Drainage filter technologies and constructed wetlands to mitigate site-specific nutrient losses

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Relevance of drainage filter technologies !

Danish "Green growth plan" – reductions

- 19000 (9.000) t N/year
- 210 t P/year

Nutrient load through drainage systems

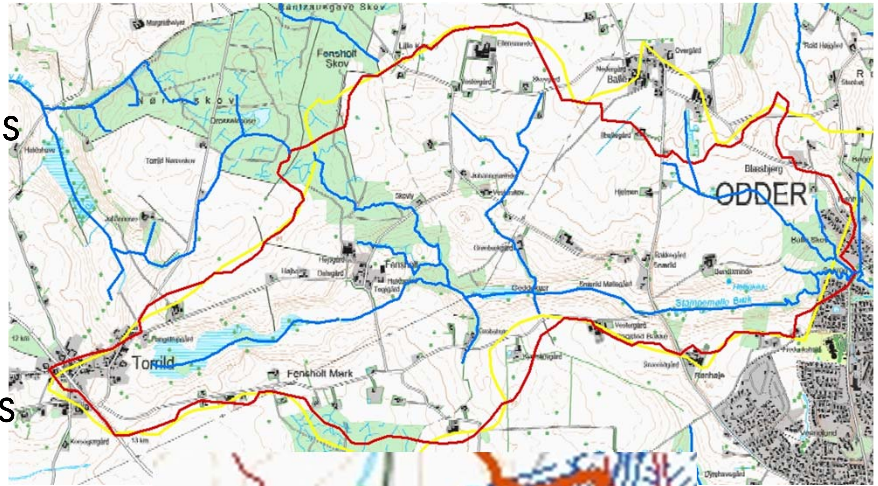
- More than 60% of DK farm land is drained
- Drainage loss of nutrients
- 33% of total P (~ 400 t P/year)
- TP < 1 mg/L (PO_4-P and PP)
- 45-60% of total N (~ 22.000 t N/year)
- TN~ 3-20 mg/L (average 13 mg/L)

Drainage filters disconnects the direct transport pathway between field and aquatic systems and retains or transforms nutrients before they reaches the aquatic ecosystems

Implementation of drainage filter solutions?

Questions

- Which type of drainage filter technologies (DFT) should we apply?
- Where should drainage filter solutions be applied?
- What is the retention efficiency for various DFT – requirements for documentation?
- Other concerns – GHG emissions?
- Are DFT cost-effective solutions?
- What is the long-term efficiency?
- Requirements for maintenance?



Danish research projects on drainage filter technologies

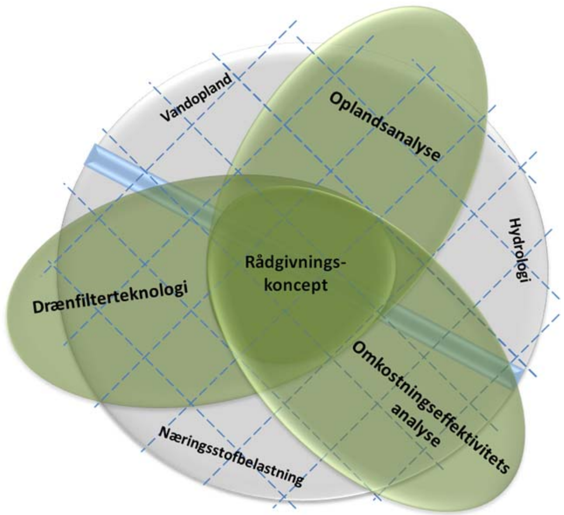
Danish Strategic Research project
DSF funding: 20 mill DKK
Sustainable Phosphorus and Nitrogen Remediation and Recycling Technologies in the Landscape (2010-2015)
www.supreme-tech.dk

SupremeTech

Research: Drainage filter technologies, P retention, N removal, GHG emissions, recycling, modelling, cost-efficiency analysis

Green development and demonstration program
GUDP funding: 13 mill DKK
Implementing and optimizing drainage filter solutions (2011-2015)

Content: Subcatchment tools for implementing and optimizing filter functions. Technical solutions.

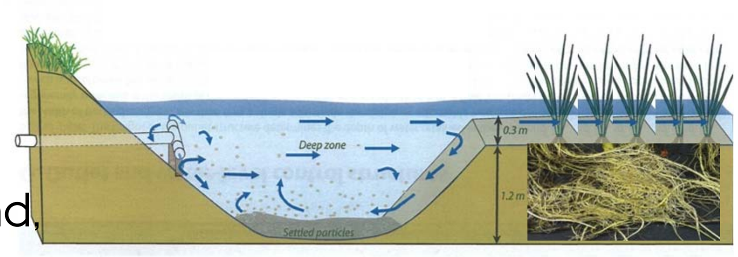


Types of drainage filter technologies

Constructed wetlands:

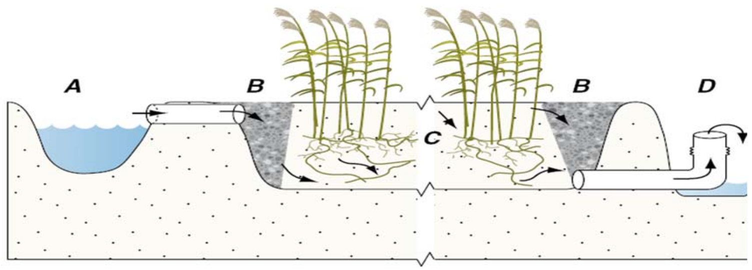
1. **Surface-flow constructed wetlands**

   Known from Sweden, Norway, New Zealand, USA



2. **Subsurface-flow constructed wetland**

   Known mainly from wastewater treatment systems. Only very few pilot investigations treating diffuse drainage discharge.



