2009-2015), (2015-2021) and (2021-2027) set the targets to meet the requirements of the Water Framework Directive.

N RETENTION

De Nationale Geologiske Undersøgelser for Danmark og Grønland.
Aarhus Universitet:
DCE – Nationalt Center for Miljø og Energi
DCA – Nationalt Center for Fødevarer og Jordbrug
N reduction target

N Load
POTENTIAL AREAS FOR SF-CW

**Constructed wetlands** are instruments targeted agricultural areas where drainage via drain pipes is the primary transport route. Effective and cost-effective use of targeted instruments such as constructed wetlands/drainage filters requires:

- That we have evidence of the effect under local conditions
- That we know where to target the effort
- That we have the administrative basis that allows for targeted regulation.

POTENTIAL AREAS FOR SF-CW

<table>
<thead>
<tr>
<th>Classification</th>
<th>Criteria for the classification</th>
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<tbody>
<tr>
<td>Suitable area</td>
<td>Areas with ≥12% clay in the C or D horizon. Drainage area not directly connected to the lowland in the river valley</td>
</tr>
<tr>
<td>Conditional suitable area</td>
<td>Areas with ≥12% clay in the C or D horizon. Drainage area directly connected to the lowland in the river valley</td>
</tr>
<tr>
<td>Potentially suitable area</td>
<td>Areas with &lt;12% clay in the C or D horizon. Drainage area not may be directly connected to the lowland in the river valley</td>
</tr>
<tr>
<td>Potentially suitable area</td>
<td>Areas with &lt;12% clay in the C or D horizon. Drainage area may be directly connected to the lowland in the river valley</td>
</tr>
<tr>
<td>Not suitable</td>
<td>Lowland in the river valley</td>
</tr>
<tr>
<td>Local evaluation</td>
<td>Reclaimed drained areas require local assessment with regard to suitability</td>
</tr>
</tbody>
</table>

AREAS WHICH MAY RECEIVE SUBSIDIES FOR CONSTRUCTING SF-CW

Source: http://miljoegis.mim.dk/cbkort?profile=lbst
RECOMMENDED DESIGN OF A SF-CW

SupremeTech design

A combination of low-water vegetation zones and open deep water zones gives the possibility to optimize the hydraulic retention time and hence the N denitrification rate.
PERFORMANCE OF SF-CW

Constructed wetlands work in relation to both nitrogen (N) and phosphorus (P).

The total water surface of the SF-CW needs to be at least 1% of drainage area to achieve a sufficient hydraulic retention time (HRT) for the processes to be effective.

PERFORMANCE OF SF-CW

Constructed wetland Fillerup. Mass balance for (a) total N (TN) and (b) total P (TP) calculated as mass loaded on and exported from the SF-CW arranged on a monthly basis as an average over 4 measurement years (2013-2017). The solid lines indicate the average monthly TN reduction efficiency and TP retention efficiency, while the dotted lines indicate the average annual TN reduction and TP retention.

PERFORMANCE OF SF-CW

Linear relation between annual nutrient supply to the SF-CW (kg per ha SF-CW area per year) and annual reduction/retention (kg per ha), respectively for a) total N (TN) and (b) total P (TP). Data from 14 Danish SF-CW in the period 2013-2017.

Biofilters for N and P removal from drainage water

Carl Christian Hoffmann Institute for Bioscience, Aarhus University
Design

Dimensions: 10 x 10 x 1m

Grain size:
- Mussel shells: 2 – 4 mm
- Woodchips: 8 – 32 mm

Cost-effective filter technologies targeting P-retention and N-removal in agricultural drainage discharge

www.supremetech.dk
Measured Parameters

- Hydraulic load / hydraulic residence time HRT (daily)
- Water analysis (influent, effluent) continues sampling (ISCO)
- Water analysis internal / spacial variation (piezometers)
- Water analysis: Temperature, O₂, pH, EC, Cl⁻, SO₄²⁻, TOC/DOC, BOD5
- Water analysis nutrients: TN, NH₄⁺, NO₂, NO₃⁻, org-N, TP, PO₄, org-P, PP
- In situ redox potential
- Green house gases N₂O(g), N₂O(dissolved), CH₄(g), CH₄(dissolved)

Representability

- Hydraulic residence time (HRT) from 3 hours to >10 days
- Drainage water concentrations in influent 5-14 mg TN L⁻¹
- Results / models can be up scaled
HYDRAULIC LOAD CW1 - GJERN SITE

Graph showing inflow and outflow data with precipitation and evaporation percentage influence. The graph includes data for Basin 1 with inflow and outflow trends over the months.
HYDRAULIC LOAD – SKOVLYVEJ

Flow M³

SEP15 DEC15 MAR16 JUN16 SEP16 DEC16 MAR17 JUN17

mm

0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500 3600 3700 3800 3900 4000
## Gjern: Mean daily flowrate in M$^3$

<table>
<thead>
<tr>
<th>Horisontal</th>
<th>CW1</th>
<th>CW2</th>
</tr>
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<tbody>
<tr>
<td>Season</td>
<td>Flow</td>
<td>Min</td>
</tr>
<tr>
<td>Winter</td>
<td>74,0 ± 10,7</td>
<td>17,6</td>
</tr>
<tr>
<td>Spring</td>
<td>31,7 ± 3,9</td>
<td>22,2</td>
</tr>
<tr>
<td>Summer</td>
<td>21,1 ± 3,0</td>
<td>0,2</td>
</tr>
<tr>
<td>Autumn</td>
<td>25,0 ± 3,9</td>
<td>14,2</td>
</tr>
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± 95% cl
## Gjern: Water residence time during the four seasons

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Nitrate reduction in subsurface flow constructed wetlands of different design and with a matrix of woodchips and mussel shells (biofilter)

From Hoffmann & Kjærgaard, 2017
Yearly variation in N-reduction efficiency

From Hoffmann & Kjærgaard, 2017
TN BALANCES

From Hoffmann & Kjærgaard, 2017
## TN Removal Efficiencies

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# Nitrogen Mass Balances

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<th>%</th>
<th>Load NO₃ (g N m⁻² y⁻¹)</th>
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<th>%</th>
<th>Load NO₂ (g N m⁻² y⁻¹)</th>
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<th>%</th>
<th>Load NH₃ (g N m⁻² y⁻¹)</th>
<th>Ret. NH₃ (g N m⁻² y⁻¹)</th>
<th>%</th>
<th>Load Org-N (g N m⁻² y⁻¹)</th>
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STATISTICAL ANALYSIS

› Percentage TN removal = f(HRT, Water temperature); i.e. all six CW’s
  \[ R^2 = 0.85 - 0.88 \]

› Percentage Nitrate-N removal = f(HRT, Water temperature); i.e. all six CW’s
  \[ R^2 = 0.83 - 0.88 \]

› No effect of TN/Nitrate-N concentration

› Completely in line with results from the literature

› Quote W.D. Robertson, 2010: “In practice zero order kinetics” (i.e. above \( k_m \))
### P-BALANCES: PP & PO$_4$-P

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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW6</td>
<td>2013</td>
<td>-605</td>
<td>-50</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CW6</td>
<td>2014</td>
<td>101</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Sulphate reduction when nitrate removal is high
## Gas emissions at different flow rates

<table>
<thead>
<tr>
<th>Basin</th>
<th>Water level</th>
<th>Flow rate</th>
<th>HRT</th>
<th>Emission</th>
<th>Dissolved net export</th>
<th>Net export</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CH$_4$-C</td>
<td>N$_2$O-N</td>
<td>CH$_4$-C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N$_2$O-N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mg h$^{-1}$ SSF-CW$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1.52</td>
<td>12.61</td>
<td>93.4</td>
<td>0.6</td>
<td>8765.0</td>
</tr>
<tr>
<td></td>
<td>-25 cm</td>
<td>1.11</td>
<td>12.95</td>
<td>21.3</td>
<td>1.1</td>
<td>1032.5</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1.52</td>
<td>12.61</td>
<td>37.5</td>
<td>0.89</td>
<td>3353.1</td>
</tr>
<tr>
<td></td>
<td>-25 cm</td>
<td>1.13</td>
<td>12.78</td>
<td>14.0</td>
<td>0.86</td>
<td>3515.9</td>
</tr>
</tbody>
</table>

Jacob Bruun, 2016. Denitrification, greenhouse gas emission and solute transport in reactive drainage filters (Subsurface flow constructed wetlands). PhD thesis, Aarhus University, Department of Bioscience
Development of design
Development of design

Volume = 280 M³

Volume = 220 M³
TN mass balance for the two stage constructed wetland. The calculation is based on a total area of 500 m² (280 m² pond + 220 m² bioreactor). As the depth is approximately 1 m the unit can also be expressed as g TN m⁻³.

<table>
<thead>
<tr>
<th>Season</th>
<th>Load g TN m⁻²</th>
<th>Loss g TN m⁻²</th>
<th>Retention g TN m⁻²</th>
<th>% Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2016</td>
<td>46</td>
<td>5</td>
<td>41</td>
<td>88</td>
</tr>
<tr>
<td>Summer 2016</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>71</td>
</tr>
<tr>
<td>Autumn 2016</td>
<td>118</td>
<td>51</td>
<td>68</td>
<td>57</td>
</tr>
<tr>
<td>Winter 2016/17</td>
<td>66</td>
<td>14</td>
<td>52</td>
<td>78</td>
</tr>
<tr>
<td>Yearly balance</td>
<td>233</td>
<td>71</td>
<td>162</td>
<td>70</td>
</tr>
</tbody>
</table>
Research needs and challenges