In-line drainage filter systems

3. **Drainage well filters**

   New innovative filter technologies targeting both suspended solids and nutrient removal

Surface-flow constructed wetlands (SF-CWs)

1. Deep sedimentation basin (~1 m)
- Reduces water velocity / increases HRT
- Sedimentation of particles and PP

2. Shallow vegetation zone (0.3 m)
- Stimulates biological denitrification

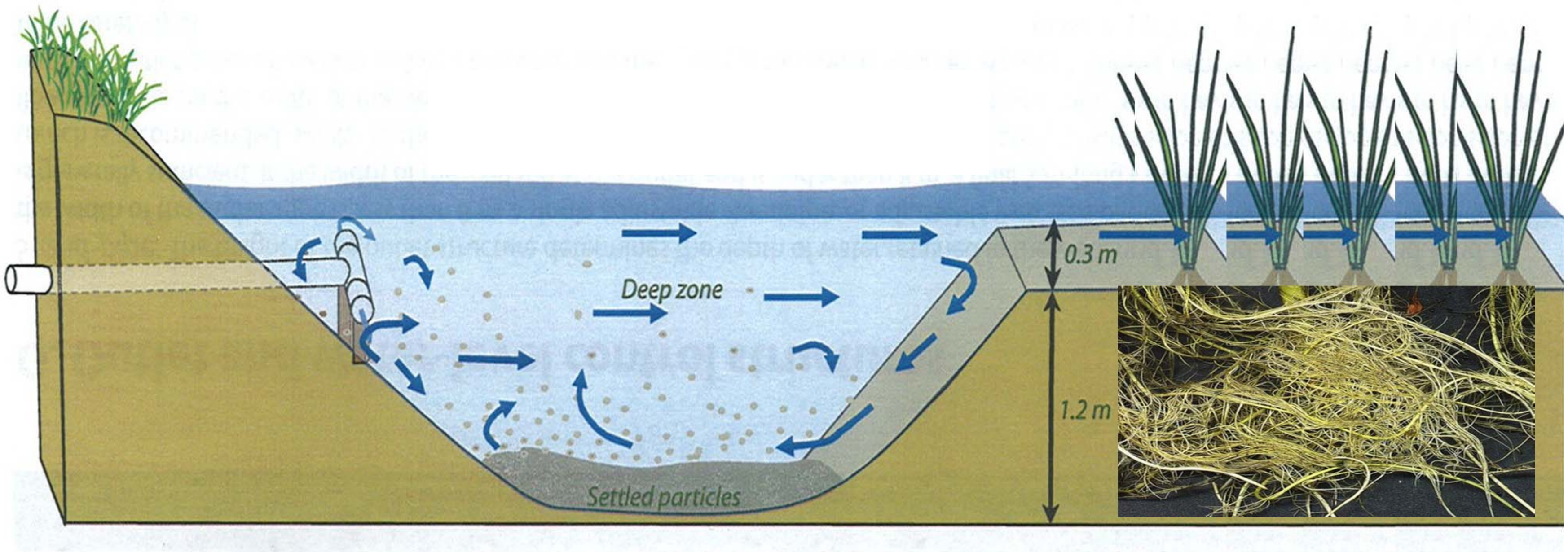
$$2\mathbf{NO_3^-} + 10e^- + 12H^+ \rightarrow \mathbf{N_{2(g)}} + 6H_2O$$

NO_3-N denitrification rates:

0.001-0.48 g m^{-2} d^{-1} (Fleischer et al., 1994)

up to 0.28 g m^{-2} d^{-1} (Xue et al., 1999)

0.22 g m^{-2} d^{-1} (Kovacic et al., 2006)



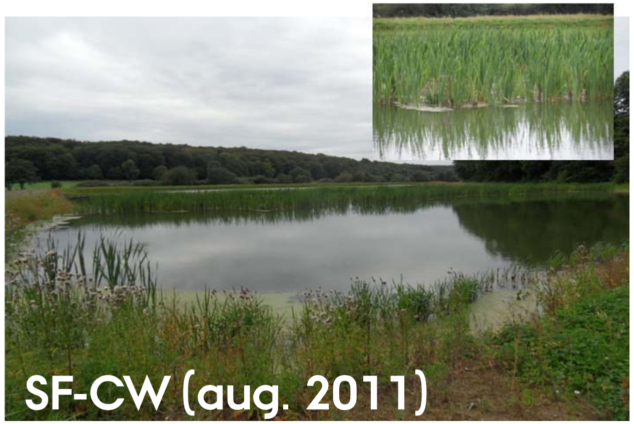
Danish experiences with SF-CWs

About 10-20 SF-CWs established – but without monitoring until last year

SUPREME-TECH – just started

- One-year measurements of two SF-CWs established by Vejle municipality
- Planned construction and 2-years monitoring of ~10 SF-CW (2012-2014)