• $\text{H}_2\text{S}$
• $\text{CH}_4$
• $\text{N}_2\text{O}$
• Decomposition of woodchips
• Grain size - Porosity
• Re-oxidation
• Odeur
• Design solutions
• Life time
• Operation in practice
  • Winter – summer
  • Surveillance & inspection
CHALLENGES

› Low flow situations especially in summer with little or no drainage discharge and high temperatures resulting in complete nitrate reduction followed by sulfate reduction and methanogenesis

› Solutions are currently being investigated
CONCLUSIONS

- Annual TN removal rate up to 0.7 – 0.8 kg N g N m⁻² year⁻¹ (also nitrate)
- At the Gjern test site percentage TN and Nitrate-N was removal highest for the horizontal flow design i.e. approx. 55% while the vertical design was approx. 45% (some variation).
- New design solutions may handle peak flow situations better
- Percentage removal of TN and Nitrate-N solely dependent on temperature and HRT and in line with international studies
- Models can be used elsewhere and up scaled (see Vand og Jord nr. 3 2017)
- Methane emission is easily solved by having an unsaturated top layer of minimum 20 centimeter
REMOVAL OF MICRO-POLLUTANTS FROM WASTEWATER

Kai Bester
kb@envs.au.dk
Wastewater treatment –

a fascinating biotech process
Triclosan in conventional wastewater treatm.  
95% removal

Bester, 2003 and 2005, Chen et al., 2014
Env. Chemistry in the Water Cycle

Emissions

Buildings

Hospitals

Municipal

Reactor Design

New Biotechnology

Materials Source-control

Biodegradation

Effluents

Surface water

Soil/sludge

Drinking water

Stormwater

Enantioselective processes

Phototransformation

Redox reactions with bio-nanoparticles
The urban water cycle

- Rain
- City
- Surface Water
  - WWTP
  - CAS
  - Biofilm
  - Ozone
  - Biofilm
- Soil
- Ground water
- Biofilm
- Drinking water
Ozonation

Process Control
- Competing Reactions
- Transfer ozone -> water
- Transformation reactions
- Effects of Fe, Mn

MBBR

Fundamental processes
- Control co-degradation
- Aerobic/anaerobic
- BioMnOx
- Metabolites

Process control
- Control co-degradation
- Aerobic/anaerobic
- C/O₂ supply
- Metabolites

Porous medium biofilm

Membranes

Osmosis membranes MBR
- Optimise C/O₂
- Co-degradation
- HRT/SRT
Coupling of technology/Hybrids

Can biofilms be coupled to Chemical oxidation?

benefits and drawbacks
## Persistence of compound groups in wastewater

<table>
<thead>
<tr>
<th>Compound Group</th>
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<tbody>
<tr>
<td>X-ray contrast media</td>
<td>😞</td>
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<tr>
<td>Diclofenac/Carbamazepine</td>
<td>😞</td>
<td>😃</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>😃</td>
<td>😞</td>
</tr>
<tr>
<td>Sulfonamides</td>
<td>:-/</td>
<td>😃</td>
</tr>
<tr>
<td>Macroyclic antibiotics</td>
<td>😞</td>
<td>😞</td>
</tr>
</tbody>
</table>
Biofilms as the most interesting/potent approach for future water technology

What is so special about biofilms?

- Microbial communities with highly specialised functions
- Internal gradients
- Highly resistant against attacks from the outside
Removal of Organophosphates in Undergroundpassage (bank filtration)

A nice landscape?

A recreational area?

A biofilm reactor producing 200,000 m³ water per day
Removal of Organophosphates inherently not degradable (REACH)

VF: Gravelfilter (Hengsen), LS/UP: Slow Sandfiltration and Undergroundpassage (Hengsen), LS/BP/UP: Slow Sandfiltration and Soil/Underground passage (Lappenhausen)

95-99% removal
Porous Medium Biofilm

- Grains
- Biofilm
Moving Bed Biofilm Reactor with carrier chips of typically 20 mm
Reactions in Biofilms
Gradients in Biofilms

Oxidation

Reduction

Biofilm

A

B

C

O_2

No O_2
Basis of the pilot staged aerobic MBBR

Compound + Oxigen → Biomass + CO₂
Staged aerobic MBBR

- 21/26 compounds degraded >20%
- First order kinetics for most compounds
- Two phase kinetics for four compounds
- While M1 degrades faster, has M3 usually the more effective biomass

Diclofenac reaction rate \( K = 8.01 \times 10^{-2} \) \( K_{bio} : 2.58 \times 10^{-2} \)

Escola Casas et al., Wat Res., 2015
Basis of anaerobic (denitrifying) MBBR

Carbon + NO$_3^-$ → Biomass + N$_2$
Denitrifying/Anoxic MBBR

Torresi et al., Wat Res., 2017
• Denitrifying MBBR is nearly as effective as aerobic
• MeOH reactor does a bit better than the EtOH reactor
• Diclofenac cannot be degraded under denitrifying conditions
• Carbamazepine can be degraded under denitrifying conditions

Torresi et al., Wat Res., 2017
Organic micropollutants - degradation

Smart, energy friendly, but how?