Famous Danish SF-CW "Rodstenseje" in Norsminde Fjord catchment



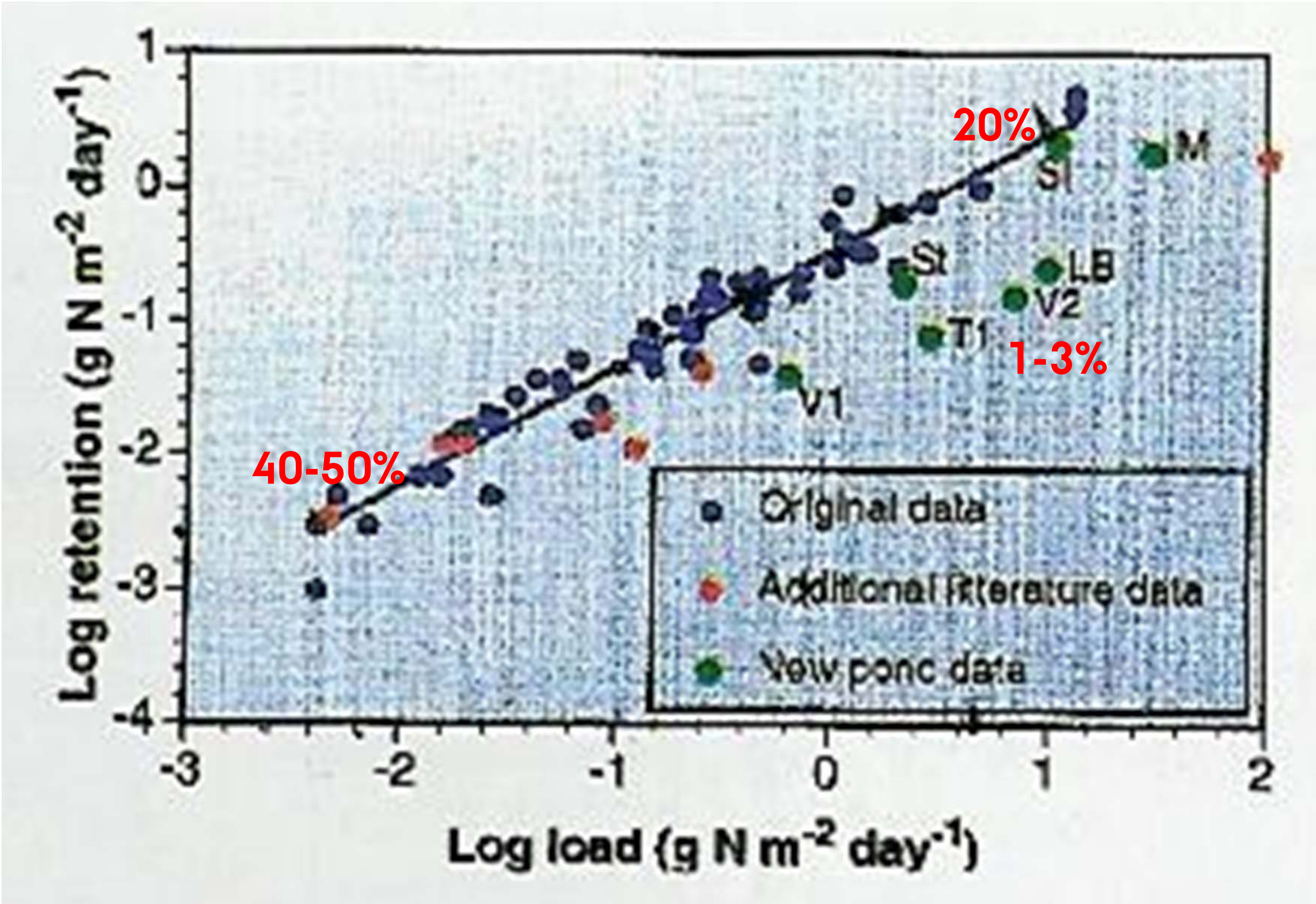
Nutrient retention efficiency in SF-CWs is controlled by system parameters as well as local variable

- Wetland design, hydraulic efficiency
- Temperature ~biological activity
- Form of nutrient (soluble or particulate)
- Nutrient load and seasonal variation
- Retention time – wetland volume vs. water discharge

	TN mass removal (%)	TP mass retention (%)
USA	23 to 44	40 to 88
New Zealand	21 to 79	-101 to 80
Norway	3 to15	16 to 83
Sweden	<3 to >60	1 to 38

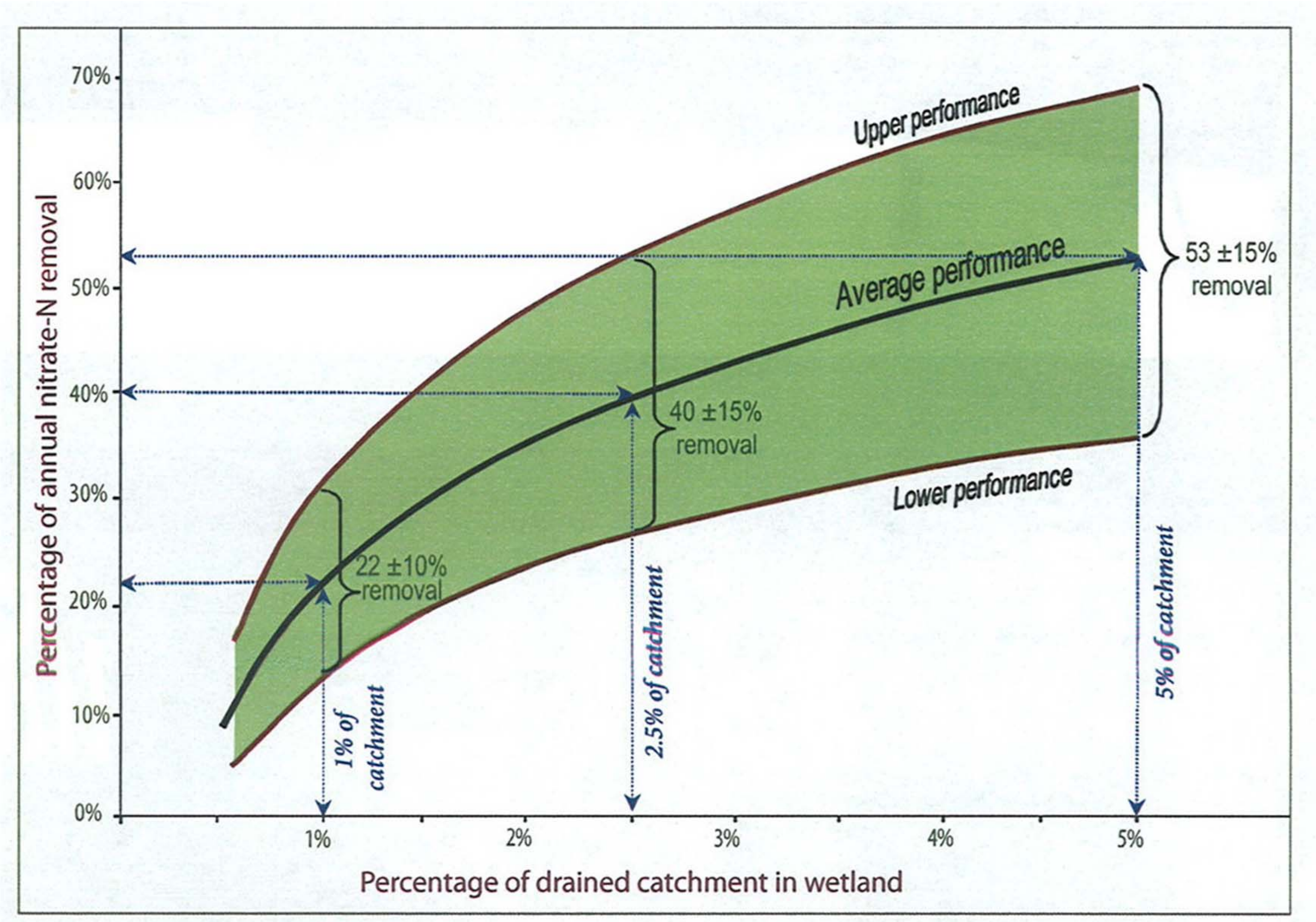
Water retention time is generally considered the most critical single factor for removal of nitrogen. A major challenges treating diffuse discharge is that most transport occurs druing high flow periods in winter.