Competition with easy food

Micro-pollutant

Easy food/BOD







Essential co-degradation

Micro-pollutant

Easy food/BOD


Intermittent feeding -> Diclofenac

Raw wastewater
3 Days
18 HRT

Effluent wastewater
6 Days
36 HRT

Tang et al., Bioresource Technology, 2017
Removal of Diclofenac with MBBR under intermittent feeding

![Graph showing the concentration of Diclofenac over time for different positions (A, B, C).](https://via.placeholder.com/150)

Tang et al., Bioresource Technology, 2017
## Comparison of Biomass related reaction rate constants

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Third of staged MBBR</strong></td>
<td>Aerobic</td>
<td>Polishing MBBR after HYBAS</td>
<td>Denitrification MBBR</td>
<td>Aerobic</td>
<td></td>
</tr>
<tr>
<td><strong>Aerobic</strong></td>
<td>8.54 x 10^{-2}</td>
<td>3.45 x 10^{-2}</td>
<td>4.10 x 10^{-2}</td>
<td>3.7 x 10^{-2}</td>
<td></td>
</tr>
<tr>
<td><strong>Erythromycin</strong></td>
<td>3.61 x 10^{-2}</td>
<td>2.01 x 10^{-2}</td>
<td>2.08 x 10^{-2}</td>
<td>2.5 x 10^{-2}</td>
<td></td>
</tr>
<tr>
<td><strong>Diclofenac</strong></td>
<td>1.48 x 10^{-2}</td>
<td>0.33 x 10^{-2}</td>
<td>--</td>
<td>--</td>
<td>23·10^{-2}</td>
</tr>
</tbody>
</table>
Reaction products / Metabolites

Biofilm

A B C D
Metabolites in aerobic MBBR
- Clindamycin -

Postulated Clindamycin metabolites in biofilm reactor

Clindamycin

Clindamycin - sulfoxide

Desmethyl-Clindamycin

Ooi et al. Wat Res, 2017
Production kinetics of clindamycin metabolites in MBBRs

Ooi et al. Wat Res, 2017
# Persistence of compound groups in wastewater

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<tr>
<td>Macro cyclic antibiotics</td>
<td>😞</td>
<td>😞</td>
<td>😊 ?</td>
</tr>
</tbody>
</table>
Hybrid technologies

Ozonation ↔ Biofilm
Ozonation of Diclofenac

- 4 OH
- 282
- 5 OH
- 328
- 178
- DCF-Amide
- Quinone-imine

DCF
Ozonation of Erythromycin, Clarithromycin, Azithromycin

Can those ozonation products be removed with biofilm reactors?

El Taliawy et al., 2018
Adaption of the biofilms

- Effluent wastewater
- Batch feed twice a week
- Low biomass (46 mg dry matter/ chip)
- Biomass adapted to tough food

El taliawy et al., J Hazardous Materials, 2018
Degradation of Erythromycin N-oxide in MBBR (1µg/L)

El Taliawy et al., 2018
Degradation of Clarithromycin N-oxide in MBBR (1 µg/L)

El Taliawy et al., 2018
Degradation of Clarithromycin N-oxide in MBBR
(elevated concentration 10 µg/L)

El Taliawy et al., 2018
Hybrid technologies

Are options to remove compounds more complete

Currently tested fullscale in Linköping as well as Landskrona
DK has a lot of dumpsites containing pesticide residues
Compounds of concern are leaching out
Can the soil/groundwater be cleaned up?
Transformations of MCPP in a biofilm

Hitherto unknown compound: chloromethylphenol sulfate: CMPS

Escola Casas, et al., Wat. Res., 2017
Enantioselective degradation of MCPP in biofilms

Reactions are enantioselective

Enantioselectivity is concentration dependent

Saturation kinetics: The amount of enzymes is limiting

Escola Casas, et al., Wat. Res., 2017
Mecoprop metabolism in biofilm Reactors – Concentrations of the metabolite CMPS

Escola Casas, et al., Wat. Res., 2017
Biofilms can be good for you

They can be well-performing technology

They can do things other bioprocesses cannot

They can do things cheaper than chemical oxidation

We need to understand co-degradation better to build good plants

We need to understand gradient systems better

Cake ryebread and oxygen are probably controlling degradation
DEVELOPMENT OF SENSORS FOR WATER ANALYSIS

FROM A SUCCESSFUL PAST TO A HOPEFULLY EVEN BETTER FUTURE
A LOOK BACK

Aarhus University – Home of Microsensors
FIG. 2. Vertical distribution of dissolved $O_2$ and $H_2S$ and of the redox potential (Eh) during day (1335 h) and during night (0400 h). September 1978.

September 1978!

This is 6 years and 9 month before I was born!
ELECTROCHEMICAL SENSORS

A  Oxygen microelectrode
- Shaft of sensing cathode
- Epoxy
- Silver wire cathode
- Ag/AgCl anode
- Soda-like glass
- Electrolyte
- Schott 8533 glass
- Platinum wire

B  Microelectrode tips
- Guard silver cathode
- Platinum
- Schott 8533 glass
- Sensing gold cathode
- Silicone rubber membrane

1 cm
10 μm
Analytes that are available

O₂
N₂O
H₂
H₂S
NO
pH
CO₂
STOX (super trace oxygen sensors) nM O₂ detection
Combined Sensors: H₂/H₂S and O₂/H₂

Redox Sensor
Electric Potential Sensor
Diffusivity Sensors
Flow Sensors
Whole cell biosensors for important analytes

- Bacteria transform certain substance
- Electrochemical sensor is used as transducer

+ Several analytes available
- Long-term stability
- Microsensors are rather difficult to build
AVAILABLE ANALYTES

Combined NO$_3^-$/NO$_2^-$

NO$_2^-$

Methane

Volatile fatty acids

Ammonium
Biosensors in wastewater treatment

A FEW APPLICATIONS

![Graphs showing NO$_2^-$ concentration over time with different markers for different samples and methods.](Image)
A LOOK INTO THE FUTURE

Where the Sensor Laboratory wants to go in the next years
NEW TOOLS FOR WATER SENSING

Extending the toolbox

Optical Sensor
- Chemical imaging
- Fiber optic sensors
- Nanosensors

Electrochemical Sensors
- New analytes
- Improved stability

Biosensors
- New analytes
- Improve long-term stability

Sensor Application
- Testing at real-world conditions
NEW SENSOR DESIGNS AND ANALYTES

Optical Sensors

Micro-Optode

Bulk-Sensor Macro-Optode

Planar-Optode

Sensor Particles

Sensor Patches

O₂ nanoparticles indicator inside a polymeric matrix

O₂ microparticles indicator inside a polymeric matrix

O₂ sensor patch similar design than planar optode

Optical fiber or other means of external readout
MAKE CHEMISTRY VISIBLE
O₂ DISTRIBUTION IN NITRIFYING AGGREGATE

Image by Prof. M. Kühl;
University of Copenhagen
THE CHEMISTRY AROUND ROOTS
In an artificial sediment

USING NANOSENSORS TO SHOW $O_2$ AND PH
In real sediment

PLANAR SENSORS COMBINED WITH DGT
PLANAR SENSORS COMBINED WITH DGT
CURRENT PROJECTS
- Building up all the needed tools and setups to produce optical sensors

- Due to founding from **Poul Due Jensen Foundation** this is on a very good way

- We have (almost) all the tools to make sensors

- Also new imaging and read-out systems are available

- Start developing and producing sensors
BIOSENSOR FOR VFA

From prove of concept to application
Increasing long-term stability

Biosensors current bottle neck is the lack of long-term stability

- Find new bacteria with improved characteristics
- Engineering of bacteria
- Enable online calibration

Will be a clear focus in the next years!
A PostDoc will be hired on that very soon
TAKE “HOME” MESSAGE

- Sensors are versatile tools for water monitoring and other related purposes

- AU has a great tradition in sensor development and WATEC will stimulate future developments

- WATEC is about collaboration and finding new solutions for problems together.

You are always welcome to talk to me about using sensors!!!
THANK YOU FOR YOUR ATTENTION
Optimization of wastewater treatment for resource recovery
TREND?

Waste water treatment plant?

Ressource recovery facility?
Drivers? Circular economy

Finite materials in waste water:
- Fossil carbon (related to N)
- Phosphorous
- Metals
- Other?

System leaks
- Nitrogen
- Phosphorous
- Carbon
- Metals
STATE OF THE ART?

Household carbon:

Carbon losses
Aerobic degradation: 50%
Anaerobic digestion: 25%

Recovery:
CH4: 25% ??
biosolids

Household nitrogen:

Nitrogen losses
N removal process N₂
Effluent loss

Recovery:
Dewatered sludge: ?
Struvite precip.