Nitrogen removal efficiency in Swedish ponds

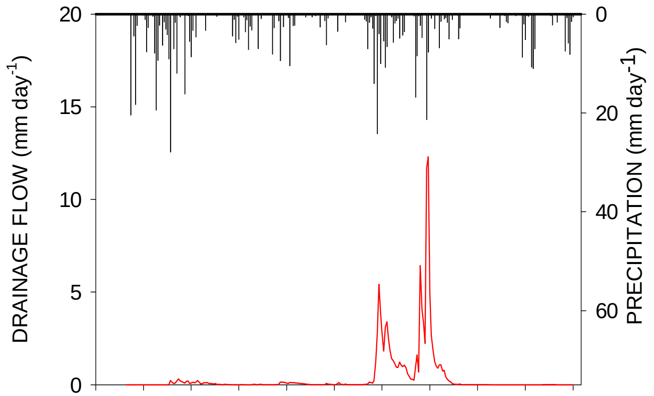


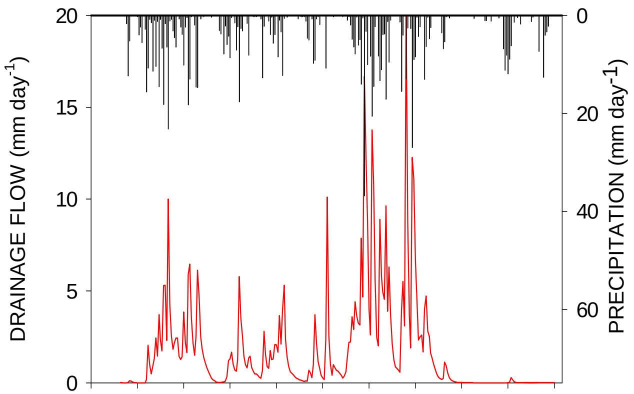
Reference: Fleischer et al. 1994

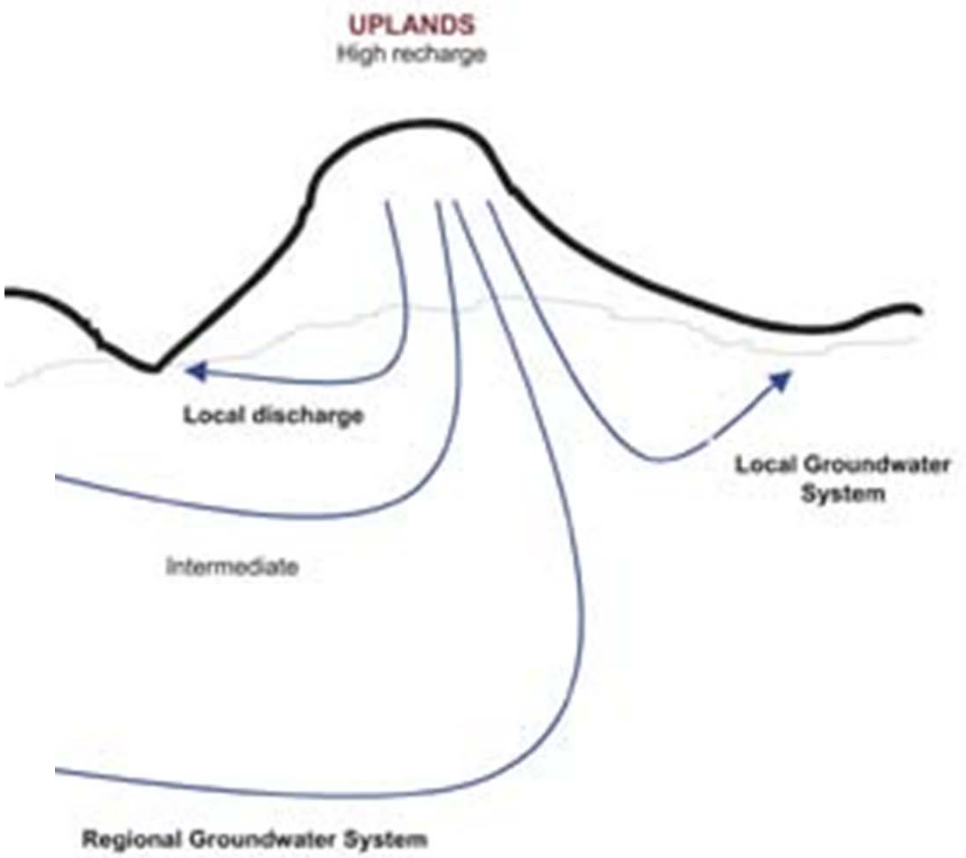
Nitrogen removal – New Zealand guidelines



Drainage discharge is a key controlling parameter







Drainage discharge is highly variable in time and space

We need tools for predicting drainage discharge (GUDP-funded project)

Subsurface-flow constructed wetlands (SSF-CWs)