Household P:

Phosphorus losses
Effluent loss

Recovery:
Dewatered sludge: ?
Struvite precip.
Marselisborg WWTP – Main Flow Diagram

1: Catchment area pumps
2: Coarse screen
3: Overflow basin
4: Inlet pumping station
5: Inlet screen
6: Screening press
7: Grit chamber & grease trap
8: Grease tank
9: Sand washer plant
10: Chemical tank (P/CX dosing)
11: Overflow tank
12: Primary clarifiers
13: Biological tanks (Nitrification/denitrification)
14: Secondary clarifiers
15: Intermediate pumping station
16: Sand filters
17: Outlet pumping station
18: Sludge thickeners
19: Sludge pre-dewatering
20: Sludge buffer/thickeners tanks
21: Anaerobic digesters
22: Gas storage tank
23: Gas treatment (activated carbon)
24: Gas boiler (standby)
25: Gas motors
26: Homogenizing/storage tanks
27: Final sludge dewatering
28: DLMON® Anammox side-stream

Primary water flow
Secondary water flow
Sludge
Biogas
Sand and grease
Screenings
Chemicals
Next generation carbon recovery?

- Get as much primary sludge out as possible (assisted settling and filtering)
- Recover DOC as biomass in high growth yield aerobic bacteria
- Recover DOC as CH$_4$ from fixed bed AD’s

Great, but what about the classical N-removal?

- Cold anammox?
- Nitrite shunt?
- Ion exchange (zeolites),
- Adsorption
- NH$_3$ stripping
- Membrane separation (RO)
Phosphorus recovery?

- Physical filtration and membrane (P in sludge)
- Chemical precipitation (P in sludge)
- Chemical extraction (acid treatment of sludge, ashes etc)
- Biological assimilation (Bio-P, or extensive in constructed wetlands)
- HTL assisted P precipitation

Driver for solutions?
Raw market economy of societal ambition?
Suggestions from literature....

Dark fermentation, e.g. pre-proces for bioplastics

Front Microbiol.
WHAT TO DO WITH THE SLUDGE?

- Food
- Feed
- Materials
- Energy carriers (carbon based fossil replacements...)
- Energy as electricity/heat
BIOFUELS

Anaerobic digestion

• Pretreatment of sludge + co-digestion
• Process design, new ideas...

General question of fitting biogas into energy systems (upgrading, Frid injection, methanation, CO₂ activation....)
Research in wastewater treatment technology.............
BIOFUELS

Hydrothermal liquefaction

Patrick Biller
REBOOT

Resource efficient bio-crude production and wastewater treatment
REBOOT HTL TECHNOLOGY

- Hydrothermal liquefaction (HTL) - High temperature and pressure process mimicking natural fossil crude formation

- Wet sludge is processed at 350°C and 200 bar to produce bio-crude, solid residue, process water, and CO₂

- Xenobiotics and microplastics are destroyed and converted to oil

Primary & secondary sludge
(0.7 MJ/kg)

HTL 350°C, 200 bar, 15 min

Bio-crude (35 MJ/kg)
HTL INTEGRATION

HTL can replace Anaerobic Digestion (AD) at a WWTP

✔ Recovers ~70% of sludge carbon as fuel
✔ Destroys pollutants
✔ Fuel production cost of ~0.7€/L
✔ Reduction of >90% in sludge for disposal
✘ Dry matter of sludge is low → low energy efficiency in HTL step
✘ ~50% of incoming C is lost as CO₂ in biological treatment

BIOMASS ASSISTED SLUDGE FILTRATION

How can we increase the dry matter content of sludge?

- We noticed that our usual HTL feedstocks from lignocellulosics are very fibrous after extrusion
- The filter cake resistance is extremely low resulting in very fast and low energy intensive concentration of sludge
- Filtration efficiencies of >90% (TS), >95% (organic) achieved.
- Sludge DM ~3% → filter cake DM ~25%
- The filter medium adds organic material for the HTL process to produce additional fuel
HTL INTEGRATION AT WTTP

HTL and biomass filter replace (AD) at a WWTP

✔ Recovers ~70% of sludge carbon as fuel
✔ Destroys pollutants
✔ high energy efficiency (~10 units out for 1 in)

✘ ~50% of incoming C is lost as CO₂ in biological treatment
REBOOT HTL WWTP

HTL and filtration replacing primary and secondary treatment at WWTP

✔ Eliminates aeration cost in biological tanks
✔ particle free streams suited for membranes and UASB (reduced fouling)
✔ Influent carbon converted to fuel and methane
✔ 70% incoming carbon recovered as fuel, 10% as methane
NUTRIENT RECOVERY

- At 350°C and 200 bar phosphates and other salts are insoluble in water
- Phosphate precipitates and is filtered out continuously

- Phosphorous recovery in concentrated solid residue is >95%

- We can combine the HTL process water rich in NH$_4$ with PO$_4$ to produce struvite

- Efficiencies recovery of ~90% from incoming HTL feedstock

- P is bioavailable
SUMMARY

✔ Complete destruction of micro pollutants
✔ Overall energy efficiency ~1000% vs ~150% for state of the art using AD
✔ REBOOT recovers 70% of the incoming carbon from wastewater as bio-crude and 10% as methane
✔ Phosphorous recovery as struvite with high efficiency
✔ Efficient filtration of primary and secondary sludge shown
✘ Filtration of raw wastewater still under development
✘ Membrane concentration and UASB digestion still under development
✘ Integration of process steps outstanding
NEXT GENERATION STATE OF THE ART.....

- How much of the influent carbon is exported as biomass/fossil fuel replacement? (forget about energy neutrality......)
- How much of the influent P is delivered in a bioavailable form, free of other substances unwanted in the biosphere?
- Until sustainable Haber-Bosch, how much N is recovered?
Are others looking at this?

Inspiration from recent visit in Ghent

Tackling the slow implementation of technology for resource recovery

- Decentralized, project based
- Targets are undefined
- Business case is limited or unclear for problem owner
CONTACT

Head of Centre
Professor, Niels Peter Revsbech
M: +45 2338 2187
E: revsbech@au.dk

Administration
Coordinator, Kristine Howe Kjer
M: +45 4017 9739
E: kkh@bios.au.dk

News and events
www.watec.au.dk
Lake and stream restoration and modelling

Erik Jeppesen, Annette Baattrup-Pedersen and Dennis Trolle
Bioscience, Silkeborg
Lakes
Ecological classification of Danish lakes – Water Framework Directive

Yellow to red: Moderate to bad

Green and Blue: OK! - Good

High <30%
Diffuse pollution

5 mill. people (great sewage treatment) and 15 mill. pigs and cattle, walking around even without any underpants!!!!!
Shallow
Deep

Nielsen et al,
2011
Danish lakes

Johansson et al
Danish lakes

Johansson et al
Reduction in algal biomass and increase in water clarity (Secchi depth)

Jeppesen et al, in prep.
Chemical and biological resistance may delay lake recovery

Jeppesen et al
Total phosphorus

Aluminium-tilsætning

Ritzel et al
Biological methods used in Denmark

Removal of zooplankti-/benthivorous fish
Stocking piscivores (pike, *Esox lucius*)
Transplanting/protecting macrophytes
Zebra mussels (only "natural" invasions in Denmark).
Others (nest traps for spawning fish)
Combined methods
Temperate lake in balance

- Fish eating fish
- Prey fish
- Water flea
- Algae
- Nutrients

Degraded temperate lake

- ‘Good guys’
- ‘Bad guys’

Jeppesen
Trawling
Algal biomass

Lake Bastrup
- Before
- After

Lake Arreskov

Lake Engelsholm

Jeppesen et al
Half the effort 2nd time

Søndergaard et al, 2017
Roach is coming back
Size declines

Søndergaard et al. 2017
Combined methods in focus now
Cyanobacterial blooms in Lake Dianchi
Removing fish

Lower the water level and restoring macrophytes

修复亚热带湖泊 - 我们预计会很困难

清理掉这些坏蛋

放养食鱼

 Zhengwen Liu
Longevity of the restoration?

Huizhou West Lake, China
Zhengwen Liu
Loss of streams and habitats

- The total stream length in Denmark has been significantly reduced (40-50%)
- Some types of habitats are almost eradicated
  - Backwater habitats and oxbow lakes
  - The habitat diversity (riffle, run and pool) has declined. Riffle habitats have been lost.

Natural, physical unmodified streams are rare in Denmark (<5% of all)
Restoration projects in Danish streams

Many restoration projects targeting physical improvements have been conducted in streams over the last decades.
How has restoration been performed?

- Most of the projects have been local, confined to the establishment of spawning grounds for trout
- Very few projects have involved re-meandering of whole stream reaches
- Many projects have used excessive amounts of coarse substrates in comparison to what is natural in Danish streams
The number of endangered species confined to coarse substrates is limited

- Approximately 25% of the endangered species are associated with gravel
- Half of the endangered species are more or less specifically associated with plants and woody debris
- Half of the endangered species are more or less specifically associated with bank and backwater habitats
- Approximately 25% of the endangered species occur only in bank and backwater habitats
Restoration – succes or failure?

- It is difficult to evaluate restoration success since few data exist for restored sites and only for a limited number of parameters—few data on fish and plants.
Comparative studies

- Generally before-after studies are few and have only been performed 1-2 years after the restoration.

Based on comparative studies over number and abundance of endangered macroinvertebrate species in 6 channelized, 6 natural and 6 restored streams in Denmark.

Fra: Pedersen et al. 2014. Plos One
River Skjern

- Restoration of River Skjern has created a number of new habitats. However, the stream width and the area with backwaters is still low and oxbow lakes are missing compared to former conditions (1871).

- The number of endangered macrophyte and macroinvertebrate species is lower than in the reference period (1942-1963).

- For the macrophytes app. 40% of the species are still missing when comparing to the reference period, especially Potamogeton species.