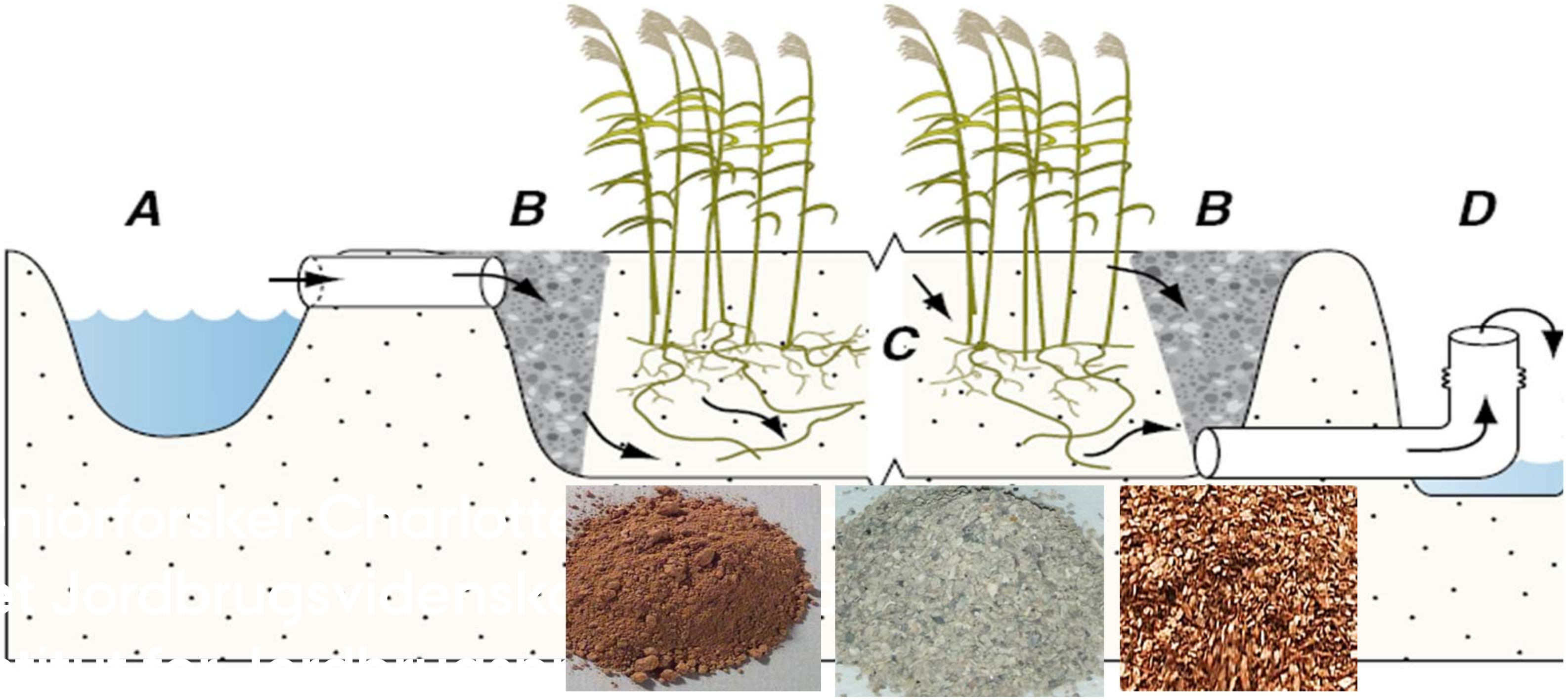
Two wetland components

1. Deep sedimentation basin (1 m)

- Reduces water velocity
- Increases retention time
- **Sedimentation of particulate P**

2. Infiltration matrix

- Optimizing P retention
- Optimizing N-removal by denitrification
- Sufficient hydraulic capacity required

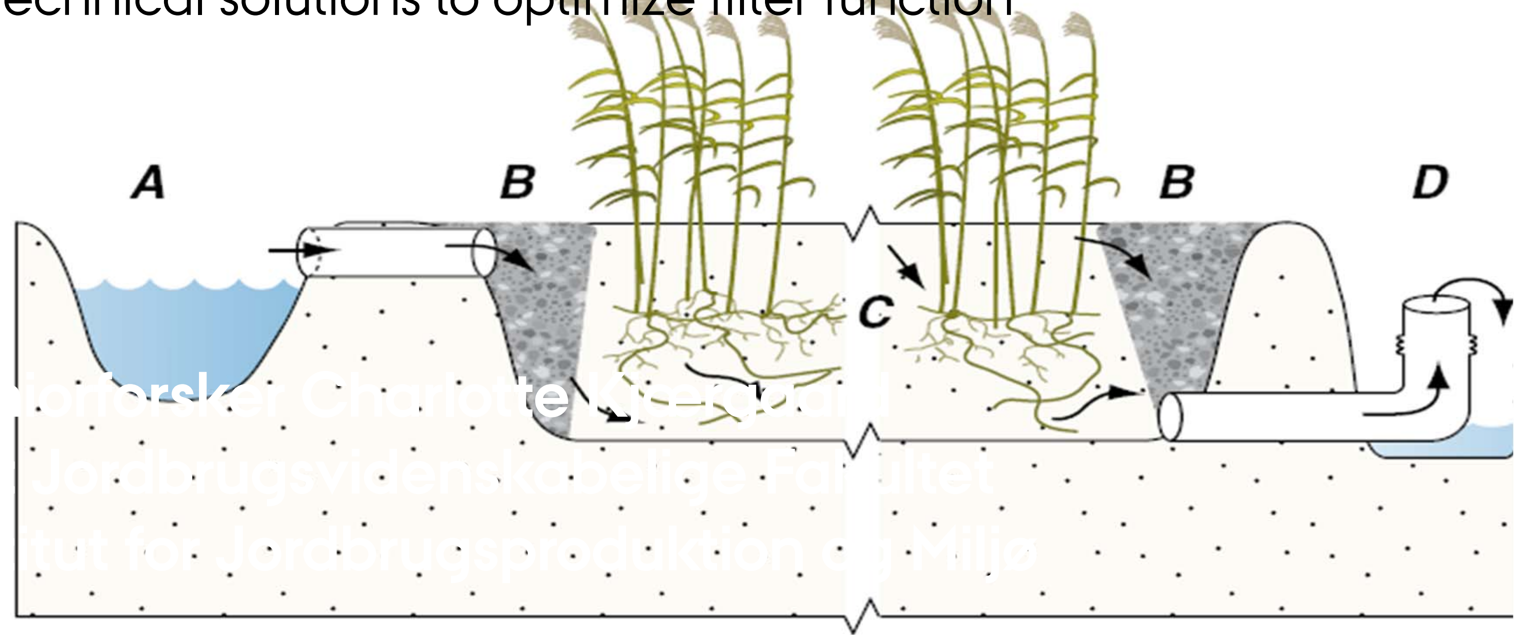


Experimental subsurface-flow constructed wetland (Orbicon project)

Optimizing SSF-CWs for nutrient retention

Supreme-Tech experimental SSF-CWs are constructed in autumn 2011

- Optimizing N removal (filter amendments, vegetation, retention time)
- Optiming P retention (filter P-affinity, retention time)
- Ensure sufficient hydraulic capacity and hydraulic efficiency
- Optimize removal of suspended sediments and PP
- Technical solutions to optimize filter function



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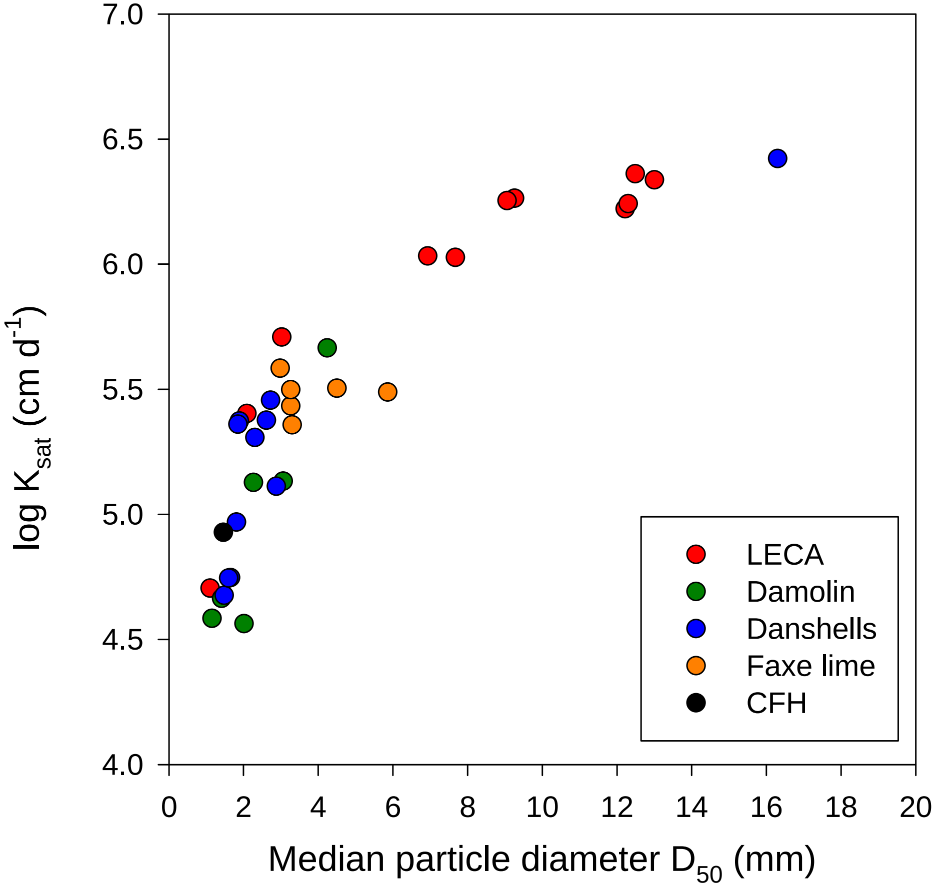
Saturated hydraulic conductivity of filters

The discharge (Q) of water is given by:

$$Q = K_{sat} A \left(\frac{\Delta H}{L} \right)$$



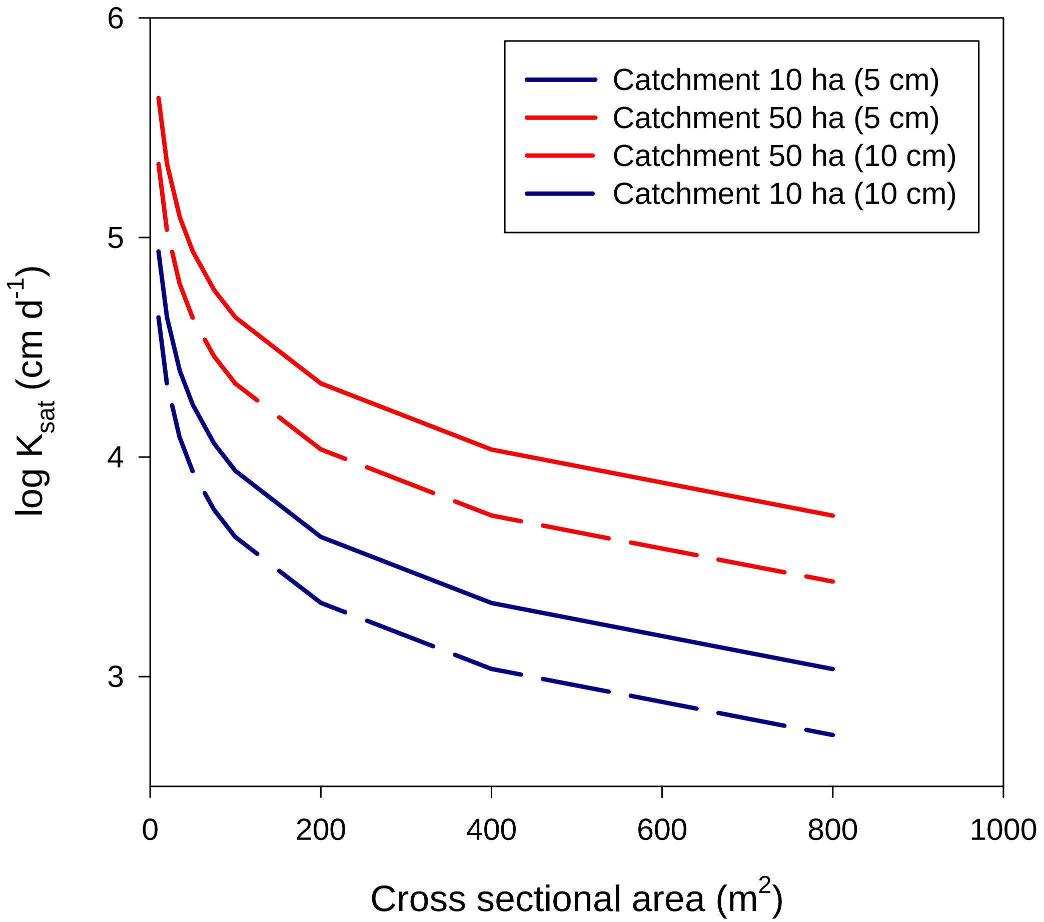
K_{sat} is saturated hydraulic conductivity
A is the cross sectional area of the filter
$\Delta H/L$ the hydraulic gradient

Challenges

- K_{sat} increases with D_{50}
- Filter reactivity decreases with D_{50}

Canga, E., B.V. Iversen, C. Kjaergaard. In prep.

Estimating filter dimensions as function of K_{sat}



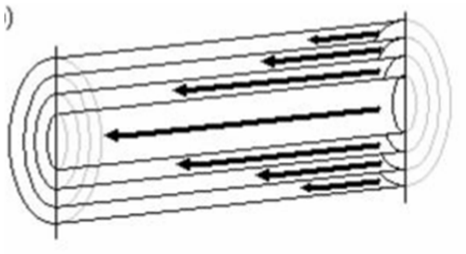
Required K_{sat} as a function of filter cross sectional area (A), pressure head (H) and catchment area controlling discharge (Q)

$$Q = K_{sat} A \left(\frac{\Delta H}{L} \right)$$

Filters with vertical up-wards flow (L=100 cm)

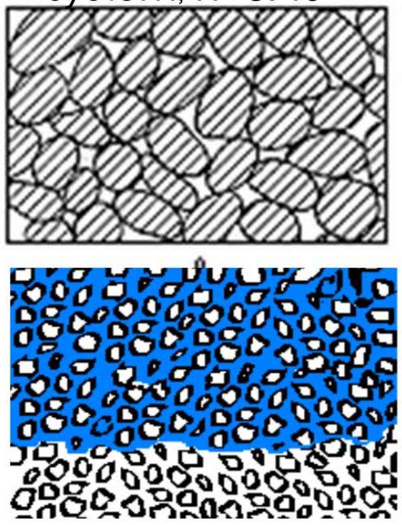
Filter hydraulic efficiency – ^3H_2O BTC

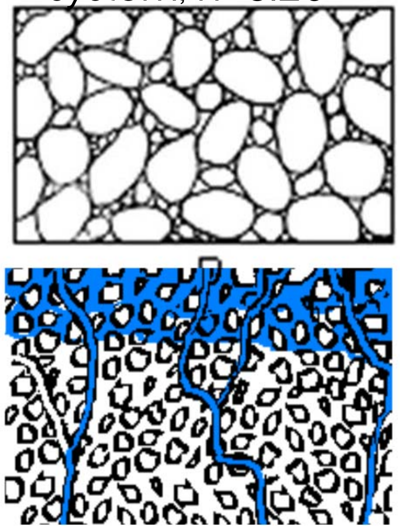
Poiseuille's law (r is pore radius): $Q \propto r^4$



Monodisperse system, n=0.48

Polydisperse system, n=0.26

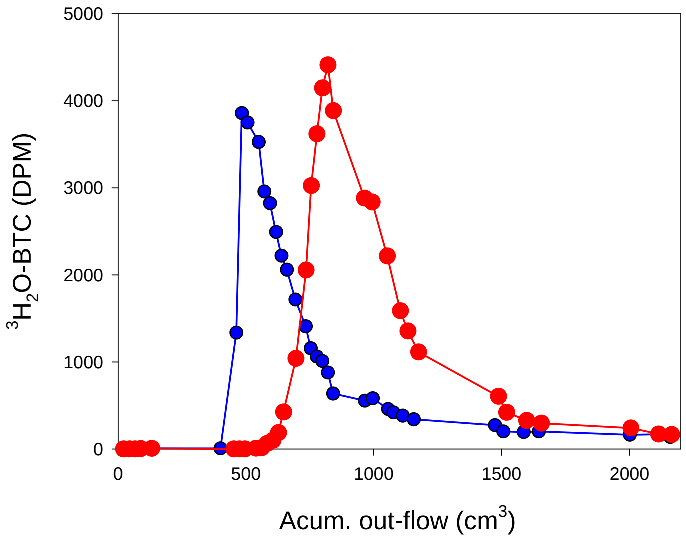




Equlibirum flow - Large active flow volume

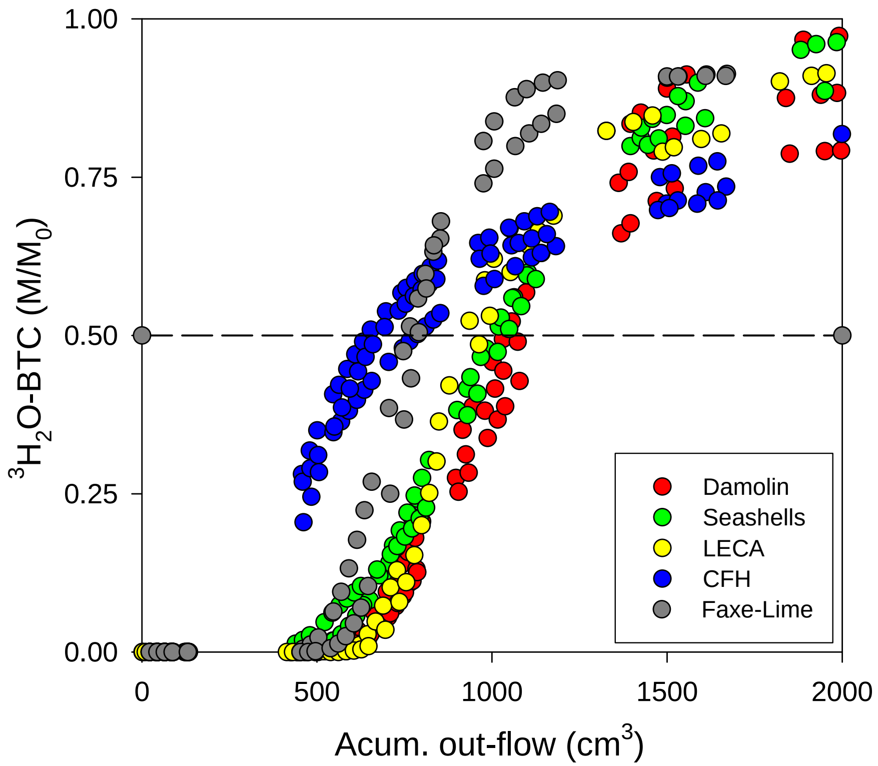
Non-equlibirum flow - Small active flow volume

Filters having identical K_{sat} but differs in active flow volume



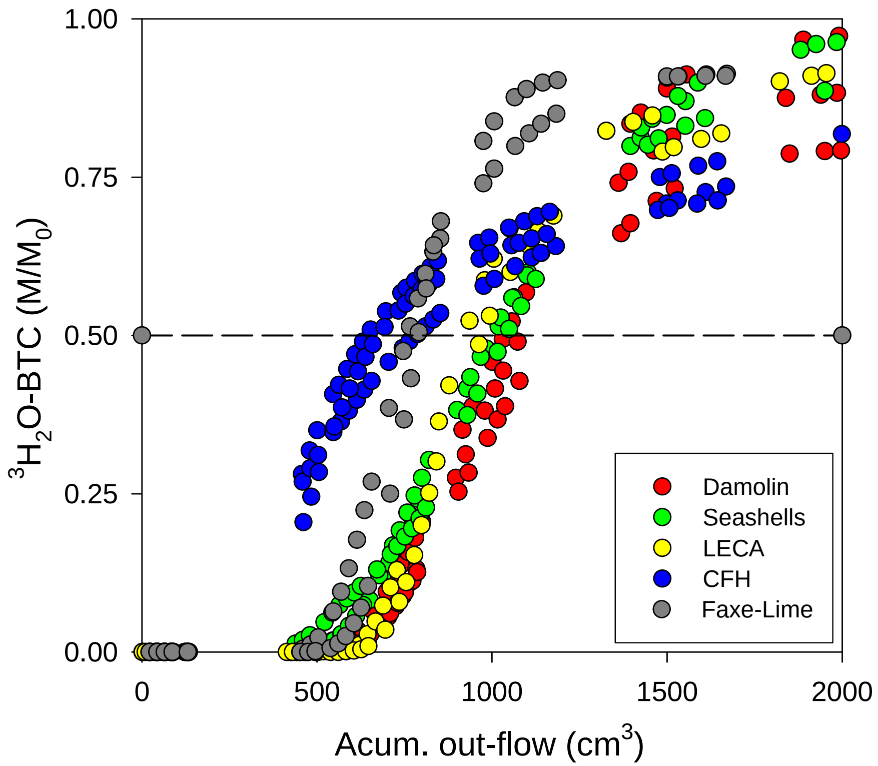
Filter hydraulic efficiency and HRT

Active flow volume from ^3H_2O- BTC

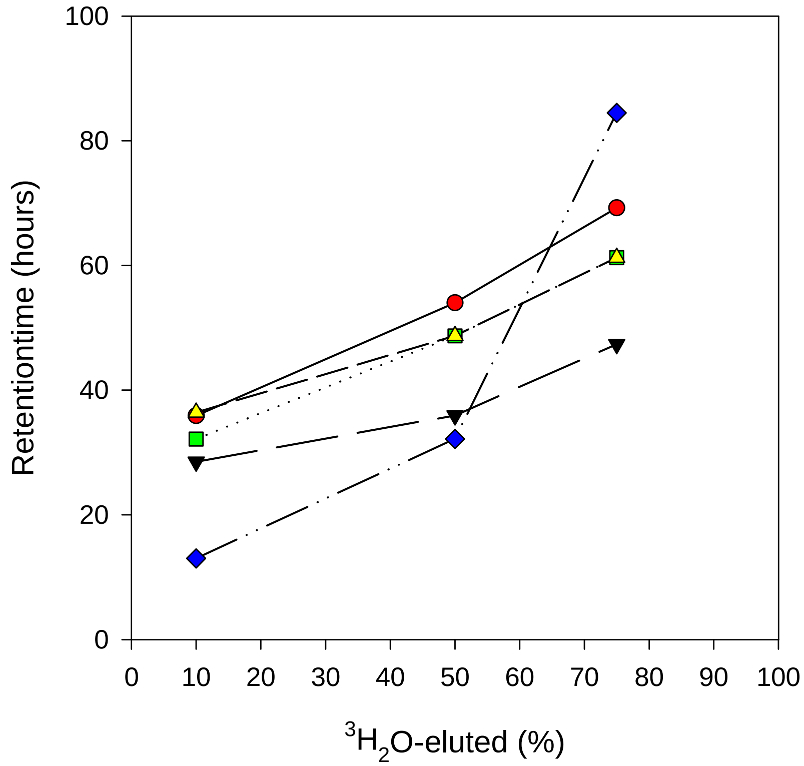


Filter hydraulic efficiency and HRT

Active flow volume from ^3H_2O- BTC



Retention time in porous filters



Scientific and pratical challenges ahead

Is drainage filter technologies cost-efficient solutions?

Existing drainage loss of nutrients

- TN loss: 18.000-25.200 t N/year
- TP loss: 400 t P/year

Potential filter reduction efficiency: 30-70%

Potential nutrient mass reduction

- TN reduction: 5400-17.600 t N/year
- TP reduction: 120-280 t P/year

DFT are quantitatively relevant solutions

Estimated costs and cost-efficiency

- Assuming catchment load of 500-2000 kg/TN year
- DFT costs: 150.000-300.000 DKK (amortized over 10 years)
- Assuming reduction efficiency: 30-70%
- Estimated cost-efficiency: 11-200 DKK/kg TN

Drainage filter solutions are potential cost-efficient solutions, BUT local parameters (nutrient load, retention efficiency and costs) determines.


Installation of drainage well filters
Thank you for your attention