- Species that are missing are mainly those associated with backwater habitats and the river margin habitats.
Climate change a big challenge for restoration

**Global Average Temperatures**

**IPCC Emission Scenarios**
- High
- Medium
- Low

**Temp Rise degC**

**Years**
- 2000
- 2020
- 2040
- 2060
- 2080
- 2100
Temperature increase

Potential negative effect of increased temperature – notable in the open land

Critical temperature for trout (*Salmo trutta*) and some mayflies (*Baetis rhodani*).

Optimal vækst <19.1 °C

Dødelig >24.7 °C (Elliot, 1994)

Kristensen, P. B et al. 2015. Inland Waters.
Water temperature changes markedly in streams running from open areas to forest.

Diel variation also reduced.

Kristensen, P. B et al. 2015. Inland Waters.
Canopy cover important

Kristensen, P. B et al. 2015. Inland Waters.
Not only effect on the temperature

Habitat complexity - food sources

Diversity

Rasmussen, J. J. et al. 2015. Unpubl. data
Temperate lake in balance

- Fish eating fish
- Prey fish
- Water flea
- Algae
- Nutrients

Degraded temperate lake

- ‘Good guys’
- ‘Bad guys’

Jeppesen
Figure 3.4. Change in annual runoff by 2041-60 relative to 1900-70, in percent, under the SRES A1B emissions scenario and based on an ensemble of 12 climate models. Reprinted by permission from Macmillan Publishers Ltd. [Nature] (Milly et al., 2005), copyright 2005.
Loading depending on runoff

33-42% increase in the last 80 years due to increase in discharge – present days fertilisation

Jeppesen et al, 2009
Warming effects

Warming enhances the risk of eutrophication and enhances the Chla:TP ratio, lower water clarity

Higher risk cyanobacteria blooming

Higher predation from fish, less zooplankton grazing

Lower nutrient thresholds needed to obtain/maintain “good ecological status”
Many of the symptoms of warming are similar to those of europhication – so we can compensate to some extent by taking…. 

Action folks!!!!

Reduce the external nutrient loading!
Modelling exercise

A 6 degree celcius increase in temperature – means a 76% extra reduction in external loading to achieve just the present ecological state in shallow Danish lakes

Nielsen et al, 2014
Scaring!!!!
Silkeborg experimental facility -

Climate-nutrient interactions in lakes

- 24 enclosures - flow-through,
- 2 nutrient levels (clear, turbid),
- 3 temperatures (control, A2, A2 + 50%),
- 4 replicates,
- sticklebacks added.
- Continuously since 2003

Longest running in the world since 2003

Jeppesen et al
Silkeborg experimental facility- streams

Diagram:
- Height-adjustable outlet pipe
- Flow regulator
- Stream pump (one pump for all stream flumes)
- Recycling pump (one pump for each stream flume)
- Dimensions of stream flumes: 0.3 m width, 12 m length, 0.6 m depth
PAN-EUROPEAN MESOCOSM EXPERIMENT: NUTRIENTS RETENTION (EU- FP7 REFRESH)

**latitudinal gradient**

1.2 and 2.2 m fiberglass mesocosms with low and high nutrients
“Space for time”

- Arctis-Subarctis
- Temperate zone
- Subtropics
- Tropics
1. Eco-hydrological modelling

Development and application of models for:

1. Understanding the influence of climate and agricultural management on water resources

2. Understanding surface-groundwater interactions

3. Understanding the influence of groundwater abstractions and point source outlets on stream ecology

4. Develop tools that enable the use of models for decision making (bridging state-of-the-art science with management)
2. Coupled hydrodynamic-ecosystem modelling

Example of model simulations for Lake Ravn

The WET tool for experimentation, by Nielsen et al. (at AU)

More info on wet.au.dk
The FABM-PClake ecosystem model, by Hu et al.

**Hydrodynamics**
- store physical variables
- advection, diffusion, time integration
- input/output

**FABM**

**Biogeochemical modules**
- provide variable names, units
- given a local environment, provide local sink and source terms

- Fasham et al. 1990
- Fennel & Neumann (1996)
- Mnemiopsis
- AED
- phytoplankton feedbacks
- ERSEM
- NPZD
- simple passive tracer
- carbonate
- benthic predator
- ERSEM
- NEUMANN
- (2002)
3. Assimilation of sensor data and weather forecasts

Combining realtime sensor data, weather forecasts and models for water forecasts (PROGNOS JPI project)

**Meteorology:**
- Wind speed and direction
- Radiation
- Air temperature
- Humidity

Real-time profiles, e.g.:
- Water temperature
- Oxygen
- Chlorophyll a

Output (online, continuously Water temperature)
- Phytoplankton (e.g. cyanos)
- Potential warning
Holistic approach

...and multi-facted

Diffuse sources:

Climate drivers:

Land use characteristics:

Landscape characteristics:

Water quantity:

Water (ecological) quality: