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NuReDrain final conference webinar:

Filter systems for nutrient removal from agricultural waters

1 June 2021

Eutrophication: too much of a good thing

Prof. Stefaan De Neve
Soil Fertility and Nutrient Management research group
Department Environment
Ghent University

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Plant nutrients: which nutrients?



Macronutrients: N(itrogen),

P(hosphorus), K (potassium) ⟺ Micronutrients





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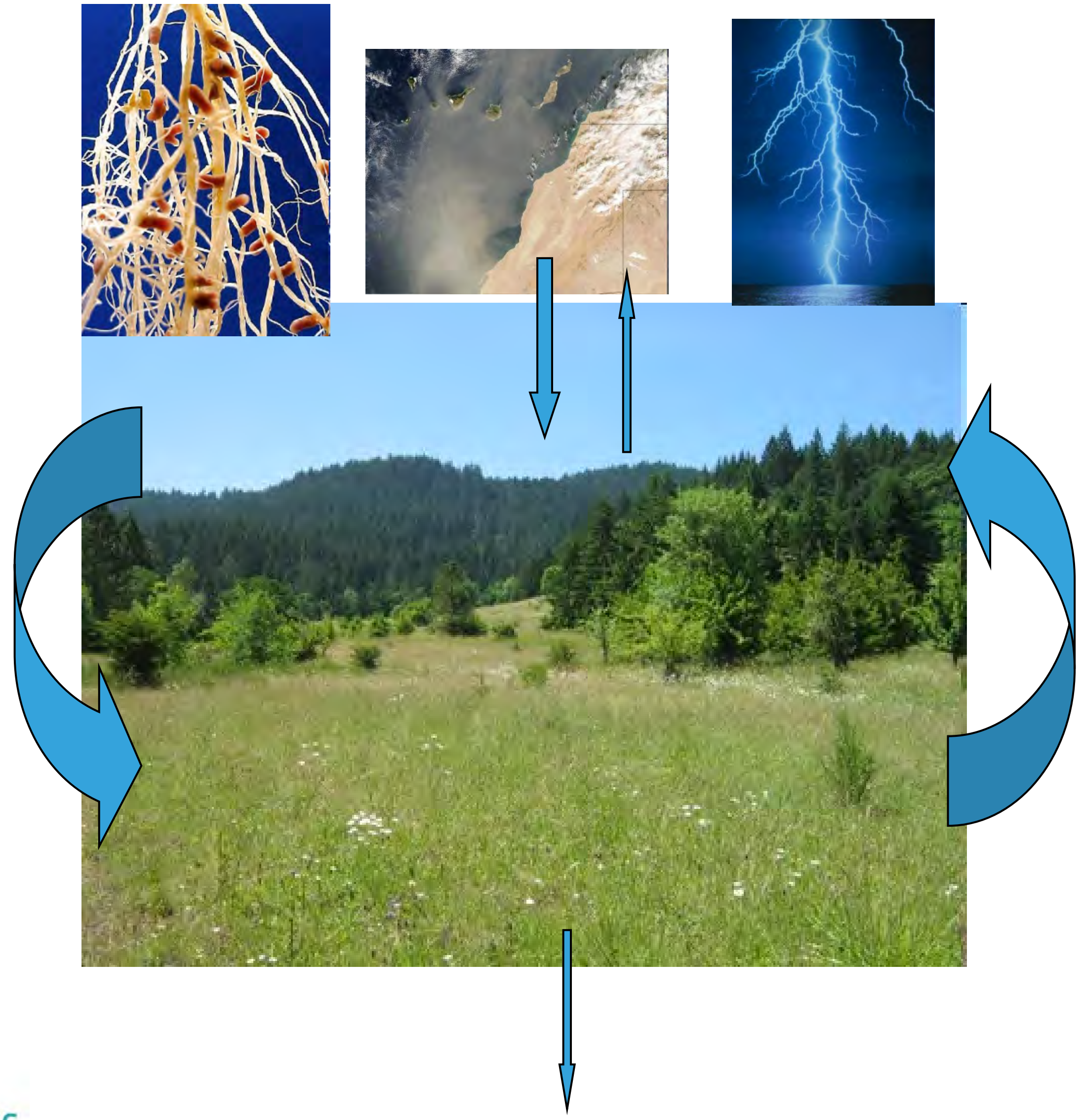
“Open” vs. “closed” nutrient cycles

Pristine, natural ecosystems:

- very small nutrient inputs
- very small nutrient outputs

Closed nutrient cycle



“Open” vs. “closed” nutrient cycles

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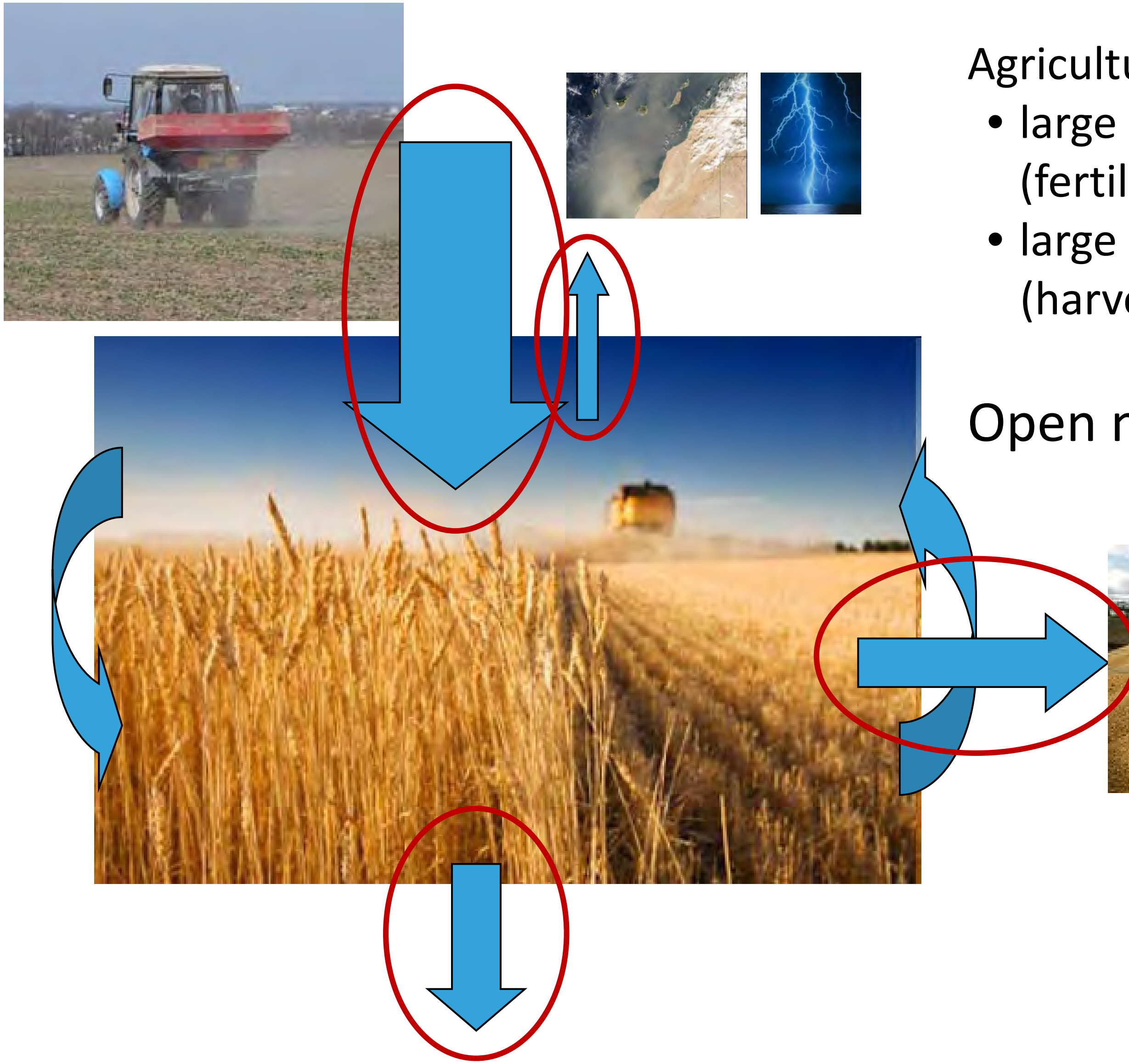
Agricultural ecosystems:

- large nutrient inputs (fertilizers)
- large nutrient outputs (harvested yield)

Open nutrient cycle



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Plant nutrients: which nutrients?

Macronutrients: N(itrogen), P(hosphorus), K (potassium) ⟷ Micronutrients



‘Agriculture is about opening nutrient cycles’




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Plant nutrients: too little, or too much?

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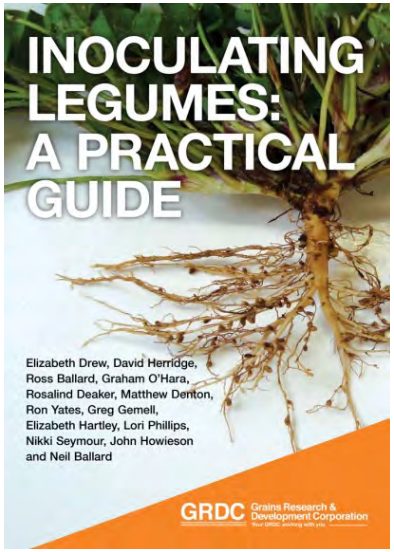
Long term inputs < long term outputs: nutrient mining: e.g. no access to fertilizer (logistics, costs)

Long term inputs > long term outputs: nutrient accumulation: e.g. fertilizer as risk insurance, excess manures

Plant nutrients: from where?

Nitrogen: fixation of (inert) atmospheric N2:



P, K, ...: mined from ores

Reserves are finite, and not in Europe!

... P is a 'CRM'

Opening of planetary nutrient cycle

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The true reason for nutrient excess problems!

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Consequences of too much

NH_3 volatilization and deposition: acid rain, eutrophication of terrestrial ecosystems → loss of biodiversity

leaching of N and P: eutrophication of surface waters, eventually eutrophication of marine ecosystems

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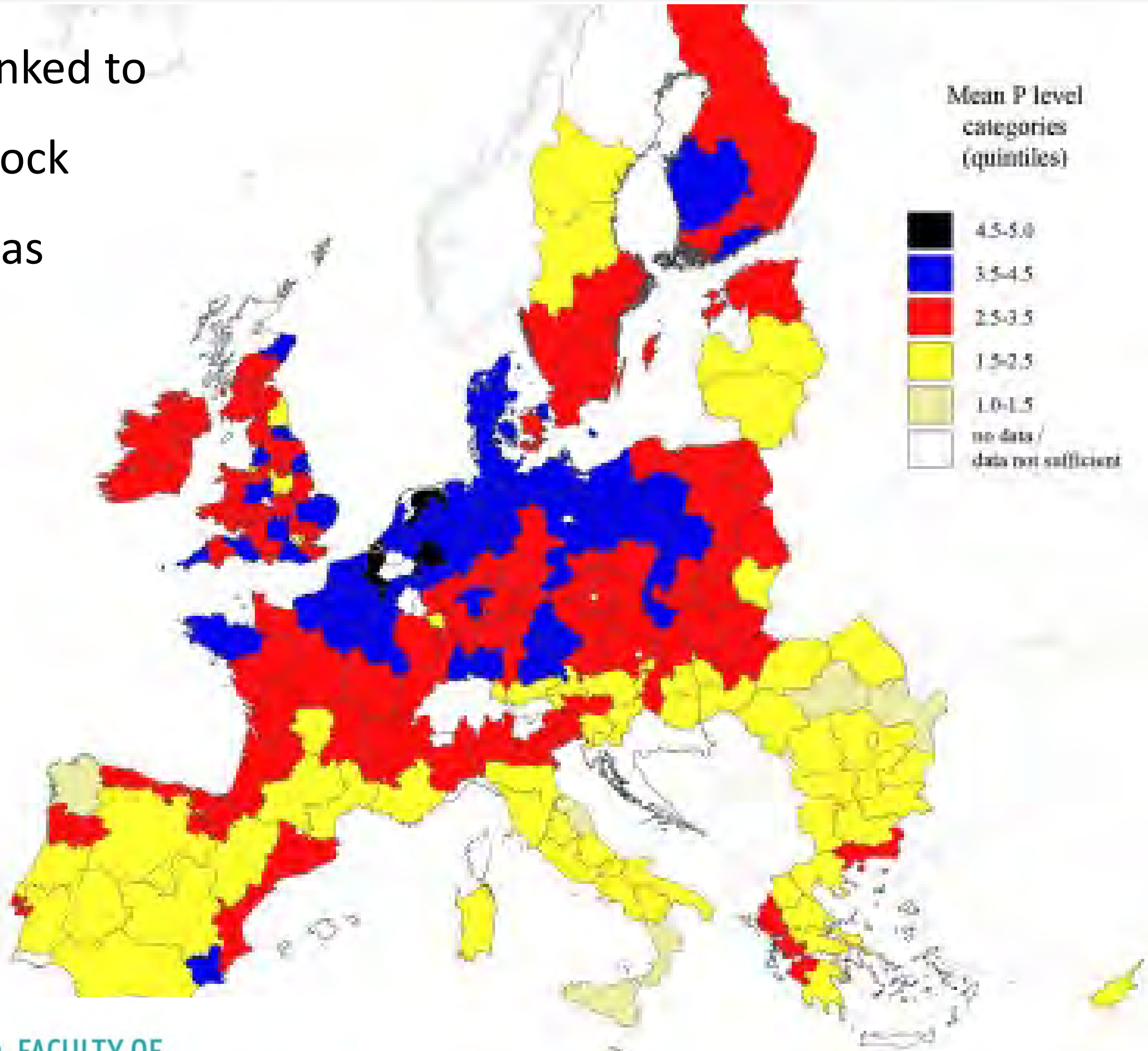
EU “nutrient hotspots”

Hotspots are linked to intensive livestock production areas



Actions that can be taken

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1. ‘Source based’ measures

- reduce nutrient inputs (optimize fertilization);
- reduce losses from soil (adapt rotations, grow catch crops, manage crop residues, ...)

Actions that can be taken

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2. 'End-of-the-pipe' measures: figuratively but more so literally

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The Nuredrain approach

Nuredrain approach:

- Cut back both N and P losses and thus eutrophication
- Try to recycle a critical raw material (P!) from the drainage water

The Nuredrain approach

Concrete Nuredrain actions:

- P filtration from agricultural drainage waters (low P - sub-ppm)
- P filtration from horticultural drainage waters (high P - tens of ppm)
- N removal from agricultural drainage waters
- ... small scale and large scale

The Nuredrain approach

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Thanks for your attention,

and enjoy watching the case studies!

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Part I: Phosphate removal from drainage water

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Low cost filter box to adsorb dissolved phosphates – case study in Belgium

Hui Xu

Department of Environment

Ghent University

Belgium

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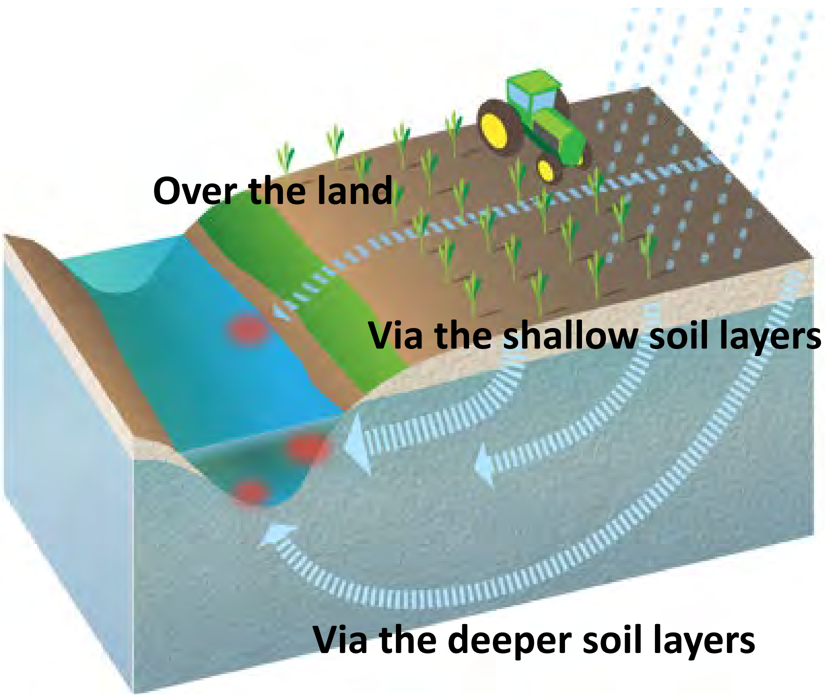
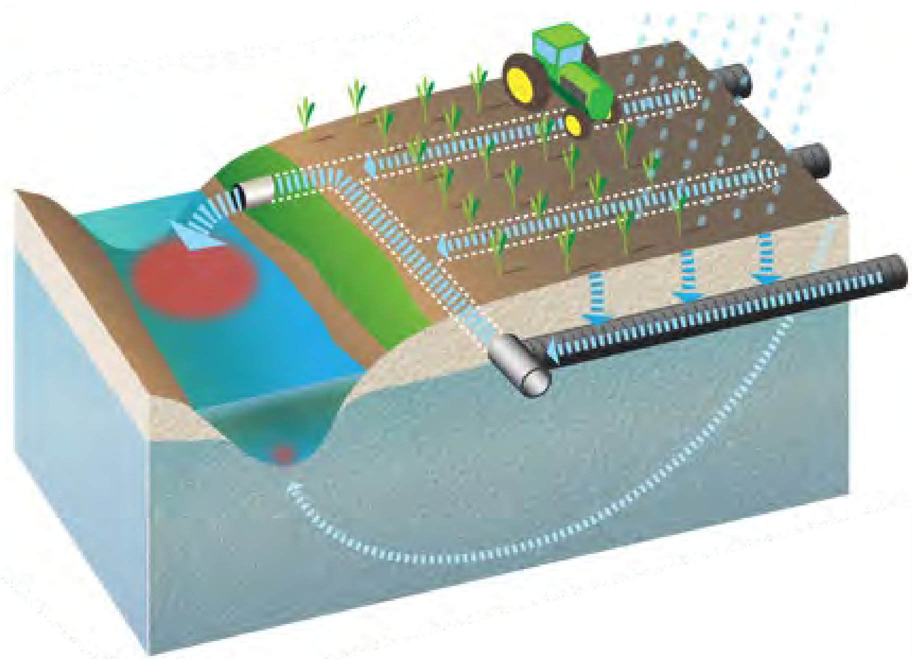
Why is it important?



17—40% agricultural field is drained in NW Europe



Directly discharge of P towards the surrounding waters

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What do farmers need?

- Reduce P loads as much as possible

  (< 0.1 mg/L, Water Framework Directive)

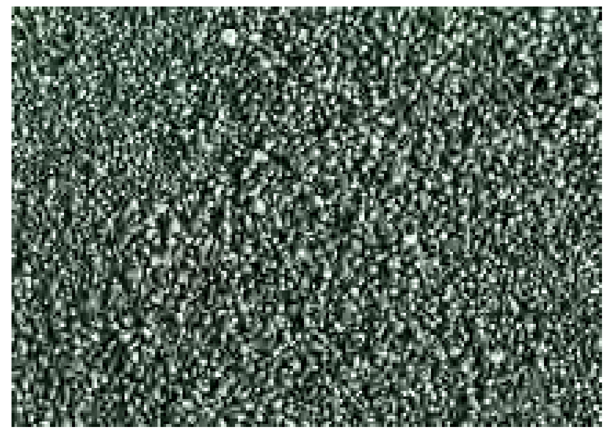
- For individual drainage pipe with water flow of 6-8 m^3 per day
- Process discontinuous flows
- Low cost and easy to install

Phosphorus Sorbing Materials (PSM)

Iron coated sand (ICS)

By-product from drinking-water industry

Ball-milled and acid pretreated glauconite

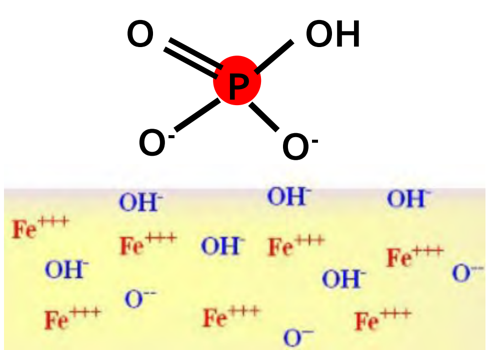


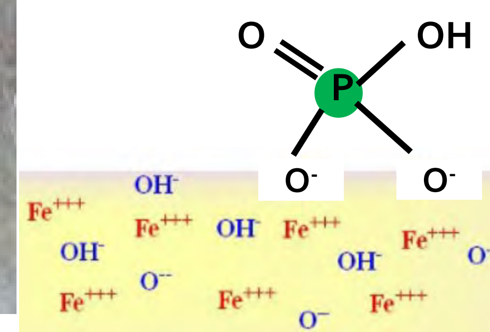
Abundantly available natural mineral

Vandermoere S., Ralaizafisoloarivony N., Van Ranst E., De Neve S. (2018). Reducing phosphorus (P) losses from drained agricultural fields with iron coated sand (- glauconite) filters. Water Research, 141, 329–339. https://doi.org/10.1016/j.watres.2018.05.022

Principle of PSM

P is removed from water by absorbing
into iron coated sand (ICS)





Prepare and test filters at lab scale

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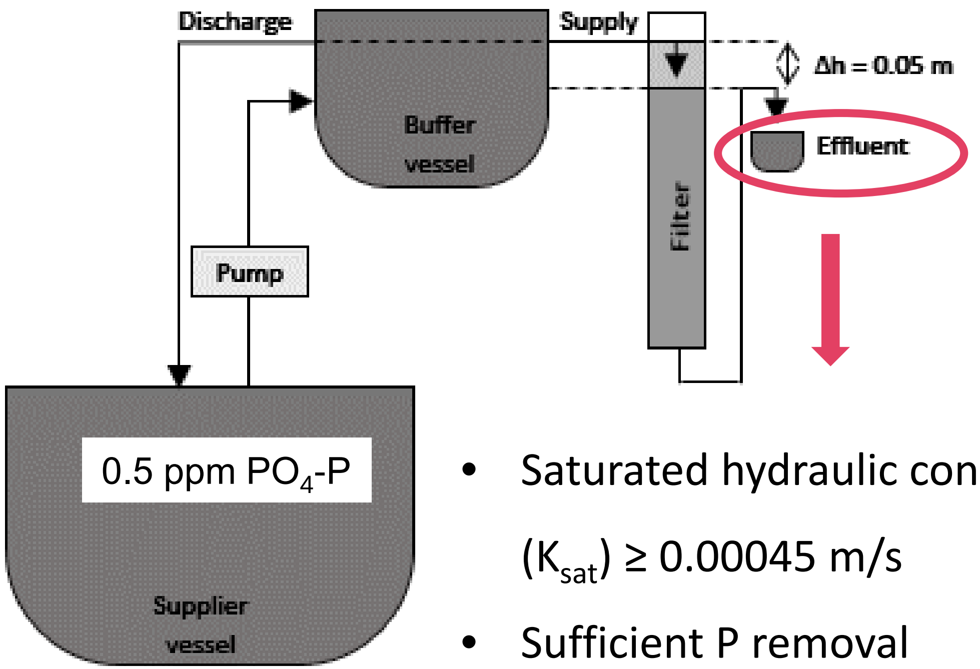

- Saturated hydraulic conductivity (K_{sat}) ≥ 0.00045 m/s
- Sufficient P removal

Vandermoere S., Ralaizafisoloarivony N., Van Ranst E., De Neve S. (2018). Reducing phosphorus (P) losses from drained agricultural fields with iron coated sand (- glauconite) filters. Water Research, 141, 329–339. https://doi.org/10.1016/j.watres.2018.05.022

Principle of P removal filter

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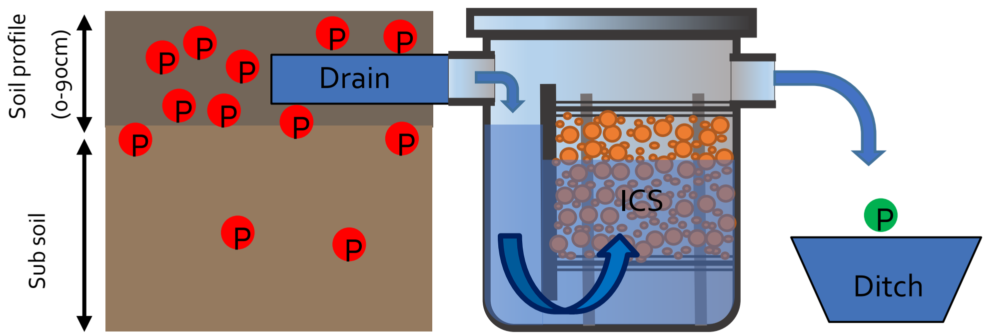
Key features:

upward oriented outlet

mesh netting at bottom



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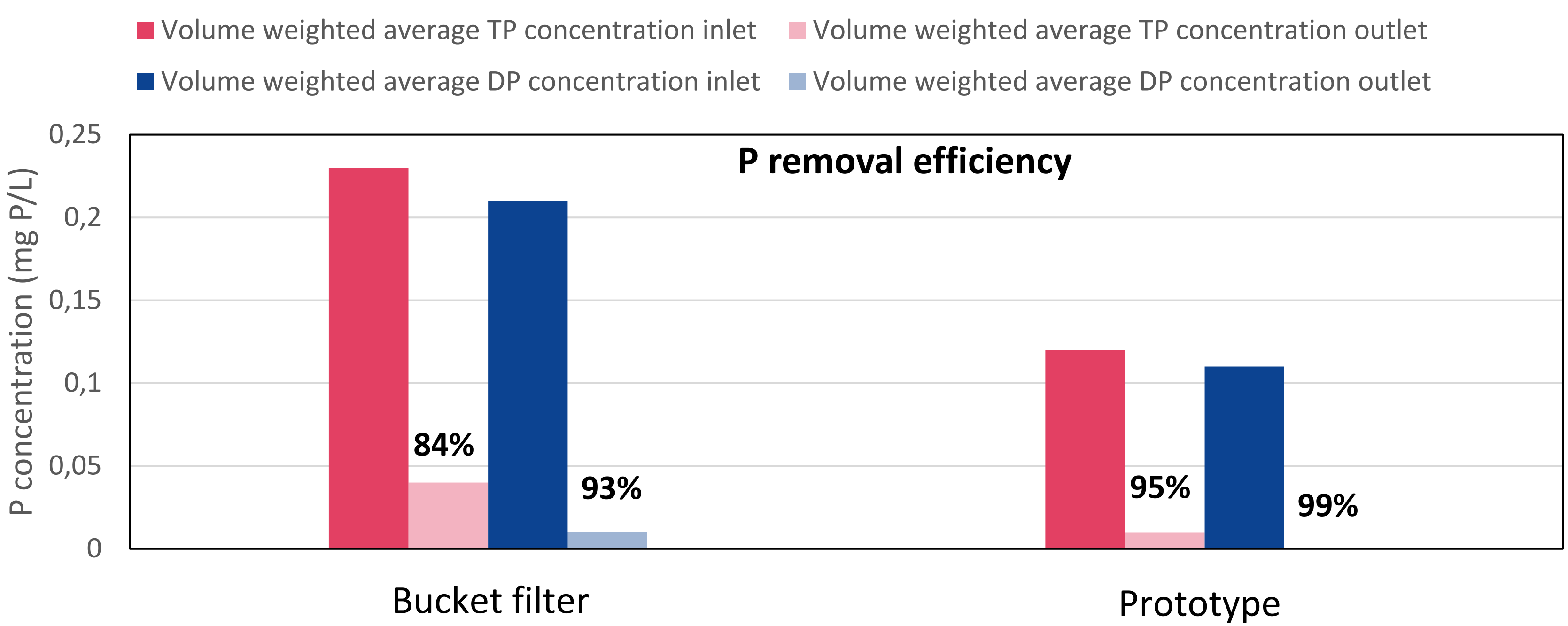
Performance of prototype

Simple bucket VS Prototype



Water flow: **0.04-4.3 m³/day** **0.04-3.6 m³/day**

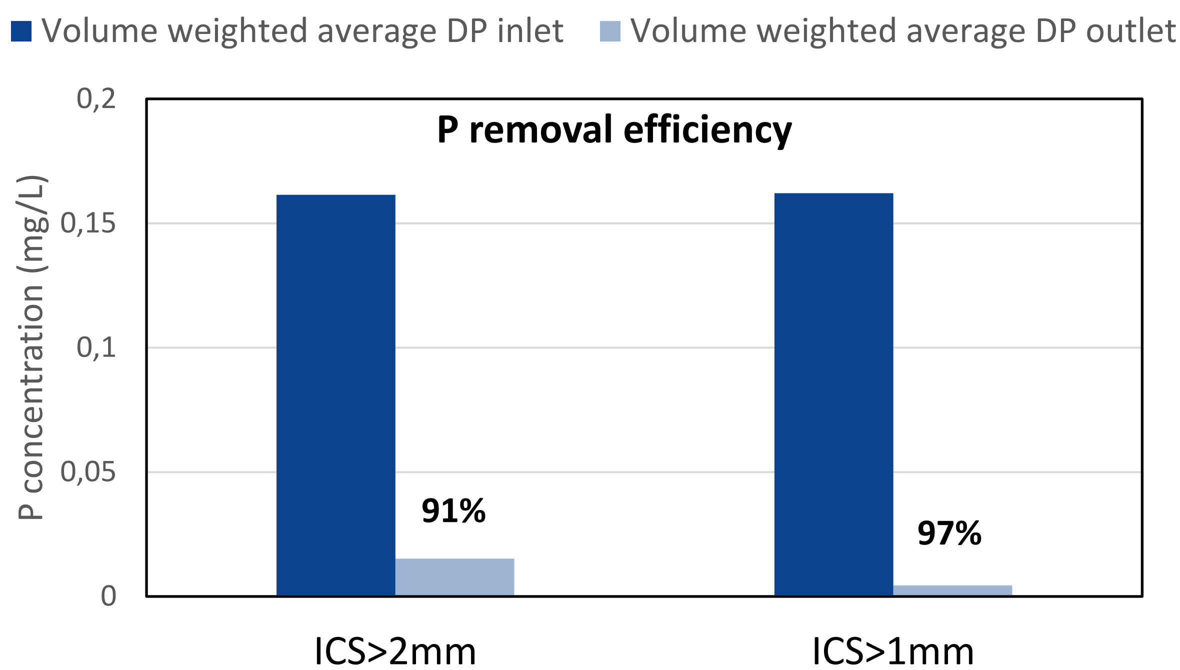
TP: Total phosphorus
DP: Dissolved phosphates

Performance of prototype

ICS >2 mm

VS

ICS >1 mm



Water flow: **0.1-2.2 m^3/day** **0.4-3.1 m^3/day**

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Long-term performance of prototype

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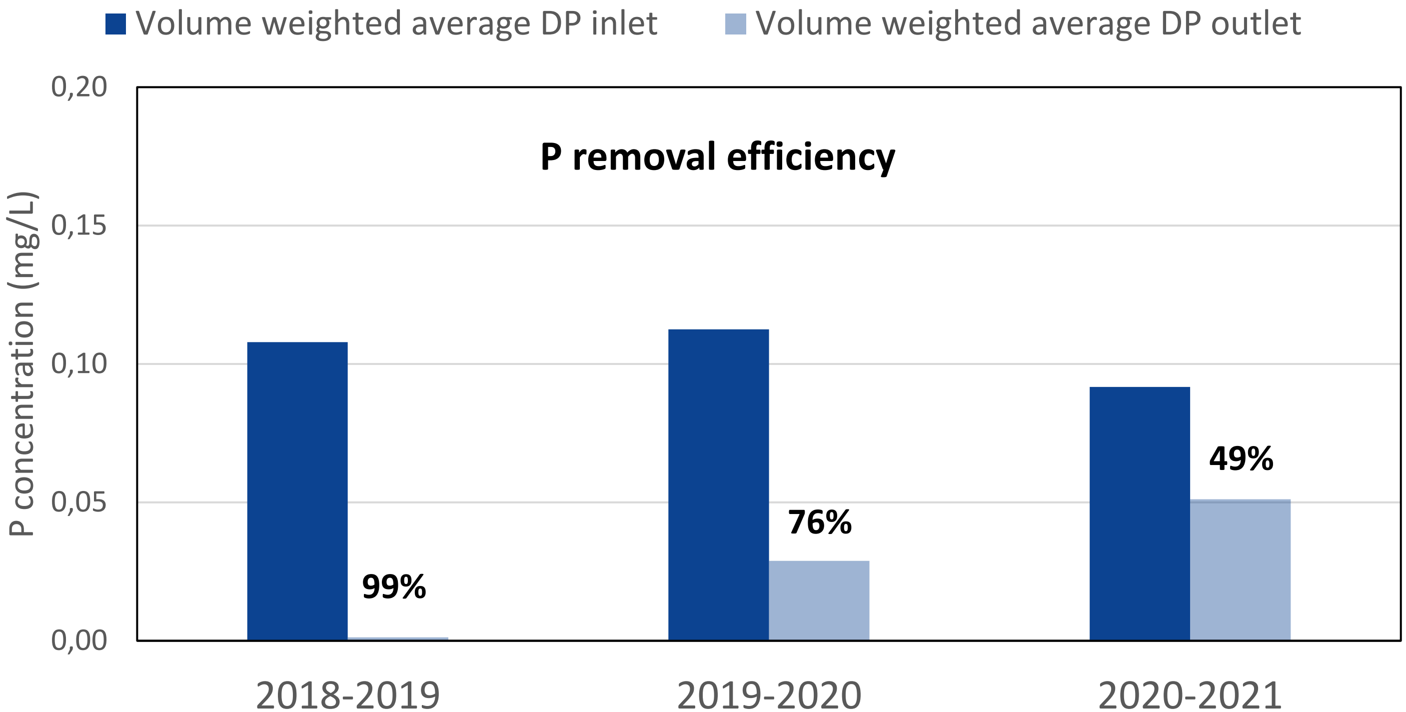
With 35L/50 kg of ICS → max 8 m³/day & 0.5 mg/L P-PO_4



Water flow: **0.04-3.6 m³/day** **0.1-7.2 m³/day** **0.1-2.5 m³/day**

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Cost estimation

	Price [€]	Life span [years]
Filter bucket	634	15
ICS materials	6.3	2
Labour for installation	40 (self-installation) /80 (external-installation)	15
Total [€/year]	**50-100**	

Evaluation of the filter

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+ Low-tech solution: easy installation and operation
+ High P removal efficiency
+ Low cost of filter materials: ICS is industrial by-product
+ Causes no other contaminations
+ No impact on accessability and landscape

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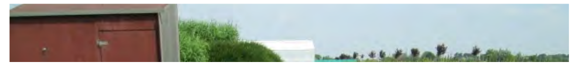
P-removal from greenhouse effluent (BE)



With 2-3 m^3 of ICS

→ Max 1 m^3/day

& 10-20 mg/L $P\text{-}PO_4$

What's next?

- Upscaling of filters for processing water from collector drains (6-10 m^3/h)
- Modular filter systems for efficient replacement of filter materials

d after 4 years

ICS

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Sediment and reactive filter to remove particulate and dissolved phosphates: case study Denmark

Lorenzo Pugliese
Goswin Johann Heckrath

Fensholt D8

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Catchment area (ha)		8.4
May 2015/16	Q (mm)	349
	Q/P (-)	0.30
	TP (kg/ha)	1.1
	Flow weighted average TP (mg/L)	0.32
May 2016/17	Q (mm)	246
	Q/P (-)	0.28
	TP (kg/ha)	0.3
	Flow weighted average TP (mg/L)	0.13

System design

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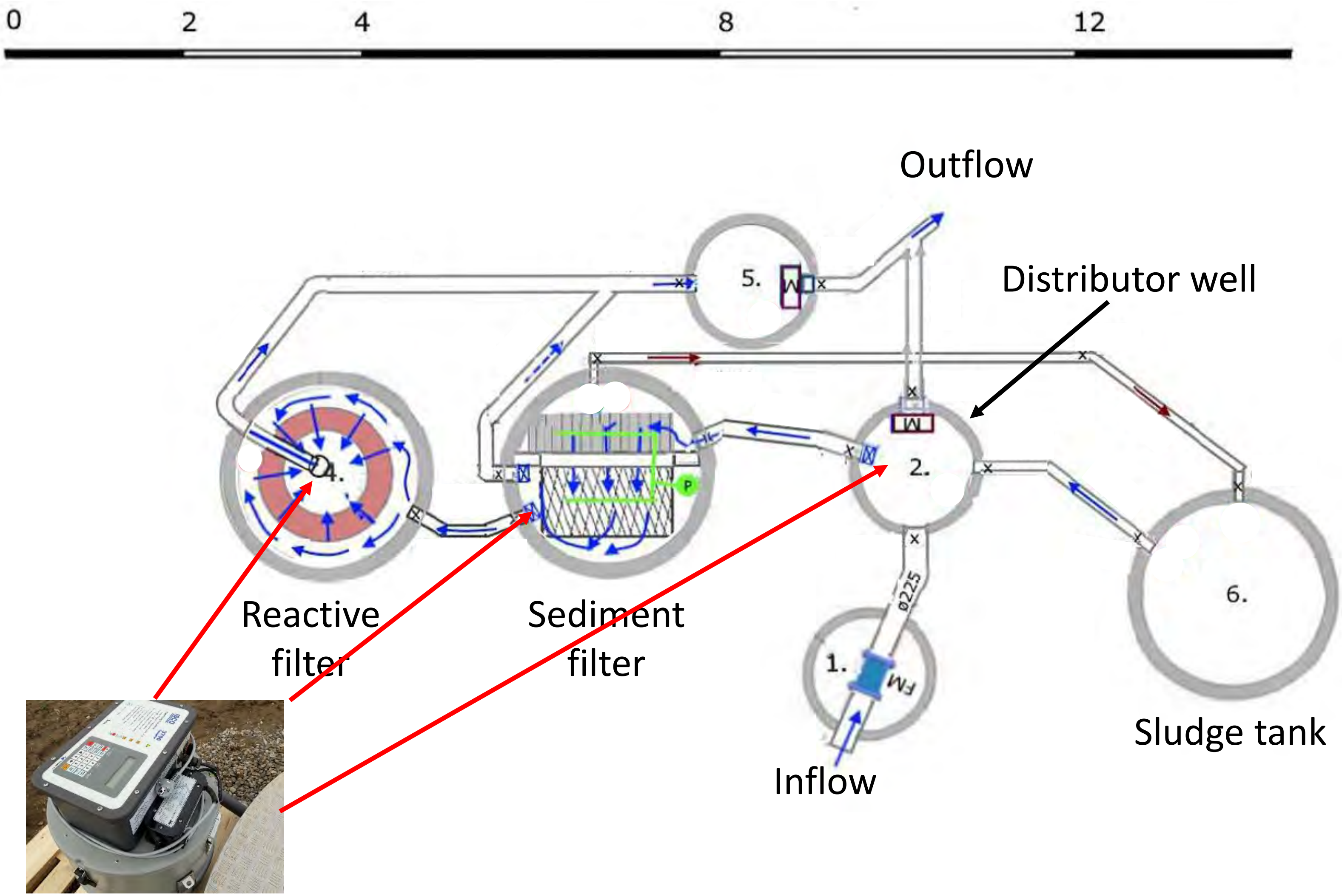
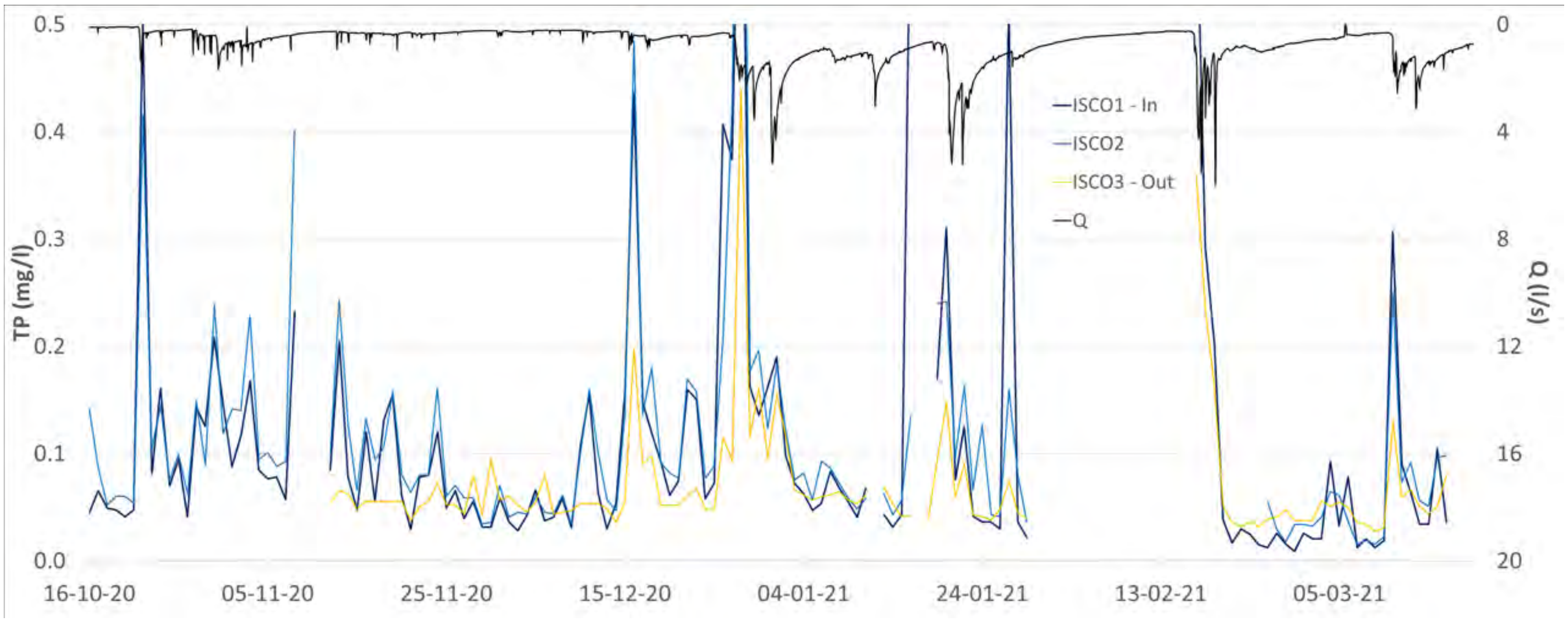


TP – Fensholt D8



TDP – Fensholt D8

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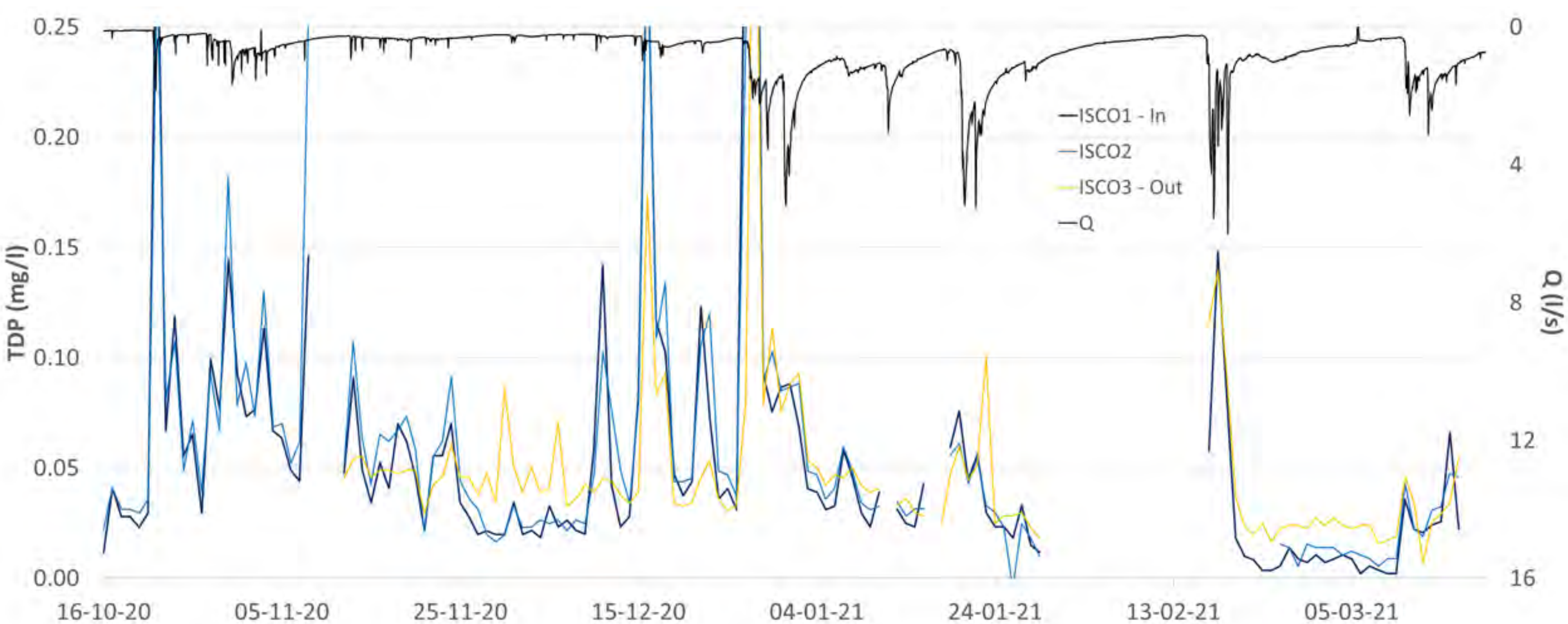

Monthly data overview

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Month	Q (m^3)	Sediment filter				Reactive filter (Diapure)				Overall system
		TP load (g)	TP removal (%)	TDP load (g)	TDP removal (%)	TP load (g)	TP removal (%)	TDP load (g)	TDP removal (%)	TP removal (%)
okt-20	645	**67**	**-24**	**44**	**-11**	**66**		**45**		
nov-20	997	87	-30	55	-19	113	23	66	-21	5
dec-20	1630	339	-14	208	-13	395	27	197	-2	16
jan-21	3651	394	-29	141	-2	354	21	141	10	0
feb-21	1815	**259**	-164	**59**	-66	**15**	-50	**4**	-125	**-87**
mar-21	2007	**101**	**-32**	**29**	**-90**	**105**	**-12**	**33**	**-67**	**-47**

Incomplete monthly data

Fensholt D3

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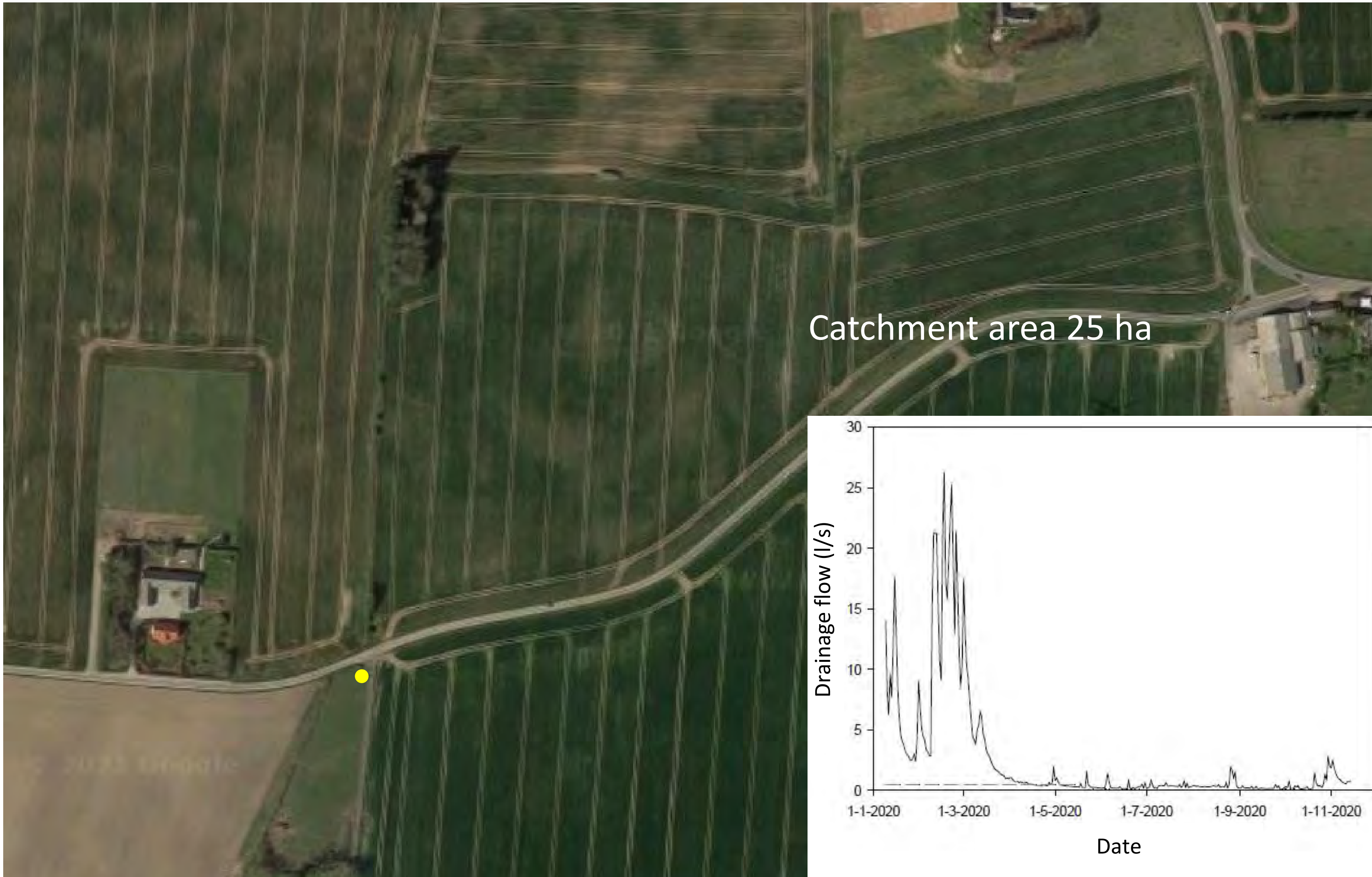

Kjærgaard, 2021

System design

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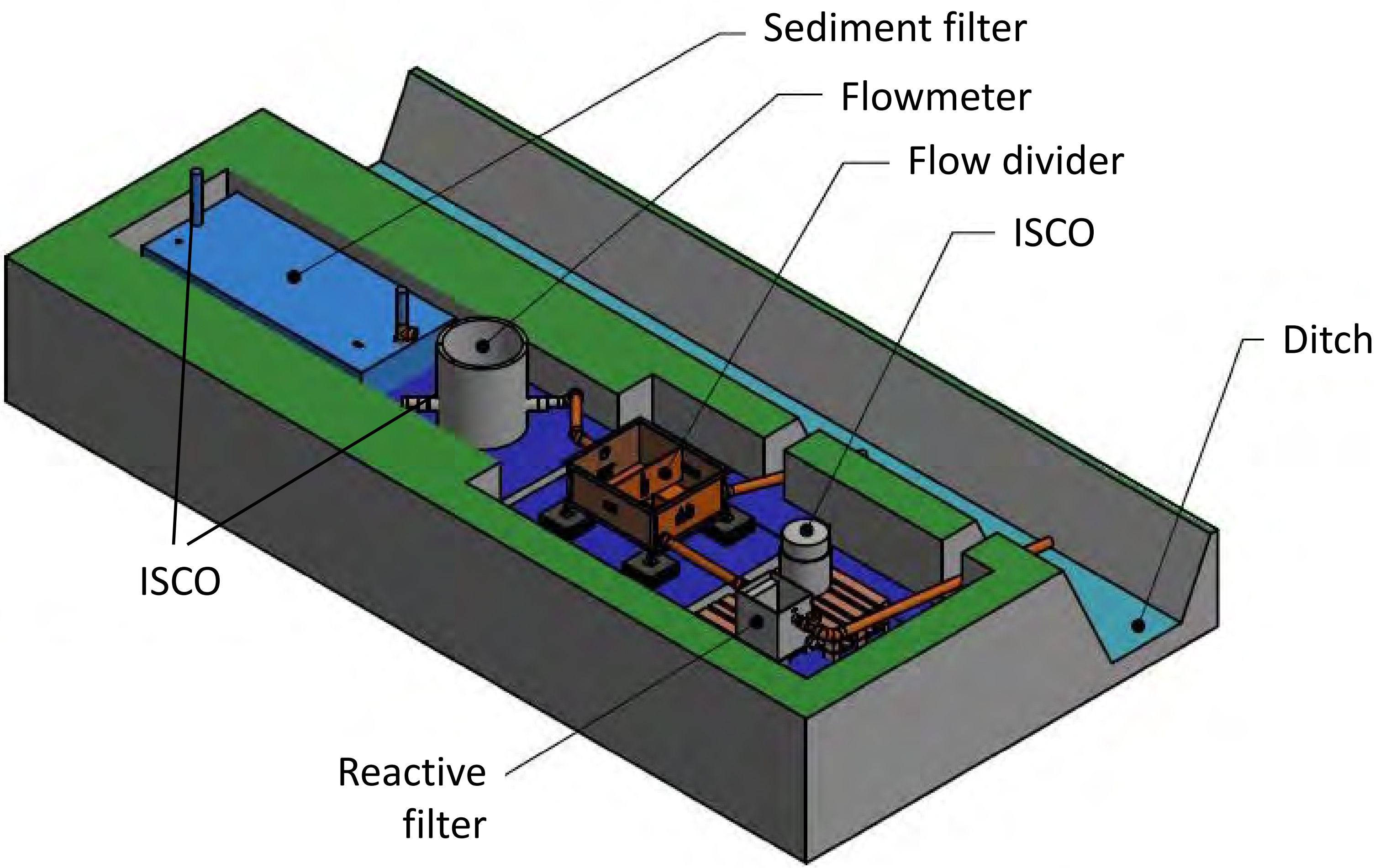

TP – Fensholt D3

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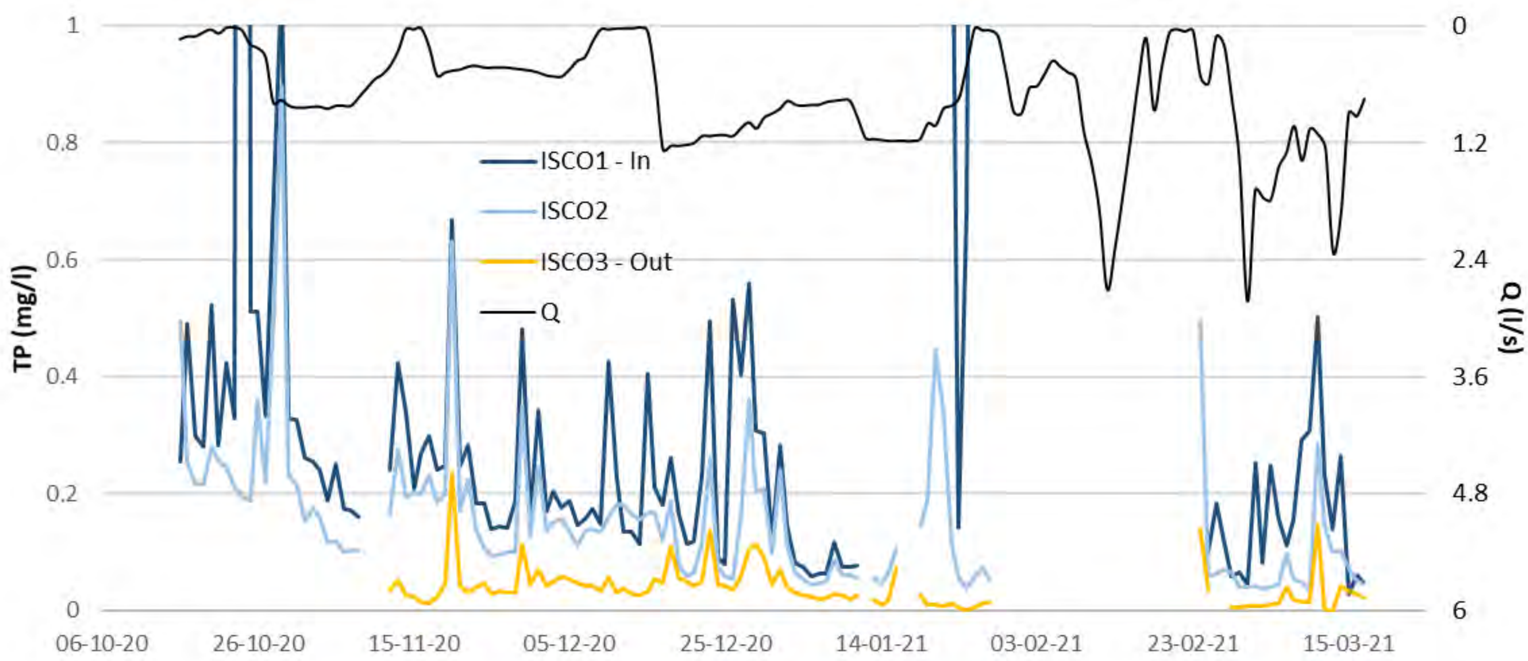

TDP – Fensholt D3

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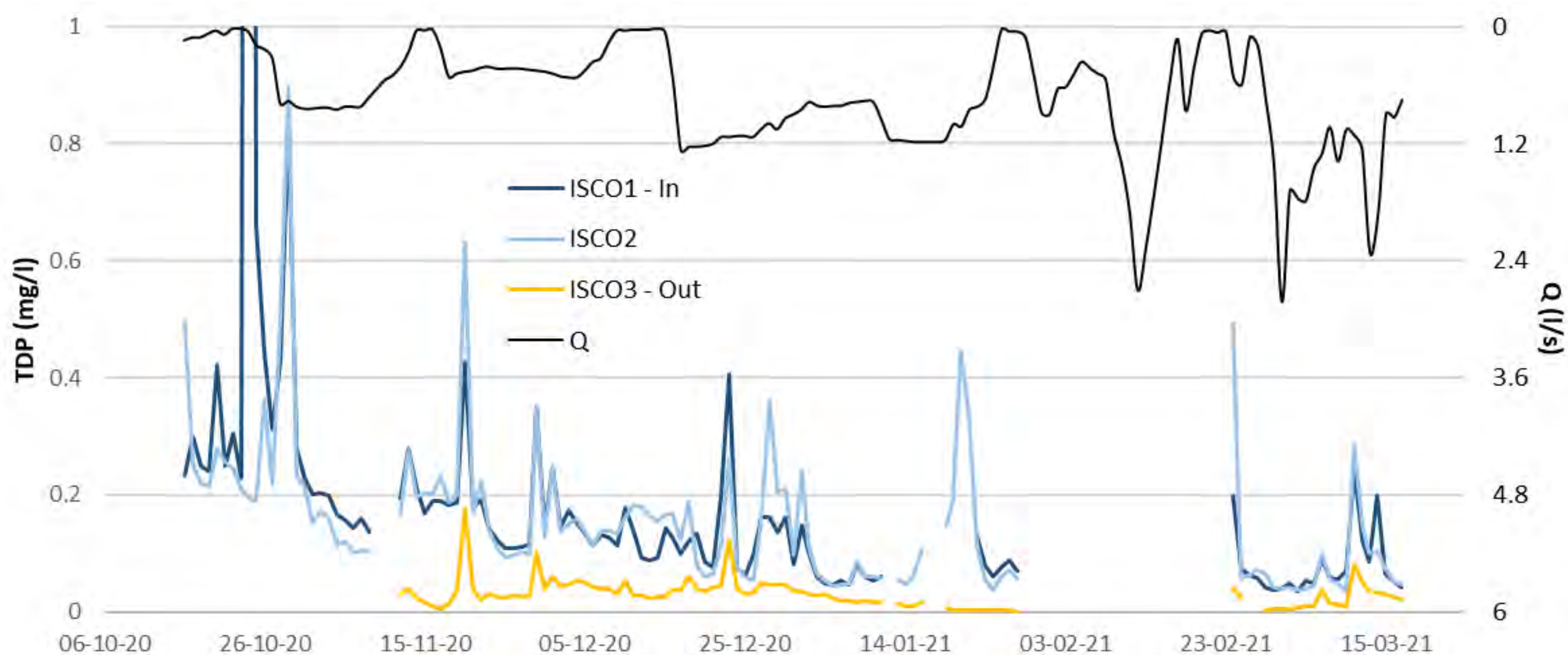

Monthly data overview

Month	Sediment filter Q (m^3)	TP load (g)	TP removal (%)	TDP load (g)	TDP removal (%)	Reactive filter (ICS) Q (m^3)	TP load (g)	TP removal (%)	TDP load (g)	TDP removal (%)	Overall system TP removal (%)
okt-20	613	243	30	190	23	61					
nov-20	1299	276	31	207	16	130	19	76	17	79	83
dec-20	1798	448	28	250	2	180	25	59	20	63	73
jan-21	2133	253	48	74	20	213	20	72	8	72	80
feb-21	1825	13	35	17	16	182	3	67	1	60	78
mar-21	2146	371	37	167	16	215	16	70	12	68	79

Incomplete monthly data

Conclusions

- Compact filter systems have shown good potential for removing particulate-bound and dissolved P from tile drainage
- Technically challenging to develop a filter system with large hydraulic capacity (peak drainage flows) and high P removal efficiencies
- Problems with upscaling were observed in DK systems primarily in connection with particulate-bound P
- Compact filter systems require maintenance during operation
- Both sediment and spent filter material can potentially be recycled on agricultural fields as soil amendment.

Future work

- The monitoring program will continue at both field facilities
- Improved sedimentation (physical and/or chemical) and overall P removal efficiency
- Study of P transformations under varying redox conditions and drainage flow characteristics
- Study of the interactions of the removal pathways of particle-bound P in a long term operation mode

Landwirtschaftskammer Niedersachsen

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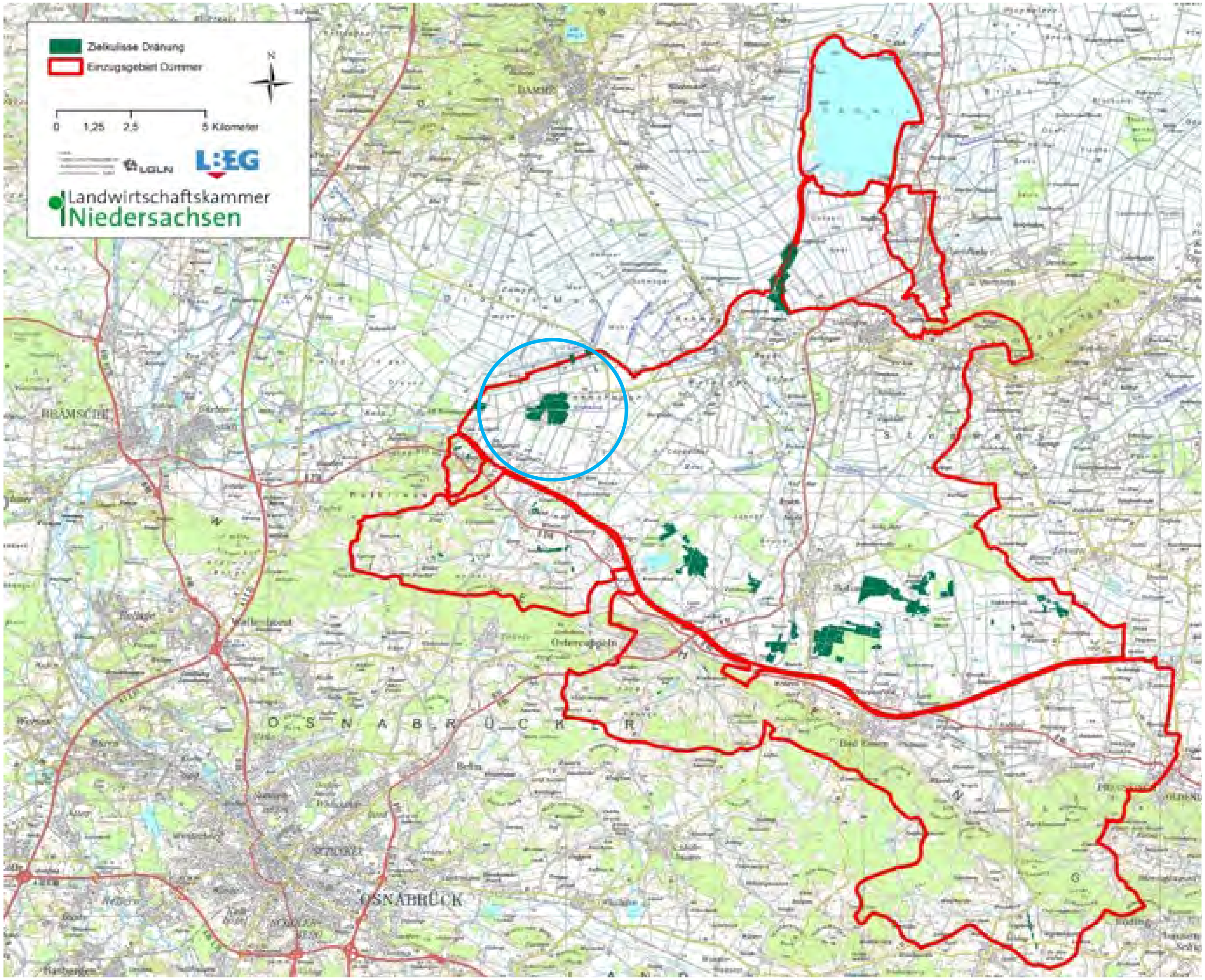
Experimental Inline Phosphorus Filtration in a Drained Arable Field

Dr. Kristine Bolte
Kristine.Bolte@lwk-niedersachsen.de

High P losses in drained fields



source: Wikipedia

"Hot Spots"

↑ P concentration

↑ drainage flow

Lowland and peat soils

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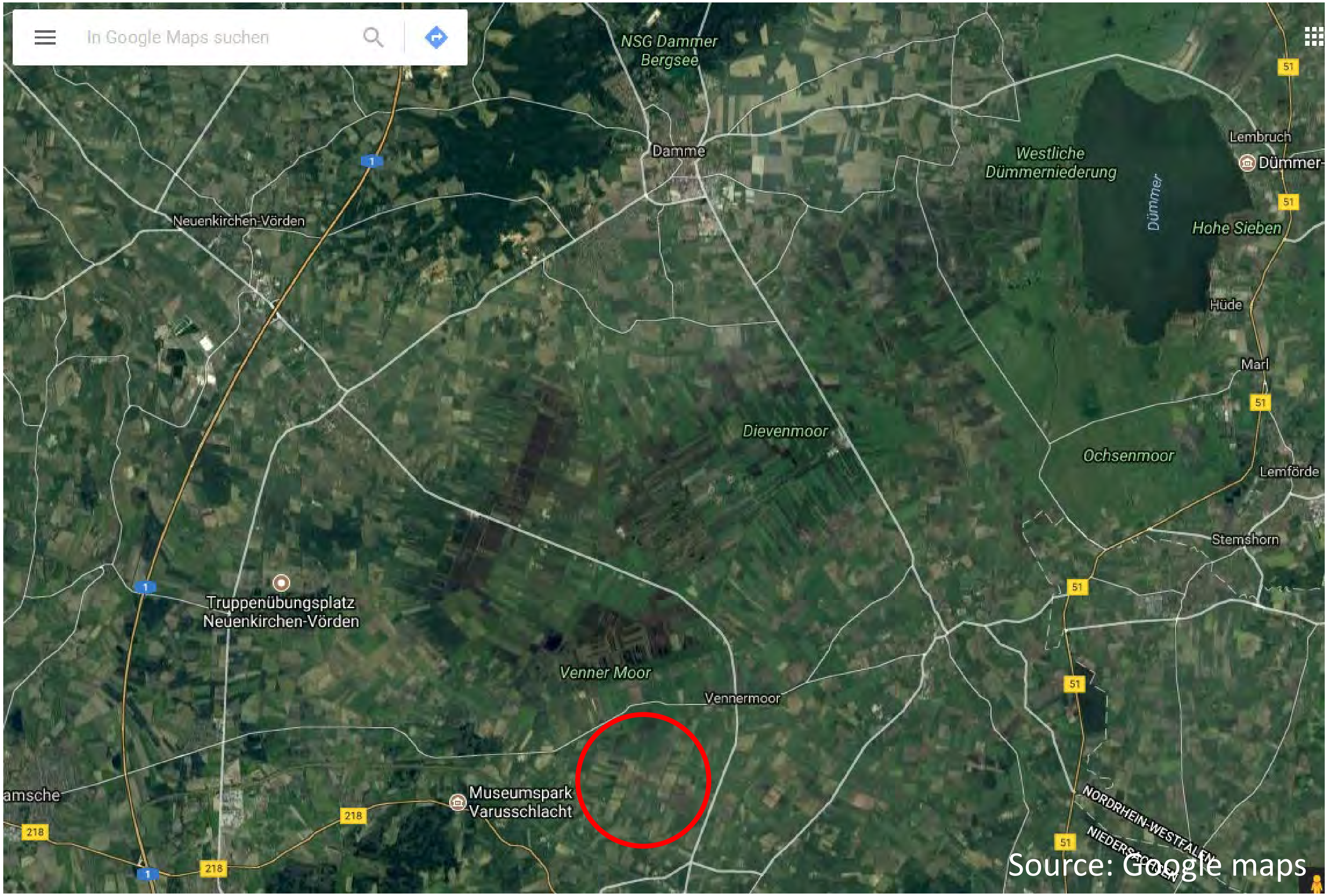

Test site specification

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soil type (topsoil)

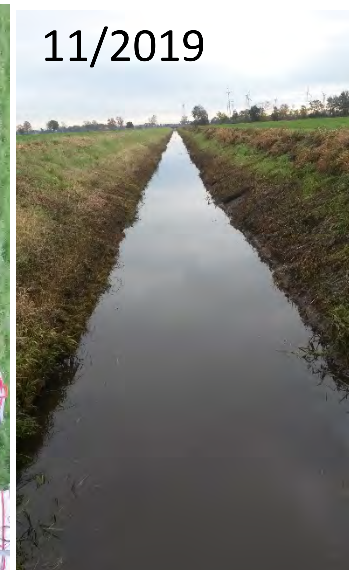
- peat soil
- loamy soil
- sandy soil, loamy, silty
- clayey soil
- silty soil
- sandy soil

Source: DTK50 der Landesvermessung + Geo-basisinformation Niedersachsen, modifiziert

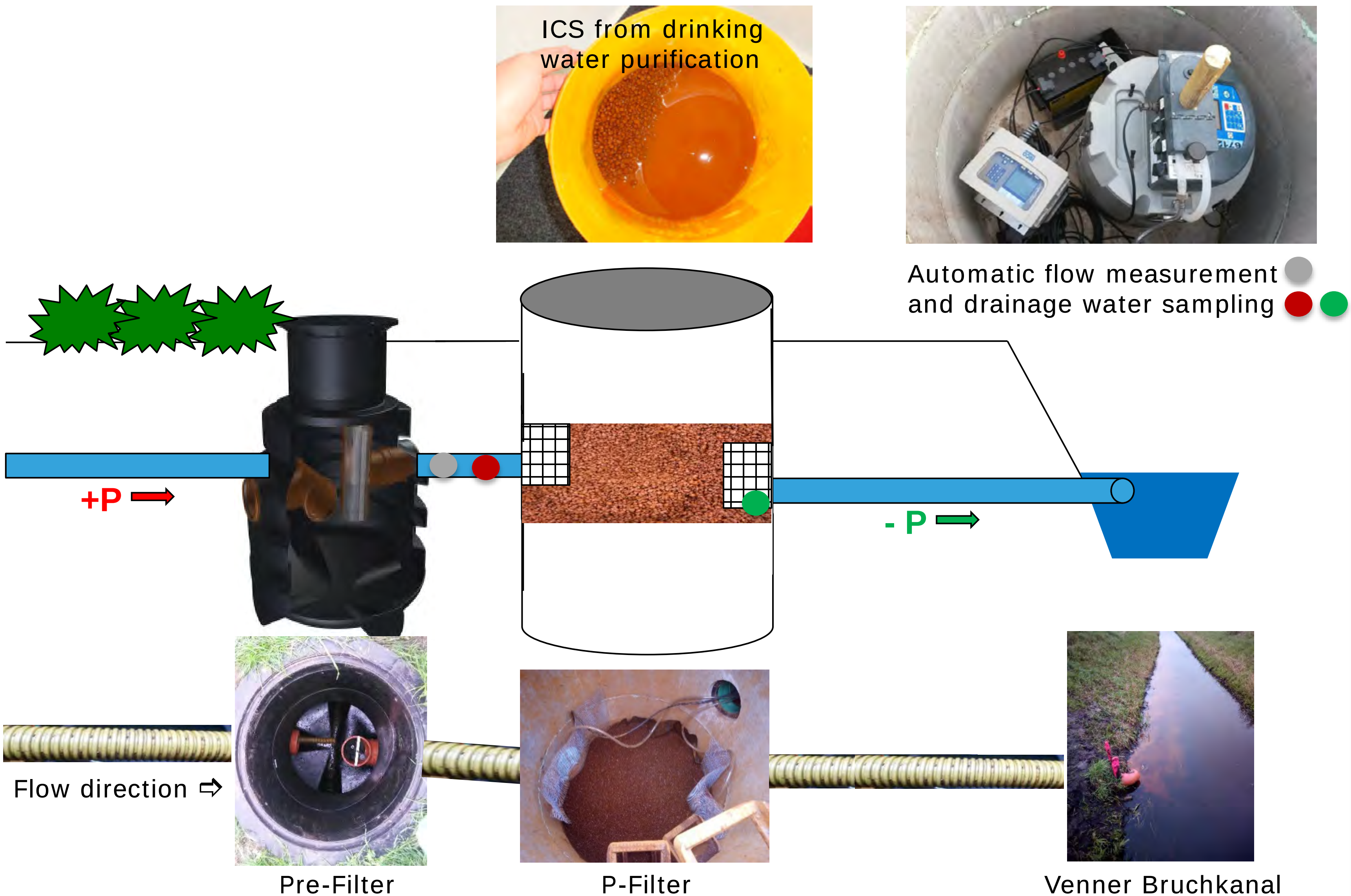
▪ Field size:	8,2 ha	
▪ Topsoil:	loamy sand, high in organic substance	
▪ Drainage:	single tile drains (8-10 m distance)	
▪ P grab samples:	P_{total}	~4,0 mg/l
	$P_{soluble}$	~0,3 mg/l

Location challenges

Amorphous organic matter input (**clogging**) and low flow velocity (**backflow**).



Setup experimental Inline P filter



Drainage water samples

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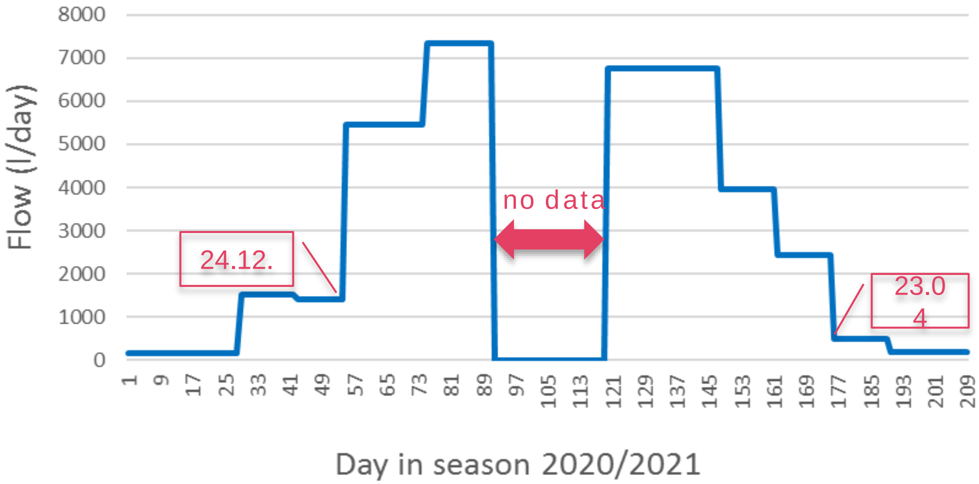
	unfiltered (mg/l)		filtered (mg/l)		
	P tot.	P diss.	P tot.	P diss.	
min	0,04	0,01	<0,04	<0,04	2018/2019
max	0,17	0,03	<0,10	<0,10	
Mittelwert	0,08	0,02	no data	no data	
min	0,04	0,01	0,04	0,01	2019/2020
max	3,07	0,10	3,19	0,02	
Mittelwert	0,22	0,02	0,18	0,01	
min	0,04	0,04	0,04	0,04	2020/2021
max	0,44	0,06	0,07	0,04	
Mittelwert	0,10	0,04	0,04	0,04	

Values **exceed the targets of the Surface Waters Ordinance** 0,1 - 0,3 mg/l.

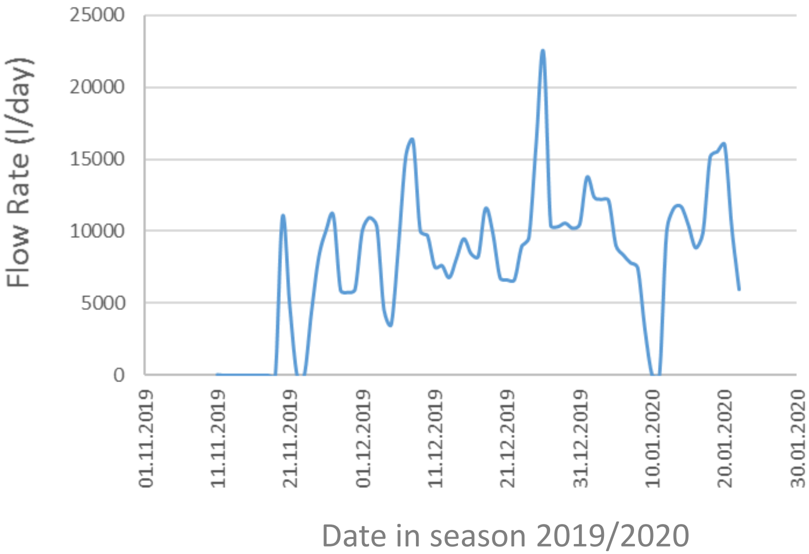
Highly fluctuating P content requires **permanent sampling**.

Drainage water samples

Manual flow measurement



Automated flow measurement

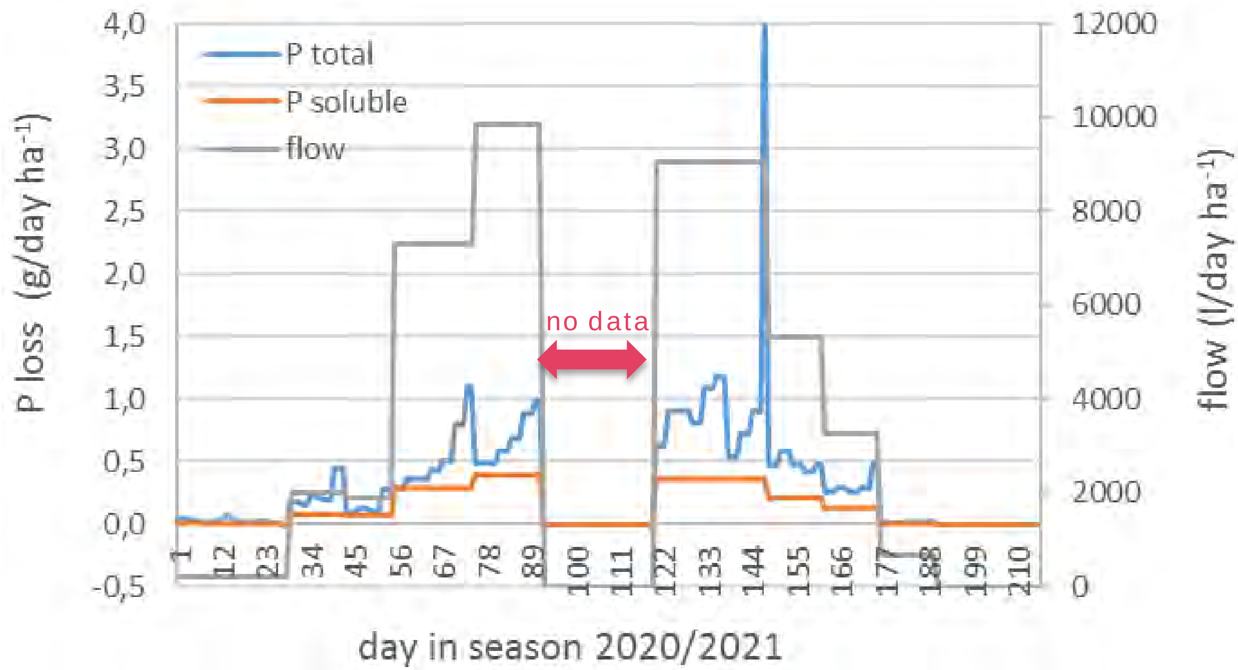


Strong **fluctuation in automated** measurement. Validation required!

Static data in the **manual** survey.

Flow-balanced P loss

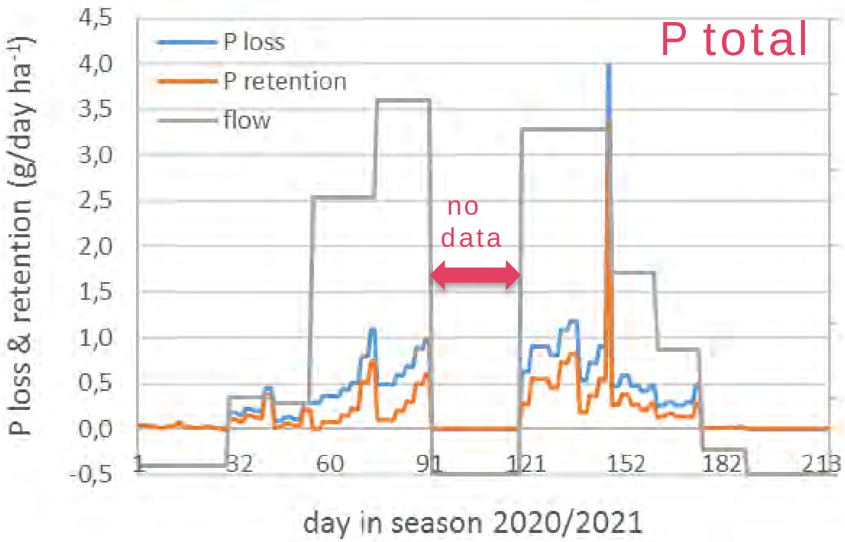
2020/2021

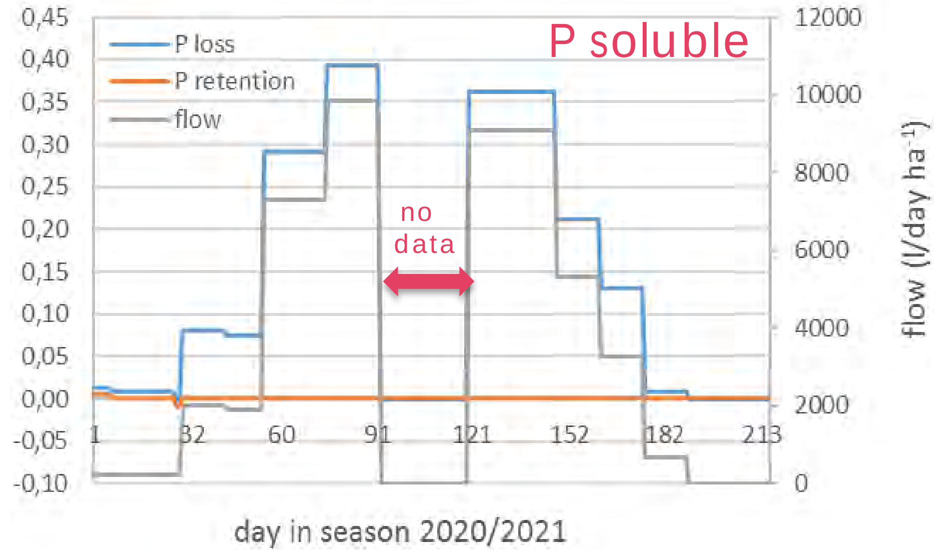


- **Positive correlation** between outflow volume and P output, especially for P total, less for P soluble.
- **Hysteresis** effect of the flow on the P loss, especially for P total, less for P soluble.
- **Cumulated** P loss per ha and year: 67 g, of which 30 g dissolved P (45%).
- **In 2019/2020:** Cumulated P loss per ha and year: 607 g, of which 7,6 g dissolved P (1,3%).

Flow-bal. P loss & retention

2020/2021

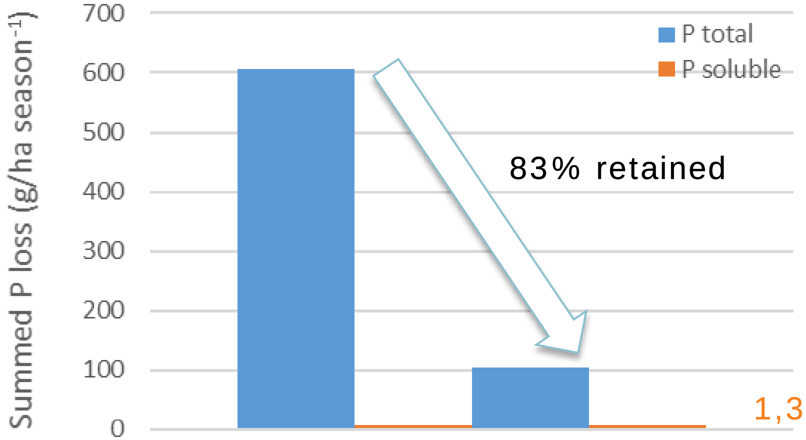




- **Positive correlation** between loss and retention for P total.
- **No correlation** between loss and retention for P soluble, **no filter effect.**
- Confirmation: P Filter **only suitable** for **particulate** bound P.
- **Filter efficiency** for P particulate **83%** (2019/2020) and **54%** (2020/2021).

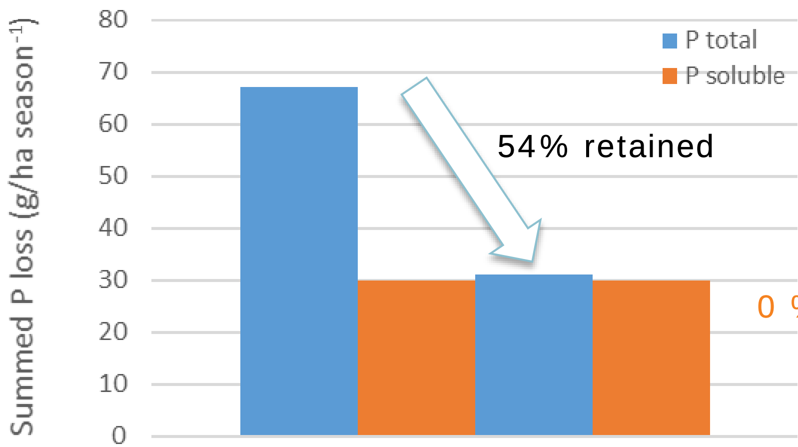
Impact P loss on algae growth

2019/2020



1,3 % retained

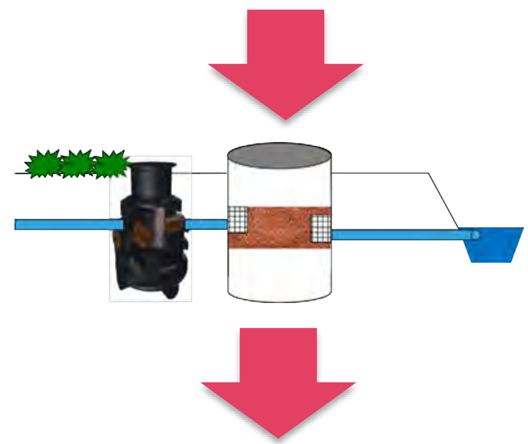
2020/2021



0 % retained

Assumption:

1 g P → 330 g phytoplankton



Saved growth of algae mass

156 kg (2019/2020) and

12 kg (2020/2021) per ha.

Cross-check with literature

... average $P_{tot.}$ export 0,29 kg ha^{-1} y^{-1} ...
... P mainly in particulate form ...
... 50 % of the annual $P_{tot.}$ export in 140 h, hysteresis effect ...

(Ulén & Persson 1999, Hydrological Processes Vol. 13, Iss. 17)

→ more data required for statements

... tile discharge highly variable within events ...

(Macrae et al. 2007, J. Agr. Wat. Man. Vol. 92, Iss. 3)

→ we can confirm that so far

... the amorphous organic substance is a carrier of P and causes a high P input into surface water ...

(Zimmer et al. 2016, Agricultural Water Management 167)

→ can explain large differences between season 2 & 1 (not shown)

... ICS has a potential for field use due to its high hydraulic conductivity ...

(Chardon et al. 2012, J. Environm. Qual., Vol. 41)

→ due to low hydraulic gradients in the field, it is important to ensure a sufficient hydraulic conductivity of the filter material

... ICS filter efficiency of >80 % possible but reduced to 54% by clogging...
→ can be confirmed so far

Transfer into practice

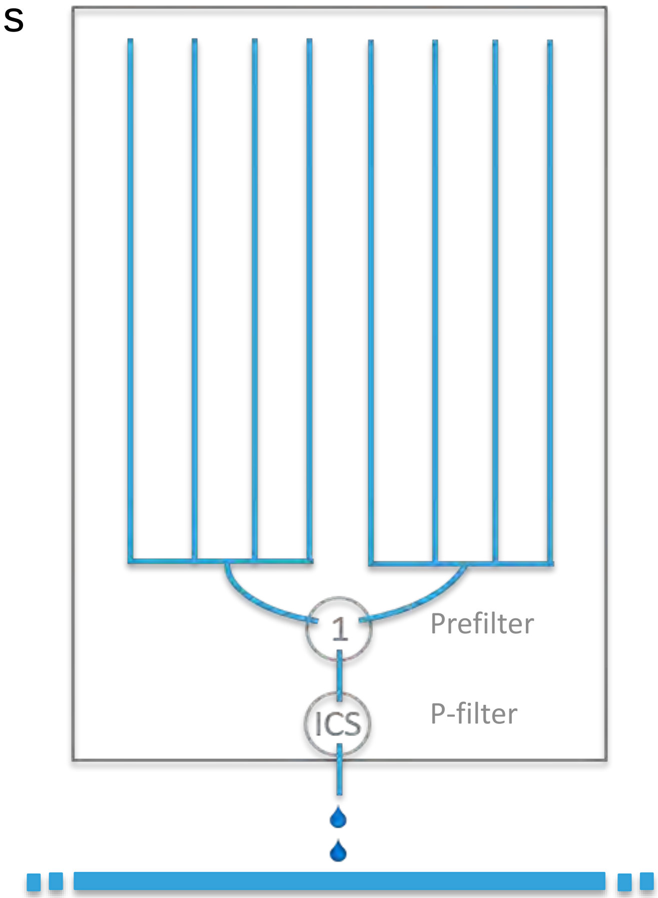
New installation
Extension of existing drainage collector systems

Benefits

- Cheap filter material ICS
- Low space consumption
- No energy supply
- Renewable (in own work)
- Long-term filter effect
- Mechanical lifting of filter material

Required before the practical introduction

- Enlargement of the data base
- Improvement of pre filtration
- Query of practical requiremets (€, §)



Q & A

Landwirtschaftskammer Niedersachsen
Wir bieten Lösungen – regional & praxisnah!

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We thank the EU for funding and all our partners and colleagues for their support!

https://northsearegion.eu/nuredrain/

Q & A

Part II: Nitrate removal from drainage water and greenhouse effluent

Moving Bed Bioreactor: Case study Belgium

Pieter Van Aken – KU Leuven
Process & Environmental Technology Lab

Introduction: Moving Bed Bioreactor

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- Biological denitrification in anoxic conditions

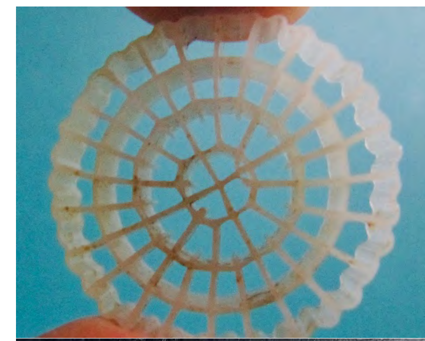
$$5C_3H_8O_3 + 14NO_3^- + 14H^+ \rightarrow 15CO_2 + 7N_2 + 17H_2O + biomass$$

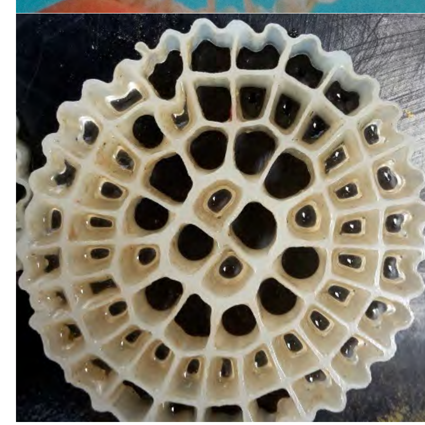
NO_2^- → NO → N_2O

Carbon source (glycerol-based)

pH increase

No recovery possible





- Moving-bed Bioreactor technology
  - Biofilm growth on AnoxKaldnes® plastic carriers (K5)
  - <u>Benefits</u>: Limited growth of biomass & high active biomass concentration
  - Treating high nitrate concentrations is possible

Considerations design MBBR concept

Tile-drained agricultural fields

- 50 – 200 mg NO_3/L
- High flow rates (7.5 – 15 m^3/d)
- November – April

Greenhouse effluent

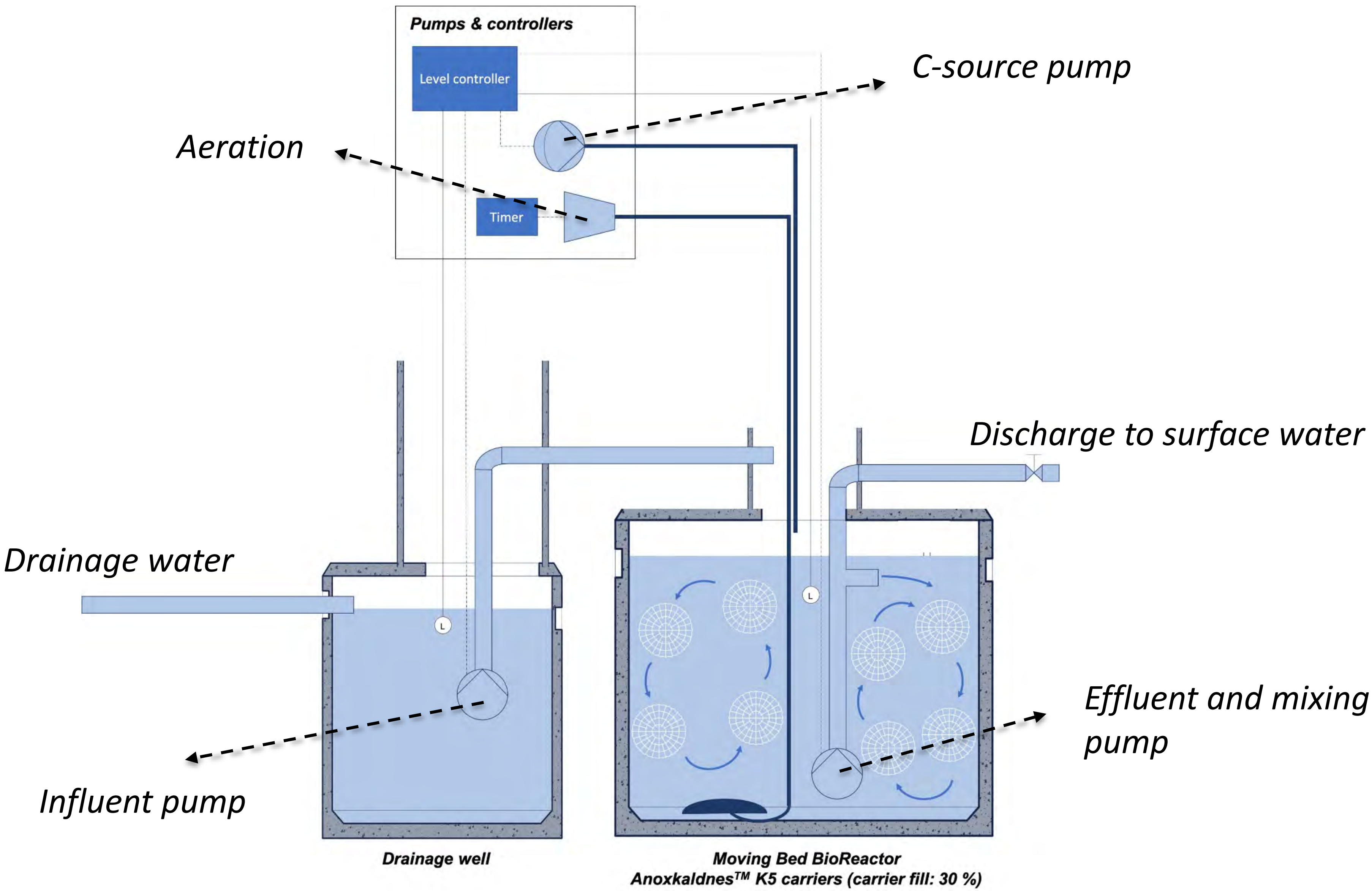
- 100 – 400 mg NO_3/L
- Low flow rates (3 m^3/d)
- During the whole year

Design considerations

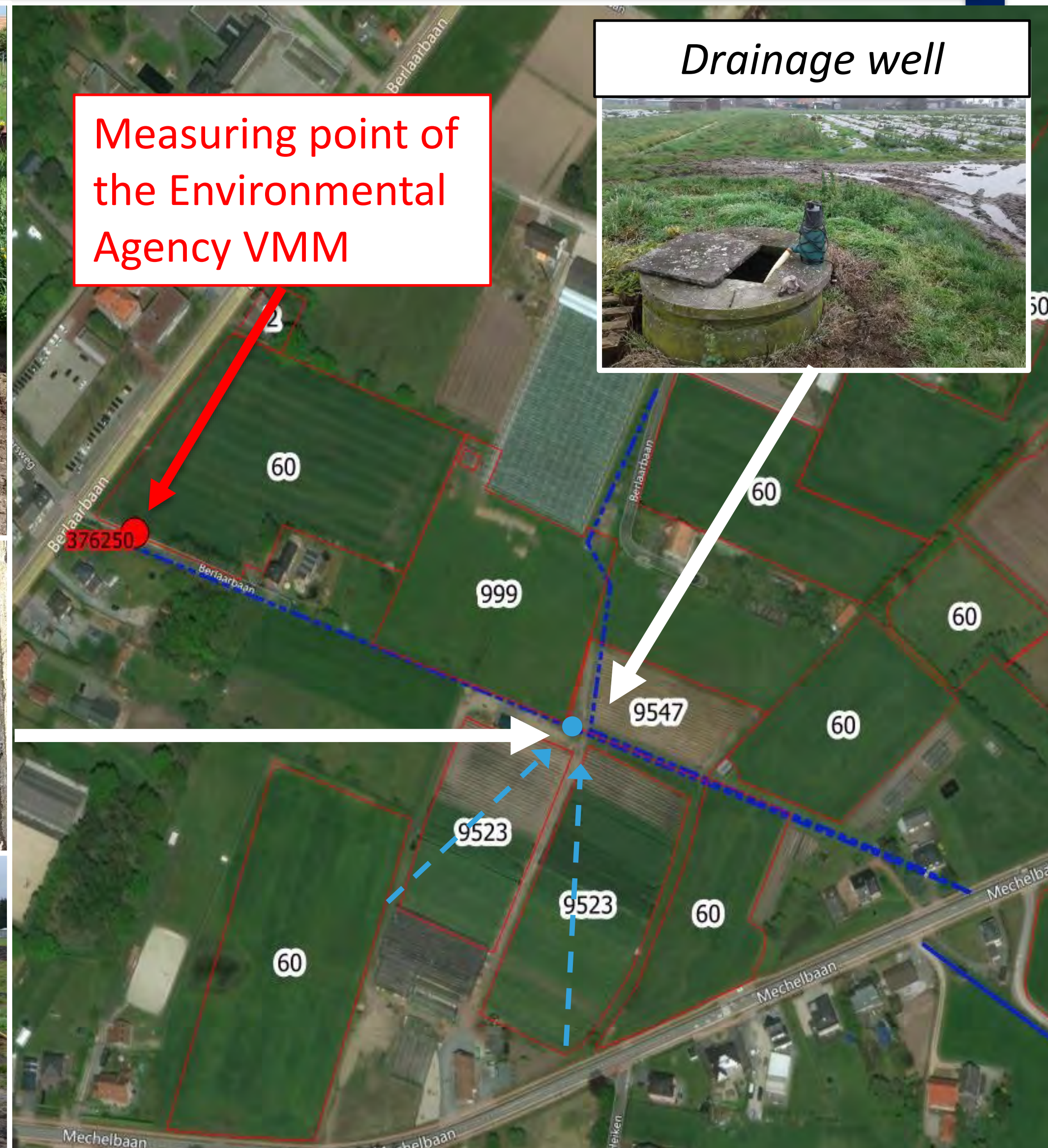
→ Simple and robust system
→ Low water temperatures (between 5 – 15 °C)
→ Variable flow rates and nitrate concentrations
→ Remote locations
→ Low budget solution

Discharge limit: 11.29 mg NO_3-N/L

MBBR concept to treat agricultural waters



Field Case – Tile drained fields



Field Case – Tile drained fields

Proefstation voor de Groenteteelt

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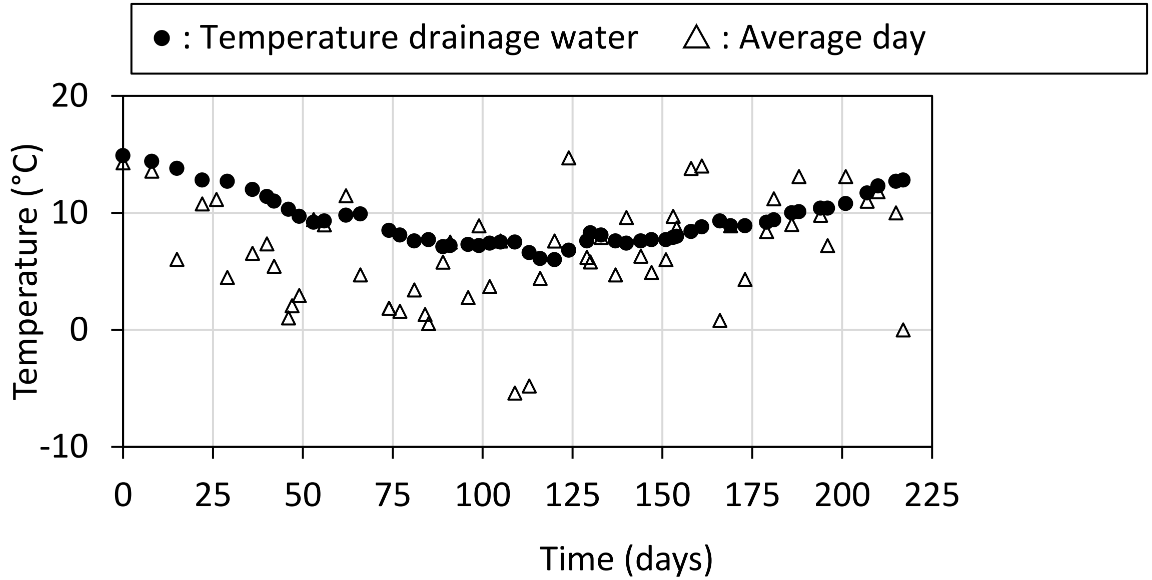
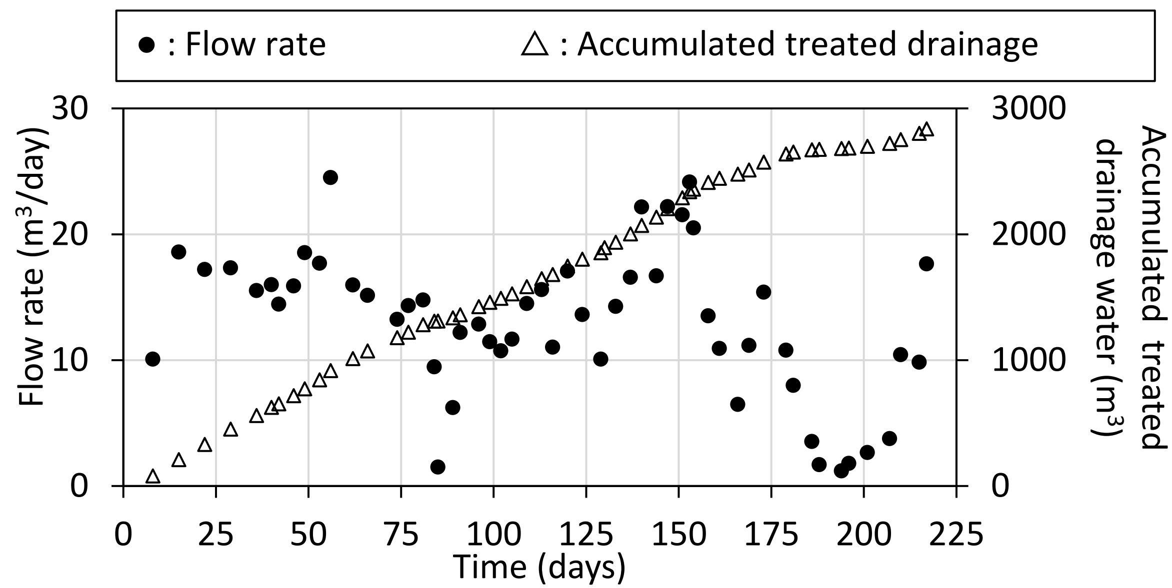
Key numbers of 2020-2021

- Drainage season: 217 days (from October to May)
- T_{max} = 14.3 °C
- T_{min} = 6 °C
- Total treated drainage water = 2837 m^3
- Flow rate: from 1.2 m^3/day to 24.5 m^3/day
- Average nitrate conc. = 30.7 mg NO_3-N/L
- pH drainage water: 6.54 ± 0.17
- pH MBBR effluent: 6.73 ± 0.16





Field Case – Tile drained fields

Proefstation voor de Groenteteelt

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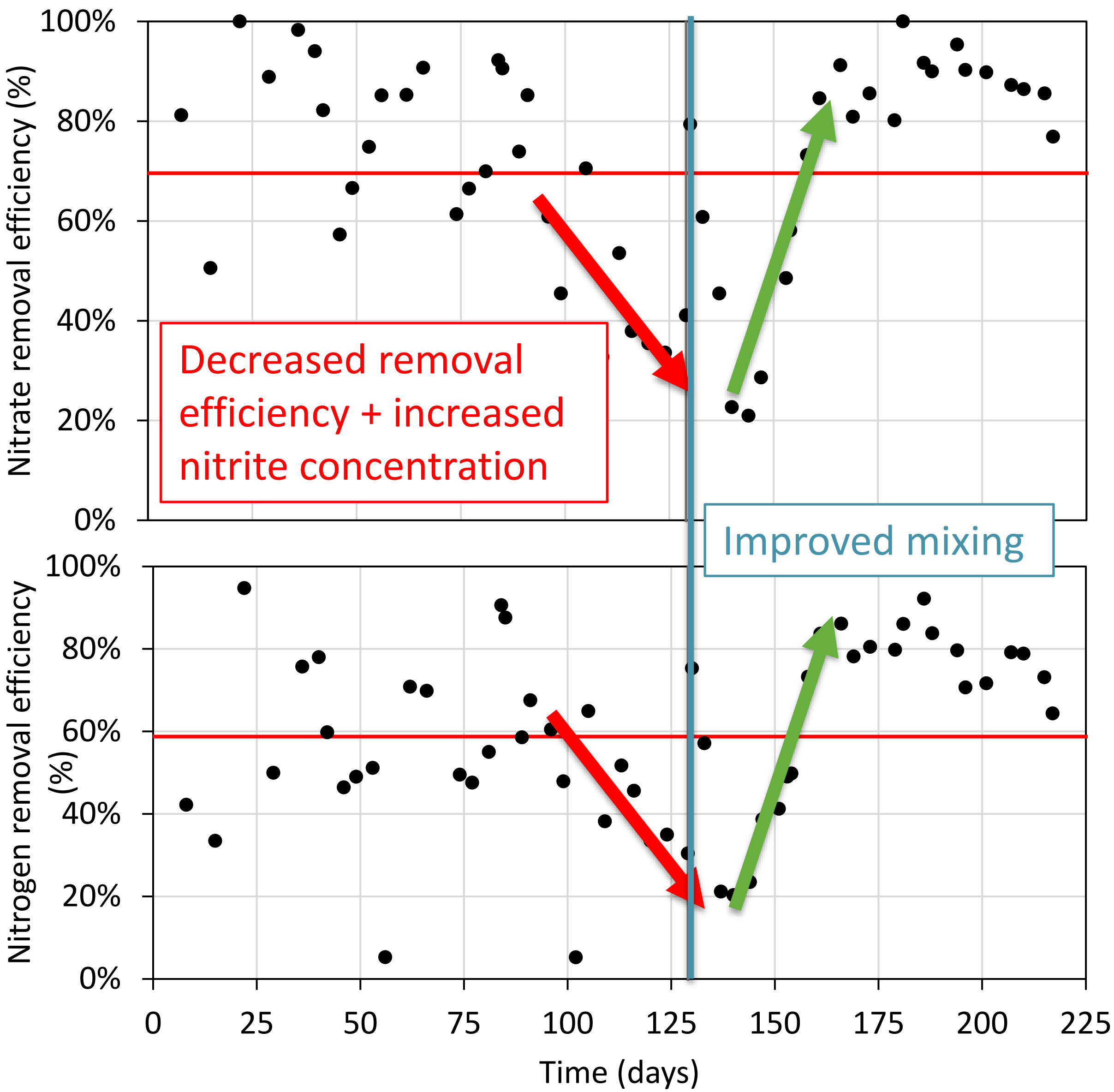

Removal efficiency

- Total period:
  - NO_3-N: 70%
  - TN: 60%
- Improved mxing:
  - NO_3-N: 87%
  - TN: 79%

Total nitrate removal

- 57.6 kg NO_3-N

Field Case – Tile drained fields

Proefstation voor de Groenteteelt

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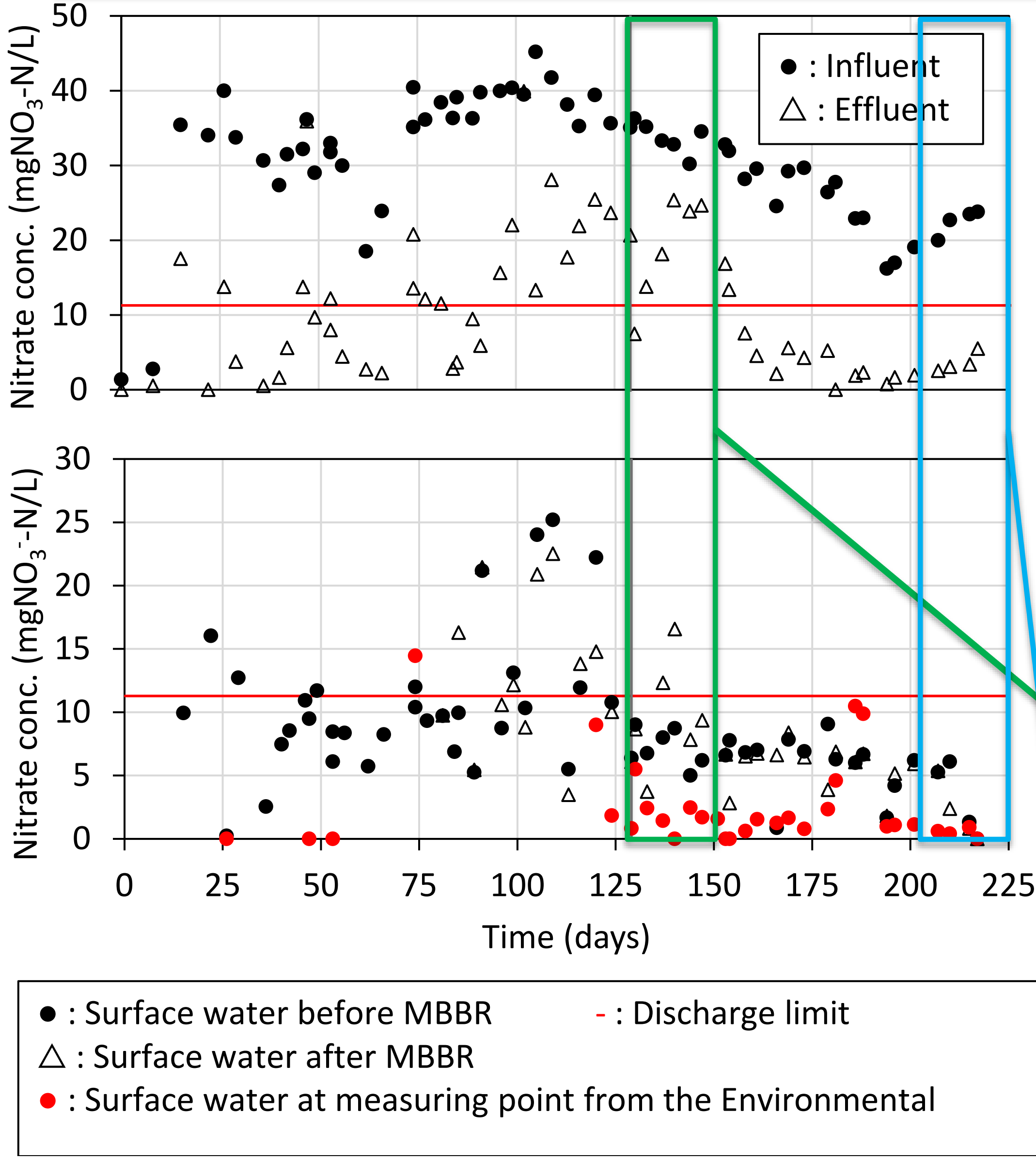


Moving Bed Bioreactor

- Influent
  - Average: 30.7 mgNO$_3$-N/L
  - Min: 16.2 mgNO$_3$-N/L
  - Max: 45.2 mgNO$_3$-N/L
- Effluent
  - Average: 10.8 mgNO$_3$-N/L
  - Min: 0 mgNO$_3$-N/L
  - Max: 39.9 mgNO$_3$-N/L

Effect on surface water

- If the removal efficiency is low, the nitrate concentration of the surface water increases
- At high removal efficiency, the nitrate concentration after the MBBR is similar or lower than before the MBBR.

Field Case – Greenhouse (DIY-concept)

HOW DO I BUILD A MOVING BED BIOFILM REACTOR (MBBR)?

1. What is a MBBR?

A Moving Bed Biofilm Reactor (or MBBR for short) removes nitrogen from water by converting nitrate into nitrogen gas by means of biological processes. A MBBR consists of a tank filled with water, in which plastic carriers are located that are set in motion (Photo 1Photo 1). The irregular and large specific surface area of the carriers forms an ideal habitat for various micro-organisms (Photo 2Photo 2). On these carriers grows active sludge (biofilm) and this carries out the denitrification.

A MBBR requires little maintenance and is simple to construct yourself with the help of this information sheet.

Photo 1: Set-up of Moving Bed Biofilm Reactor (MBBR) at PCS Ornamental Plant Research

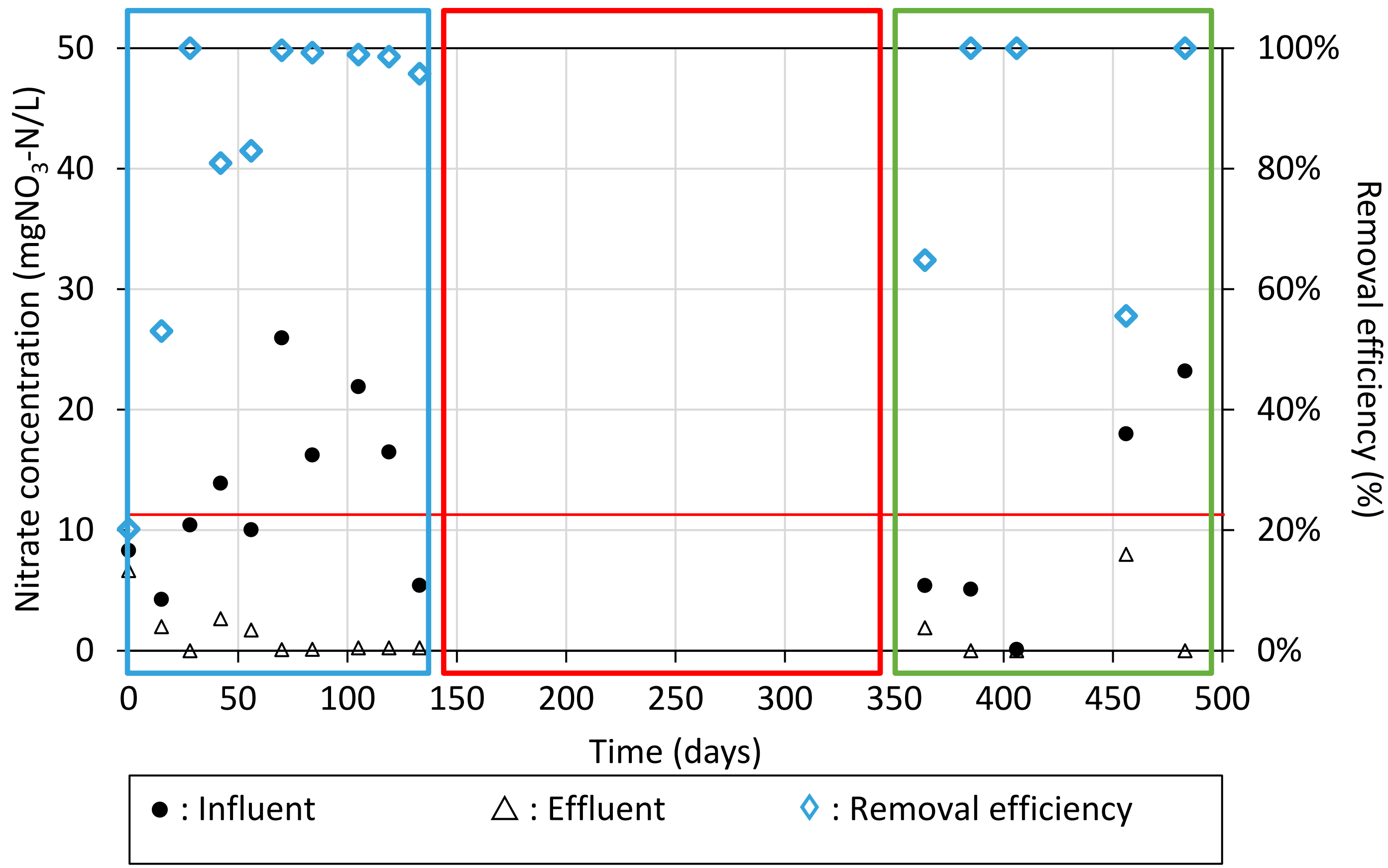
Information sheet: "How do I build my own MBBR?" - Version date 28/05/2020
Drawn up in connection with the Interreg North Sea Region project NuReDrain.

Field Case – Greenhouse (DIY-concept)

<u>Storage pond:</u> Day 0 - 133
- Influent: 13.3 $mgNO_3$-N/L
- Effluent: 1.4 $mgNO_3$-N/L
- Removal efficiency: 83%

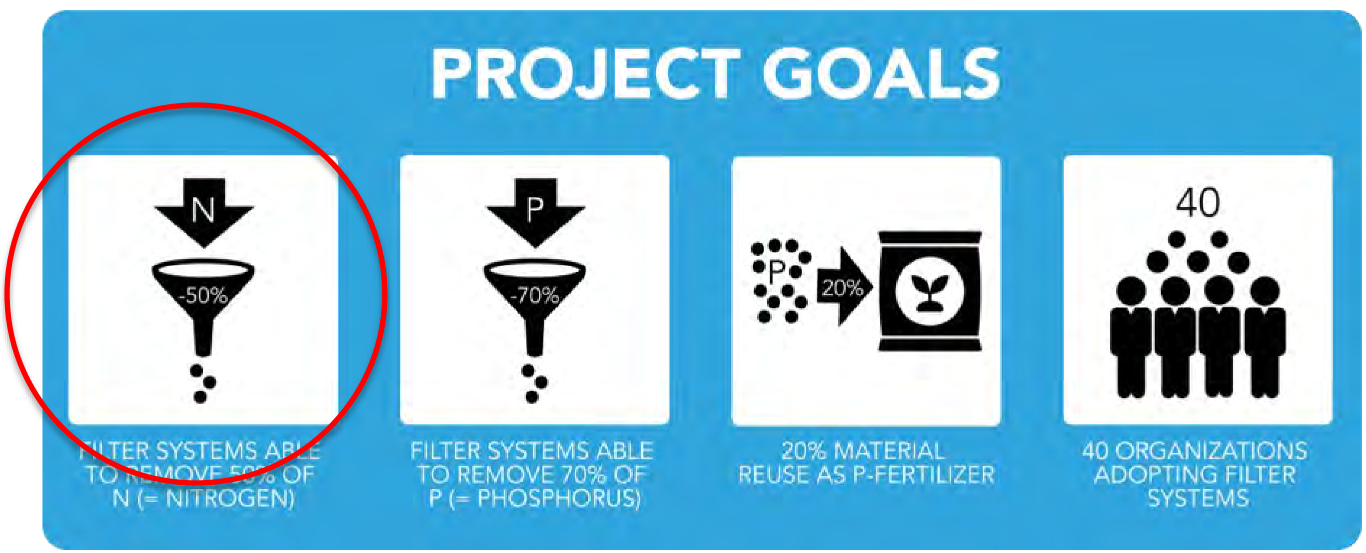
Shut down during the winter

<u>Drain water:</u> Day 364 - 483
- Influent: 10.4 $mgNO_3$-N/L
- Effluent: 2.0 $mgNO_3$-N/L
- Removal efficiency: 84%



Conclusions

- Underground MBBR: temperatures higher than 5°C
- Mixing is very important: Improved removal efficiency from 70% to 87%.
- The nitrate concentration of the surface water is similar or even lower when the MBBR achieves high removal rates.
- Total cost efficiency: 103.4 €/kg NO_3-N



Zero Valent Iron for N and P removal

Adrian Florea; Hans Christian Bruun Hansen

Environmental Chemistry

Department of Plant and Environmental Sciences

University of Copenhagen

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The Nitrogen wheel

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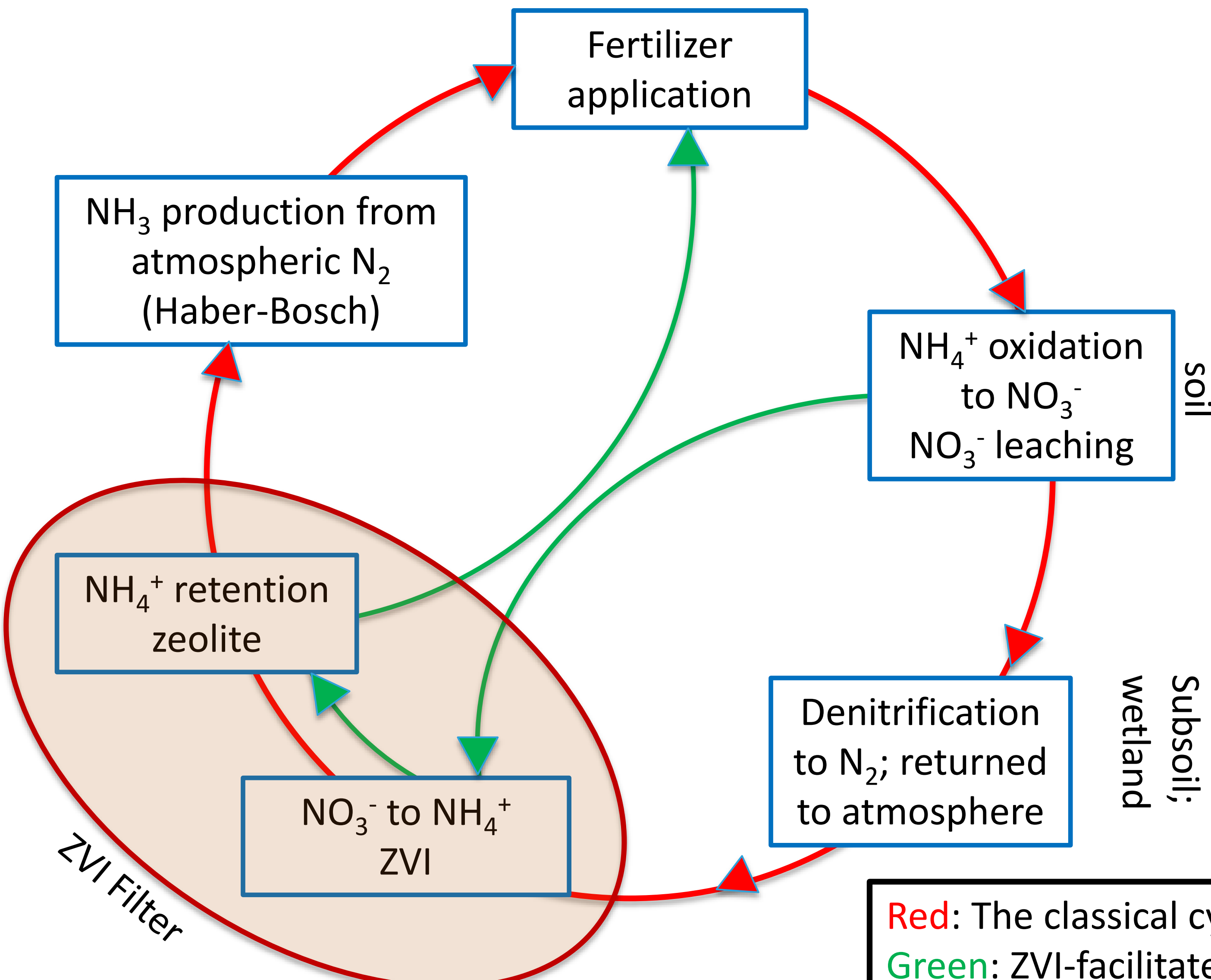

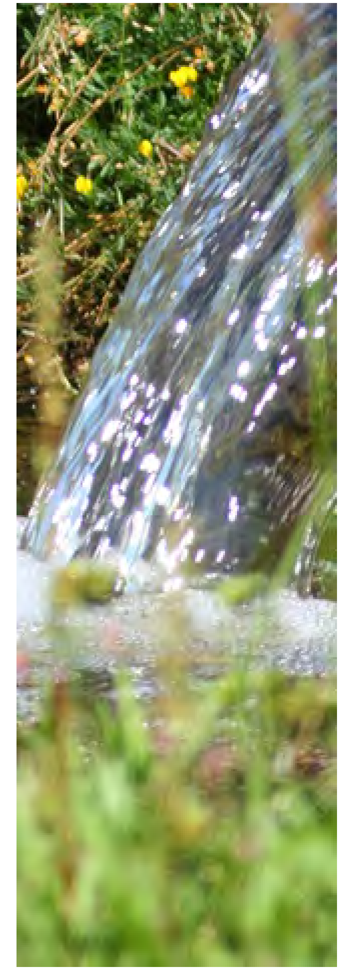

Red: The classical cycle
Green: ZVI-facilitated cycle

Zero valent iron filter

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- Objectives: to develop a filtration system that can remove nitrate (NO_3^-) and recover nitrogen as ammonium (NH_4^+) from agricultural drainage water.
- Field scale setup and principle

  $$4\,Fe^0 + NO_3^- + 10\,H^+ \rightleftarrows 4\,Fe^{2+} + NH_4^+ + 3\,H_2O$$

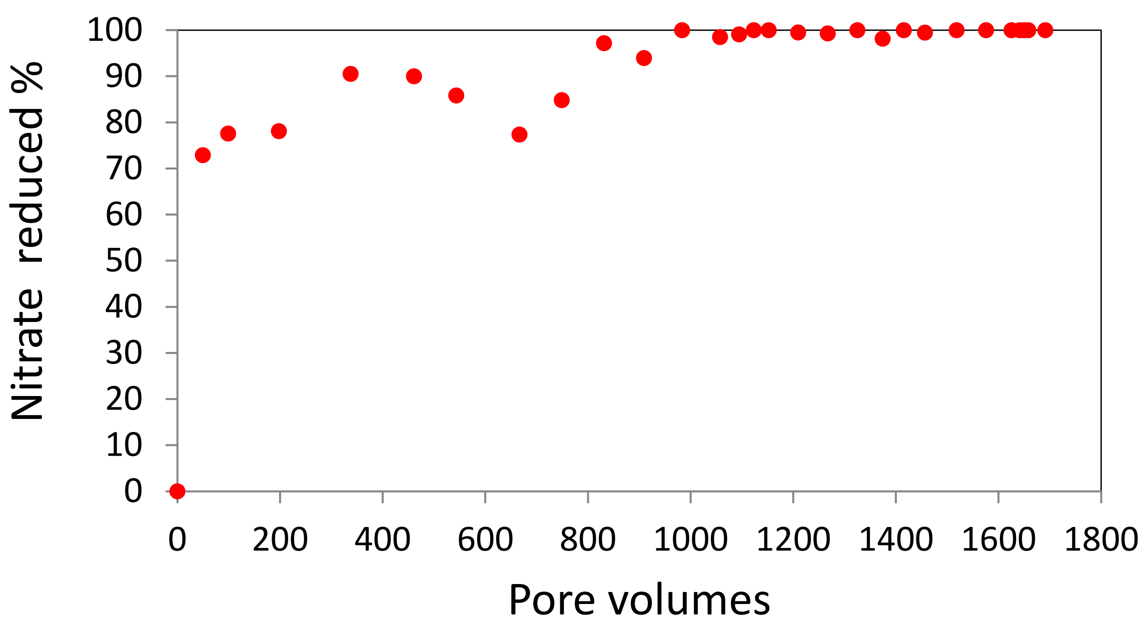
- Filter constructed of three units:
  - **Section 1**: ZVI unit + sand; 45 kg ZVI
  - **Section 2**: Oxidation (air bubbling)
  - **Section 3**: Ammonium capture (zeolite); pre-treated with NaCl; 70 kg zeolite
- Agricultural drainage water flow: 1 L/min
- Retention time: 35-45 min for each unit

ZVI

Zeolite

Results - 1

Nitrate removal

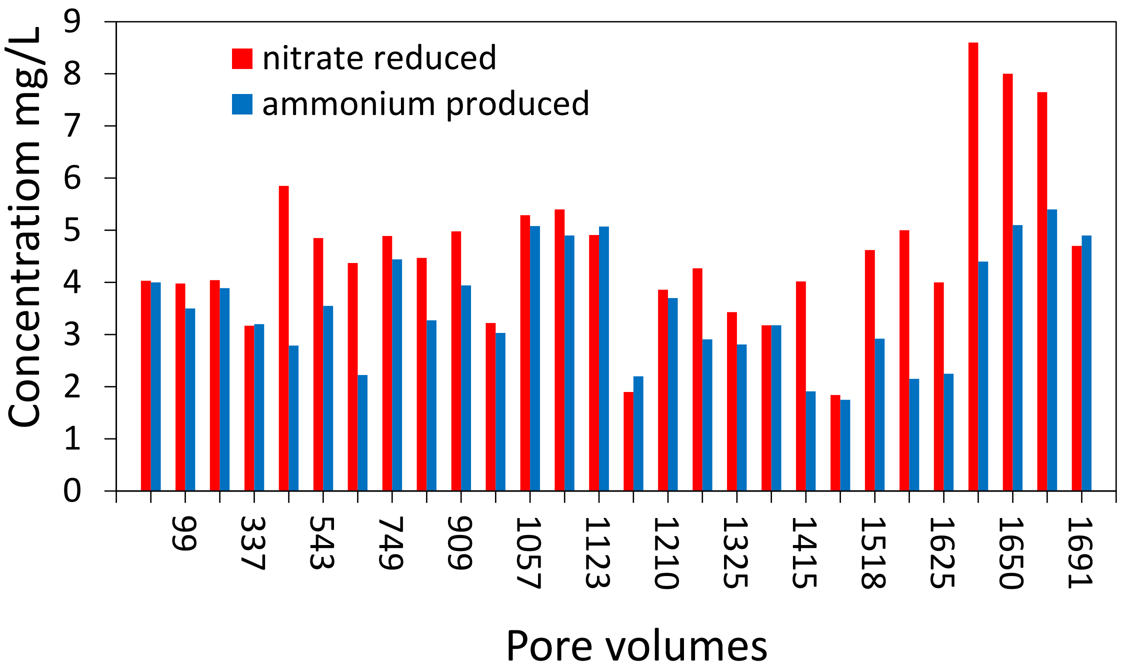


NO_3^- measured at end of column 1

- High NO_3^- removal efficiency regardless the initial nitrate concentration (3 to 8 mg/L nitrate
- Average NO_3^- reduction for the entire running period: 94%

Results - 2

Nitrate is converted to ammonium

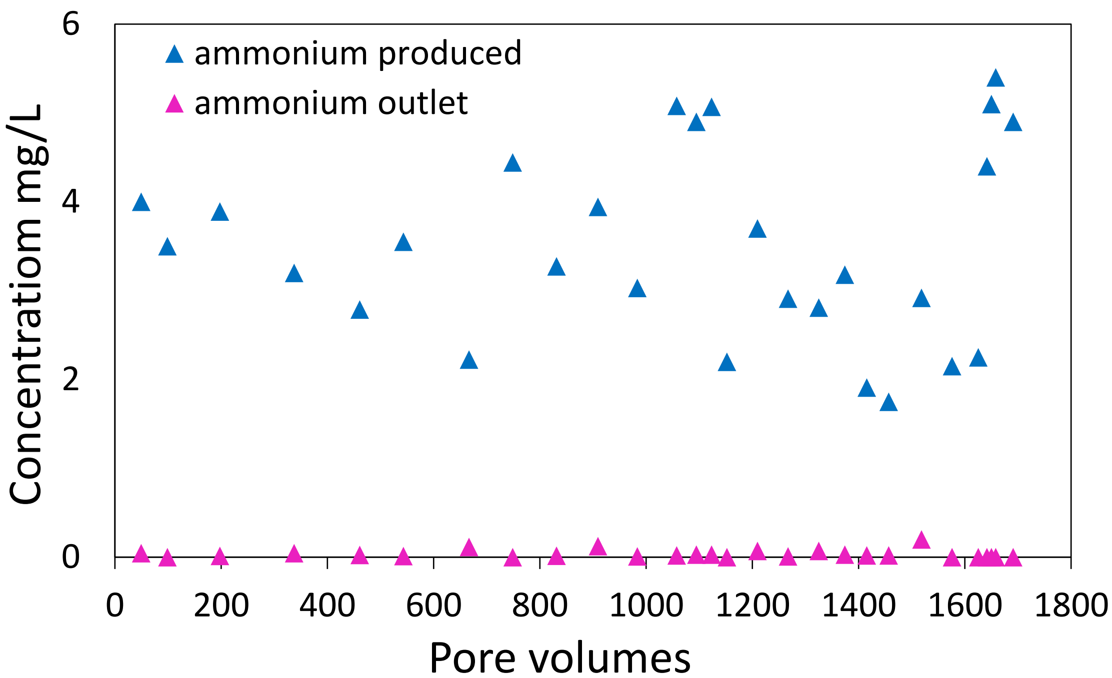


NO_3^- and NH_4^+ measured at end of column 1

- NO_3^- is converted to NH_4^+. 100 % at start and then at about 70 % at end of the period
- Similar results as in laboratory experiments
- Incomplete conversion could be due to production of unmonitored nitrogen gas species (NO_2, N_2O, N_2H_4)

Results - 3

Ammonium capture



NH$_4^+$ measured at inlet and outlet of column 3

- Almost 100 % NH$_4^+$ retained in zeolite over the entire running period
- No decrease of NH$_4^+$ retention as in laboratory experiments
- Higher efficiency of zeolite layer, as in laboratory experiments

Results - 4

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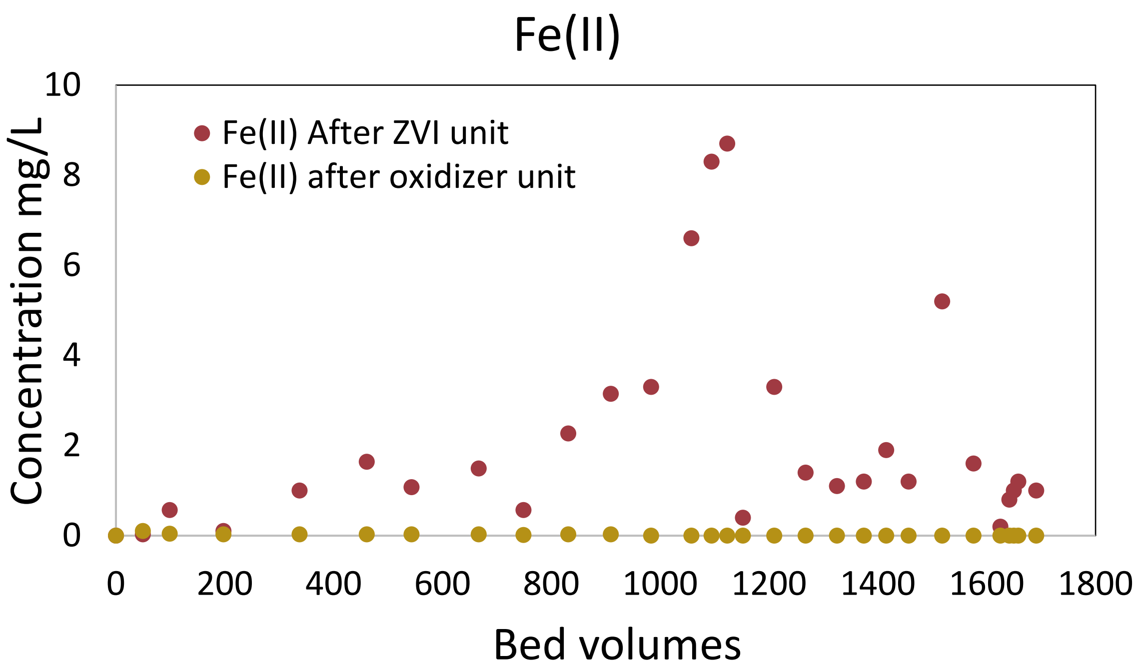
Removal of iron(II)

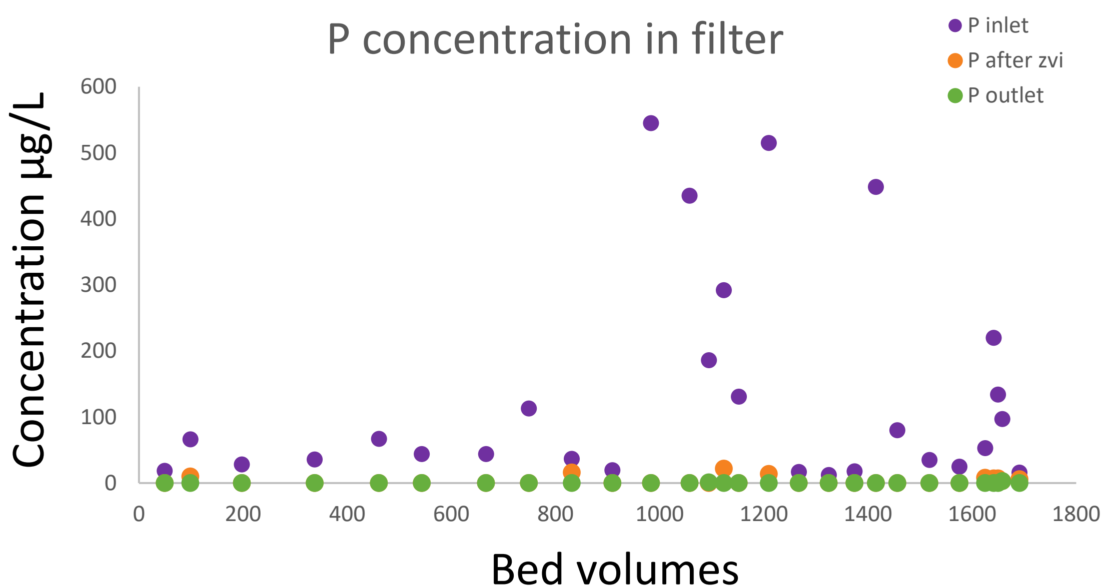


Fe(II) measured at inlet and outlet of column 2

- 100 % of iron(II) removed through oxidation in the aeration section
- Iron(II) oxidized and iron(III)oxide (”rust”) precipitated (yellow-brownish)

Results - 5

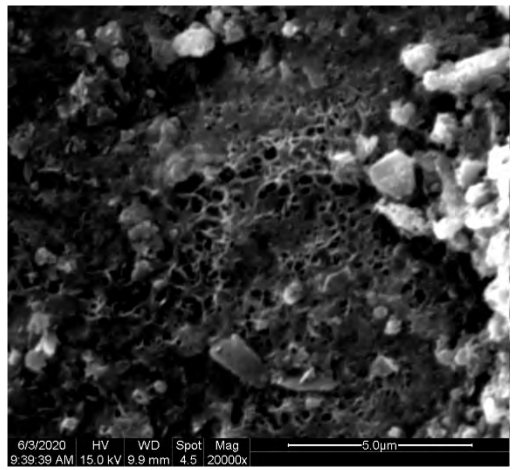
Phosphate is 100 % retained

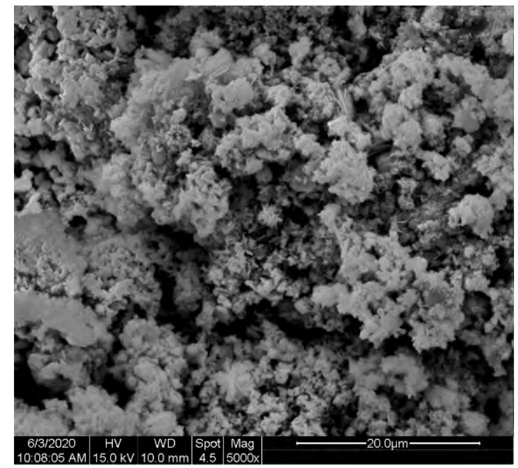


HPO_4^{2-}

- No phosphate was detected in the outlet from column 1 and 2
- Inlet phosphate concentration: 0.5 mg/L
- Phosphate sorbed to the ”rust” formed and thus is fully retained

Green rust formation in ZVI unit





- Green rust (GR) is an unstable corrosion product that forms in the ZVI unit.
- GR facilitates reduction of nitrate to ammonium and reduces the mass of ZVI needed
- GR may also contribute to phosphate sorption

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Investment and operationnal costs

Investment cost

	Price	Amount needed/ha/year (2000 m^3 drainage water)	Price/ha/year	Removal and recovery/ha/ year
ZVI	0,85 – 1 €/Kg	72 Kg	60 – 72 €	100% Nitrate removal
Zeolite	2,5 – 3 €/Kg	500 Kg	1250 – 1500 €	70% Ammonium formation + retention
Filter system + tubing + pumps	2000 €		2000 €	14 Kg N retained
Total:			3500 €	

Operational cost: electricity

Filter evaluation

Pros

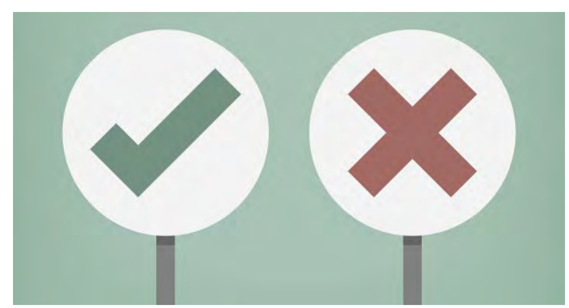
- Nitrate can be completely removed, even at low concentrations and low temp. ✓
- Ammonium can be recovered enabling nitrogen to be recycled ✓
- Phosphate is fully removed and can be recycled ✓
- Iron(II) formed during ZVI corrosion can be oxidized and removed ✓
- The unit advantageous for production facilities such as greenhouses ✓

Cons

- Nitrate removal can decrease due to passivating ZVI corrosion layers ✗
- Oxygen in drainage water will also consume ZVI ✗
- Reduction of water generates H_2 (gas formation in column) ✗
- Maintenance: requires aeration (pump) ✗
- High iron consumption ✗

Improvements

- Smaller ZVI particles to increase reaction efficiency
- Remove ZVI corrosion layers
- Recycling of phosphate



Moving Bed BioReactor and constructed wetland for drainage water
Case study Belgium

Dominique Huits
Inagro

West Flemish agriculture in figures

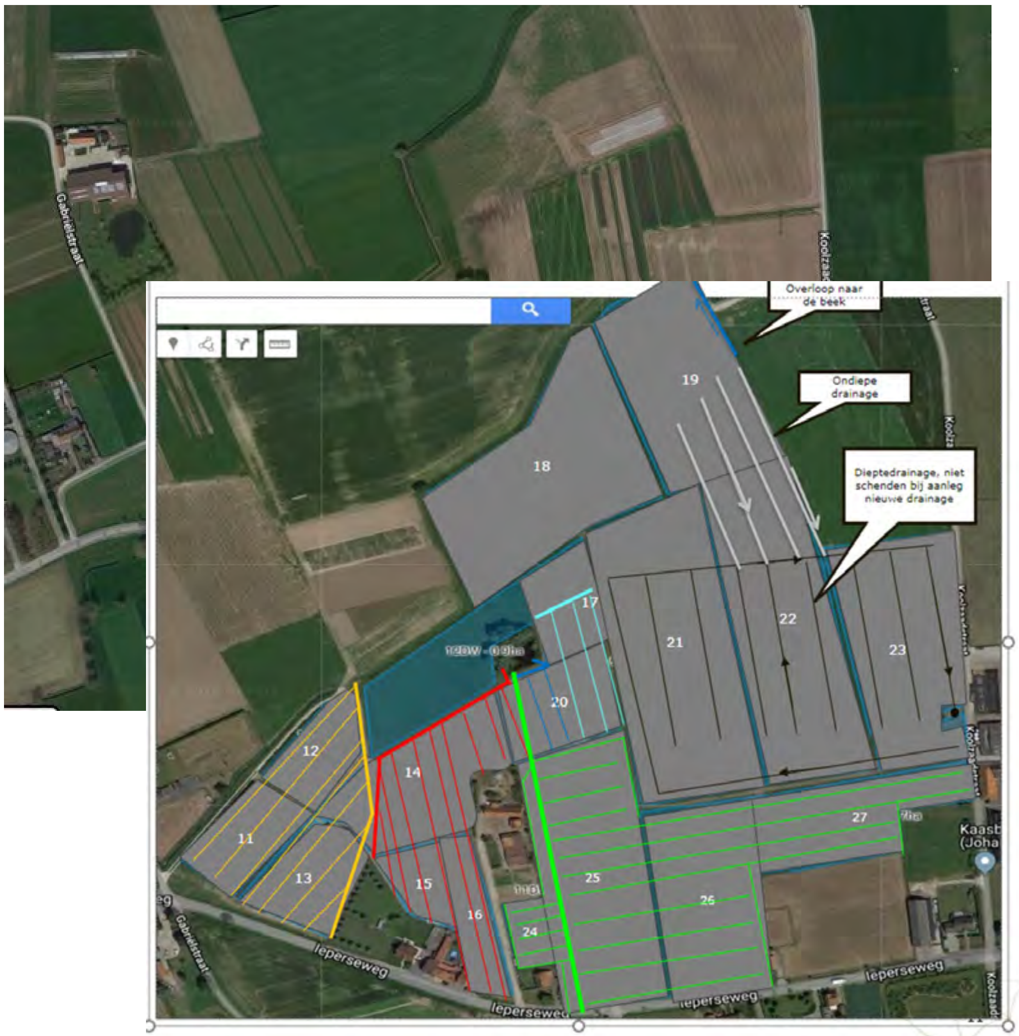
- ✓ 8300 farms good for 200.000 ha or 65% of the total surface area
- ✓ 63% of Flanders’ production of vegetables
- ✓ 49% of Flanders’ production of arable crops

Inspired by Denmark

- New field for field trials
- Drainage to be installed
- Nitrate losses from field drainage are an important issue to get under control

Can a constructed wetland be (part of) the solution?

From idea to design



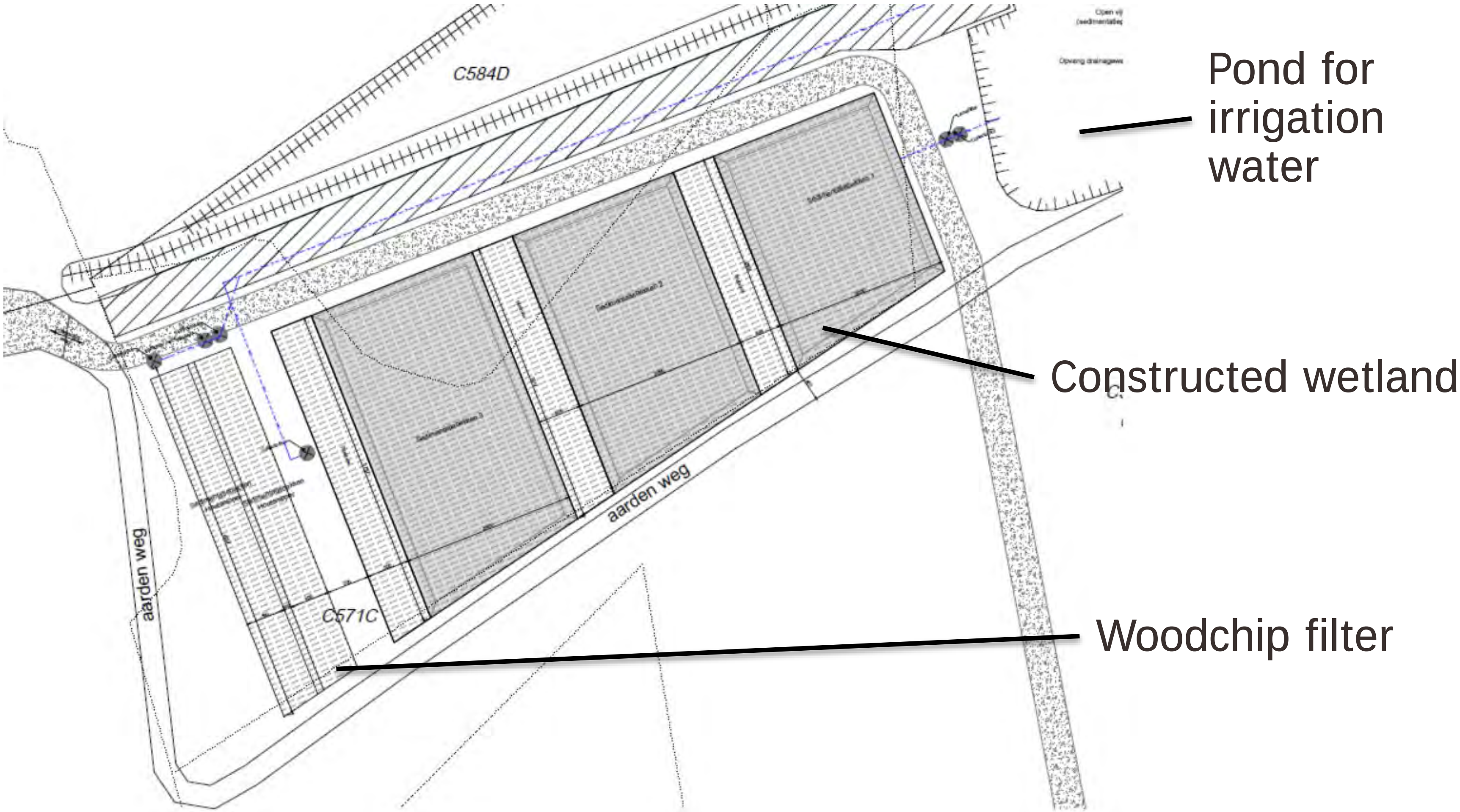
1. Reservoir to collect irrigation water

2. Determination of the location for the constructed wetland

3. Design of the drainage system

4. Design of constructed wetland

Design of constructed wetland and woodchip basin



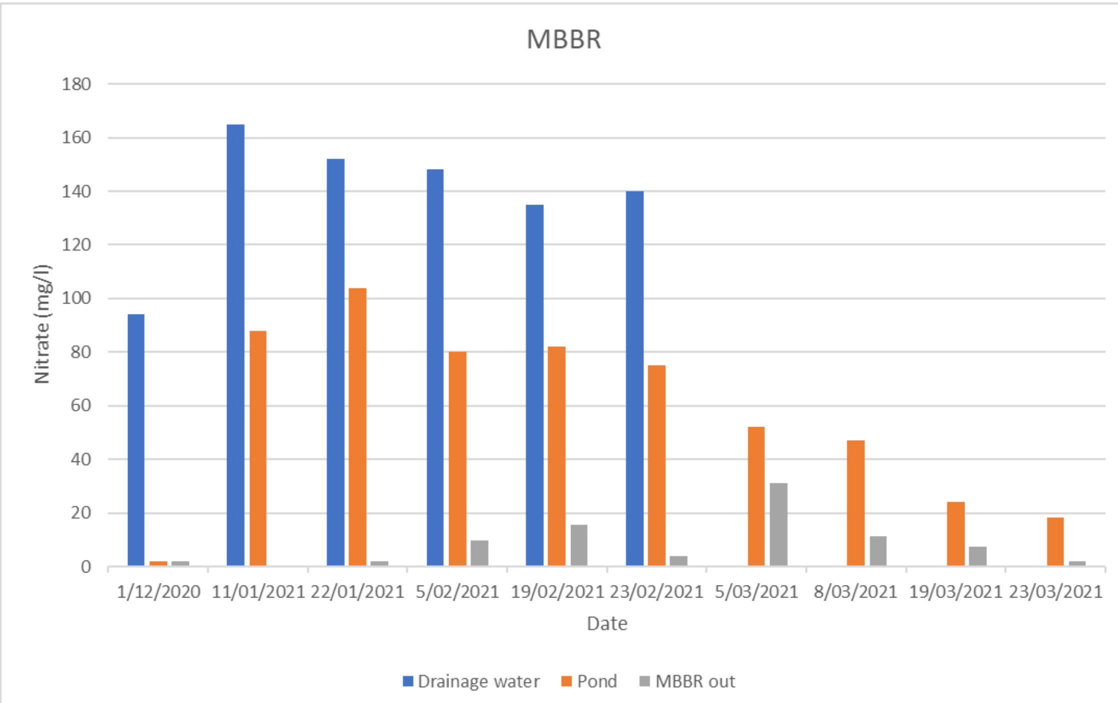
Denitrification units installed

MBBR

Wetland

Woodchip filter

Results MBBR winter period 2020-2021



01/12/2020
Start drainage season
MBBR flow 1,5 m³/h

08/02/2021-18/02/2021
Due to frost internal recirculation of MBBR

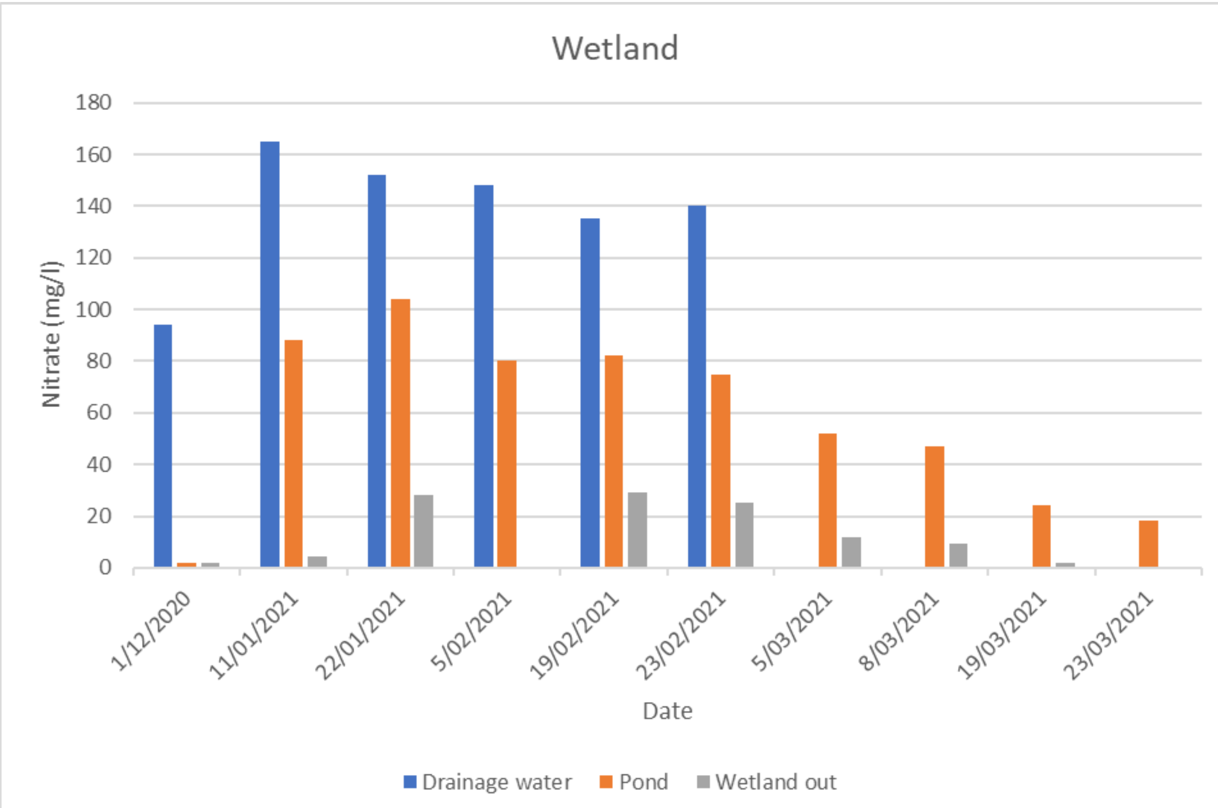
18/02/2021
MBBR flow 1,5 m³/h

03/03/2021
MBBR flow 2 m³/h

17/03/2021
MBBR flow 2,5 m³/h

CarboST dosis : 0,13 L/h during the whole period

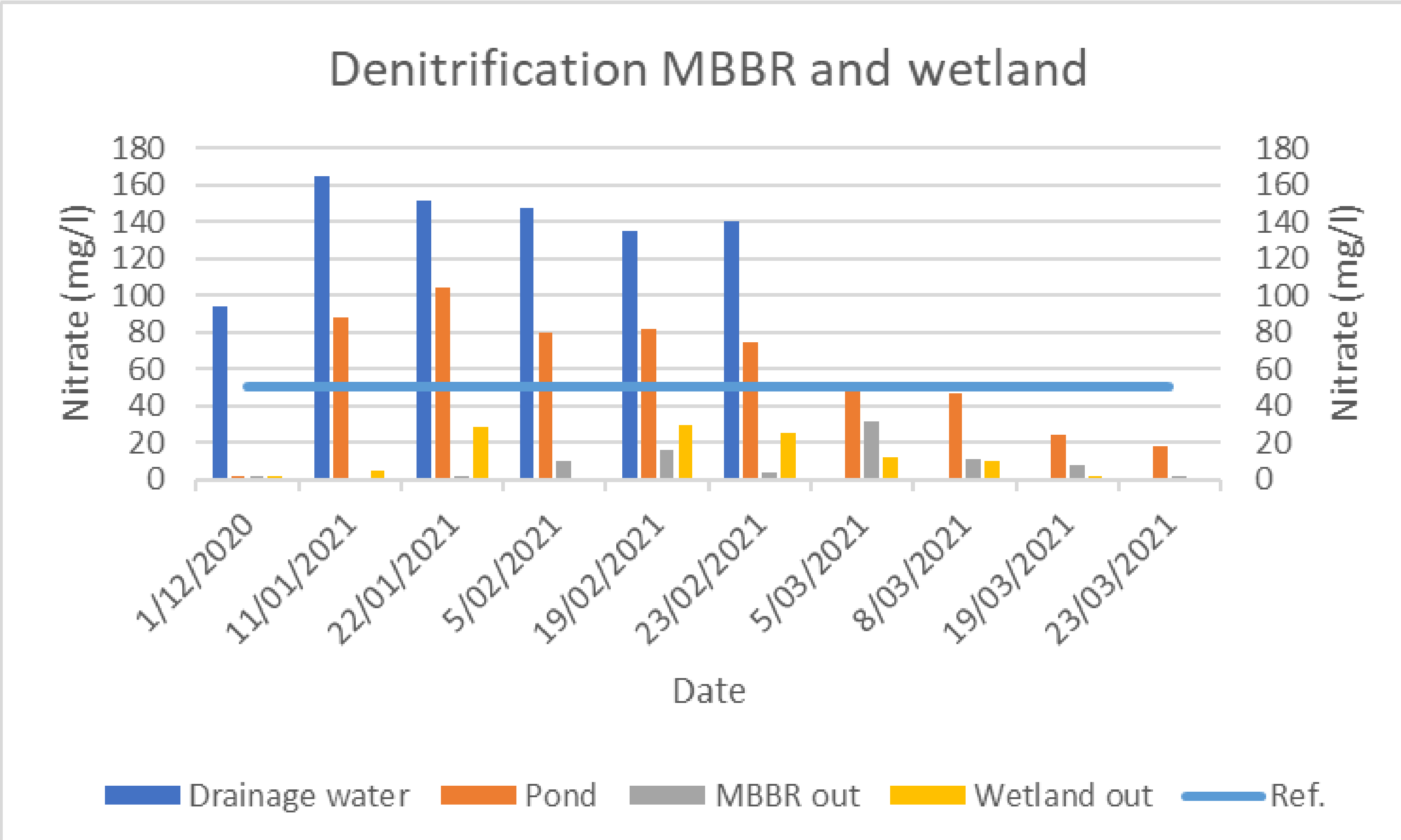
Results MBBR winter period 2020-2021



01/12/2020
Start drainage season

19/03/2021
End of drainage season

Results MBBR winter period 2020-2021



Conclusions

- First results of MBBR and wetland are quite good

But

- Only one year of experience
- Will this work at catchment level

Q & A

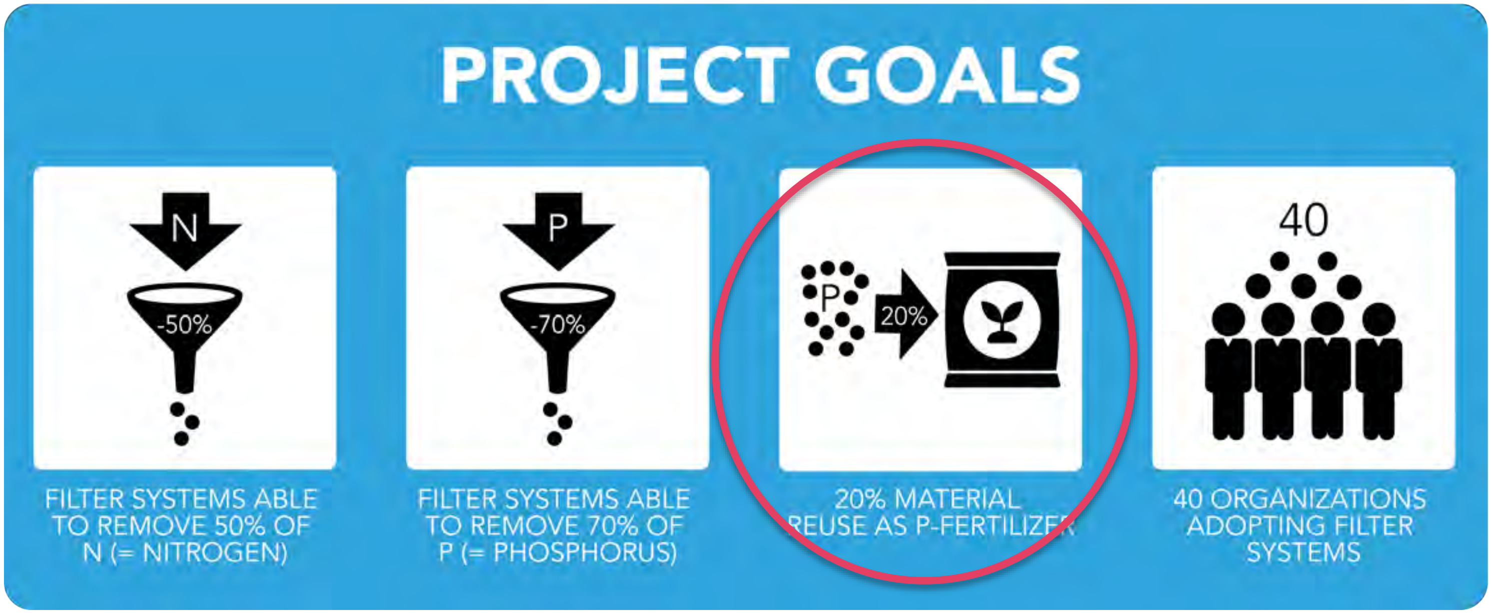
Part III: The bumpy road of phosphate recovery and reuse

Reuse of saturated filter materials as fertilizer for ornamentals and vegetables

Els Pauwels

Ornamental Plant Research (PCS), Belgium

Project goals



Problem statement

- Phosphorus recovery potential

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P-removal – Column tests

- PO_4-P solution: 0.5 ppm P
- Bed height: 14 cm ⟹ corresponds with a bed volume of 150 mL
- Temperature: 20 °C
- Flow rate: 0.66 L/24 h

ICS, Diapure, Redmedite, BaseLith, LiDonit, Vito A, Vito B, LDH, FerroSorp

Problem statement

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Available: ICS (Iron coated sand) :

- Waste product from drinking water production
- Good removal of P - rich drainage waters
- High conductivity of filters (depending on size of particles)
- (Sufficiently) available and (relatively) cheap

- Reuse as a fertilizer without treatment?

P recovery

Direct reuse as P fertilizer

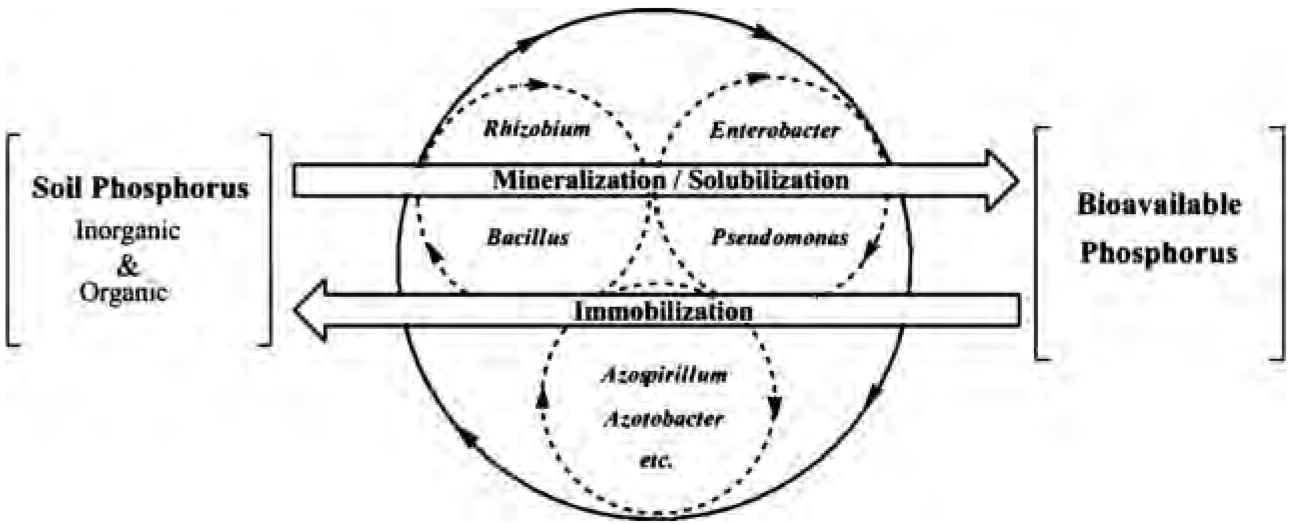
- Pot trials done on Azalea, Lavender, Boxwood, Hedera, …

		
Standard N + standard P	Standard N without P	Standard N without P + 30% ICS

→ P strongly bound to FeO, not available for the plant

PSB

Schematic diagram of soil phosphorus mineralization, solubilization and immobilization by rhizobacteria

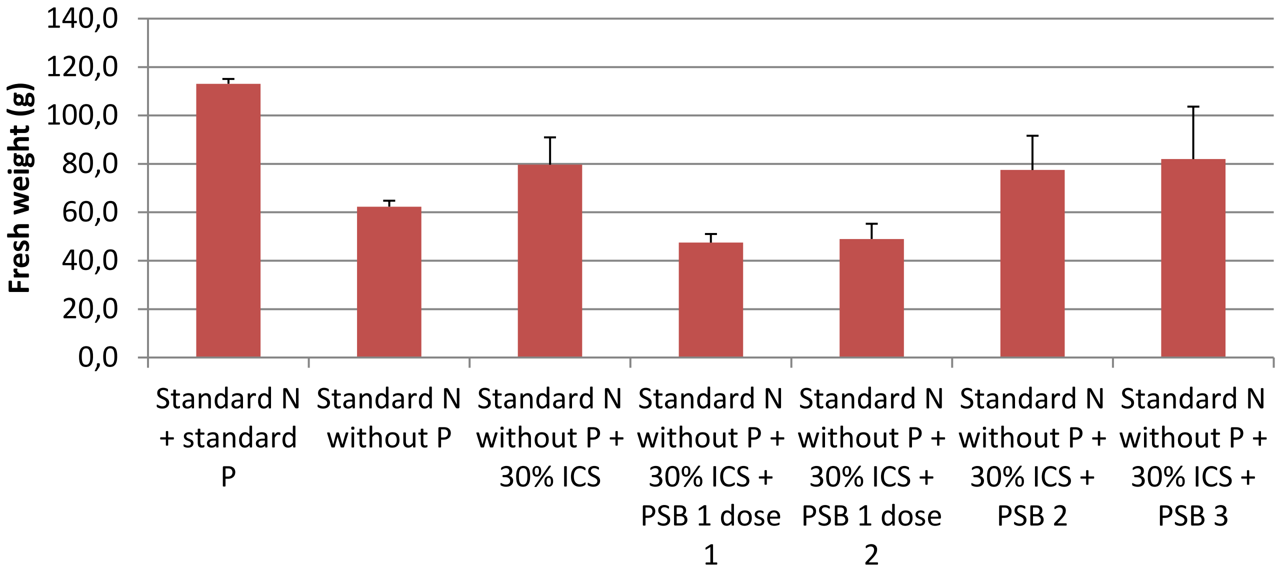


- Predominant bacterial PSB's (sharma et al, 2013):
  - Pseudomonas spp.
  - Bacillus spp.
- P – SOLUBILIZING POTENTIAL depends on :(Sharma et al, 2013)
  - Iron concentration in the soil
  - Soil temperature
  - C and N sources available

Addition of PSB

- PSB = Phosphate Solubilizing Bacteria





→ No effect of PSB

Trials Inagro in agriculture

Endive:

- growth chamber experiment + pot experiment
- Use of ICS as a P – fertilizer
- Use of PSB's
- Evaluation of commercial products

Maize:

- Pot experiment
- Evaluation of commercial products

Trial PCS: 14 different plant species

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Trial PCS: As addition to the substrate? Chlorophytum

- Evaluation at end of trial (16/07/2018)

rooting 5 (left) – rooting 7 (right)

	# rootings trough pot	rootscore 1-7	Fresh weight (13 plants)	Visual plant quality
With ICS	8,3	6,2	333,13	9
Without ICS	8,5	6,2	310,37	9

Exceptions

- **Chrysanthemum**

- **Chlorophytum**

left without ICS – right with ICS

- **Petunia**

Trial PCS 2020

20 plants/treatment

- 1. Control
- 2. 30% ICS grains
- 3. 30% pellets



Trial 2020

Trial 2020

PCS proefcentrum voor sierteelt

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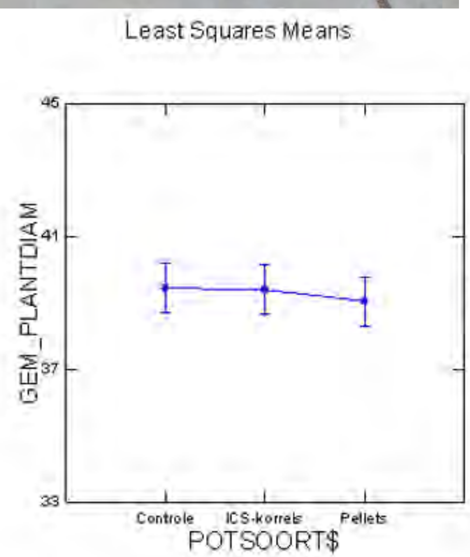
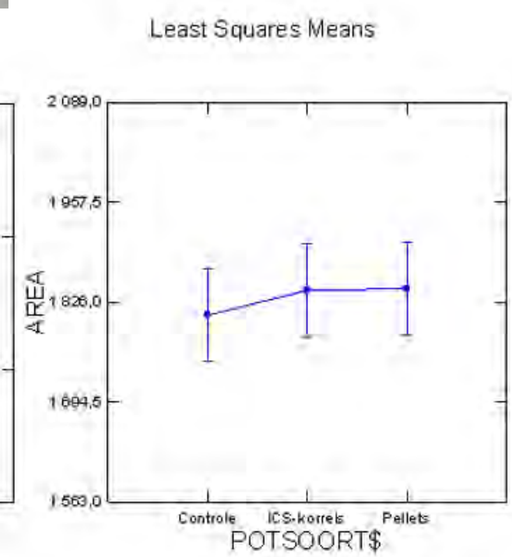
Flowering on the 15th of October: left standard, middle 30% pellets and right 30% ICS grains





Other possibilities to use ICS?

		
Standard N + standard P	Standard N without P	Standard N without P + 30% ICS

Thank you

- Subscribe to our newsletter: https://northsearegion.eu/nuredrain/news/
- Els Pauwels- els.pauwels@pcsierteelt.be - +32 9 353 94 88

Recovery of phosphorus by chemical treatment

Nico Lambert – KU Leuven
Process & Environmental Technology Lab

Introduction

Relevant research question:

What about the saturated adsorption material: should it simply be disposed of as solid waste? When is recovery/regeneration recommended?

P-recovery?

- The main objectives:
  - **Regeneration of the saturated sorbents** making it reusable in several adsorption/desorption cylces and
  - **Recovery of phosphorus** by precipitation or used directly with irrigation water as fertilizer

- The reusability of the granules is as important (or even more) than recovering phosphate
- A desorption process using an **alkaline** solution is proposed without harming the adsorbing material.

Integration of P-adsorbing material in a circular process

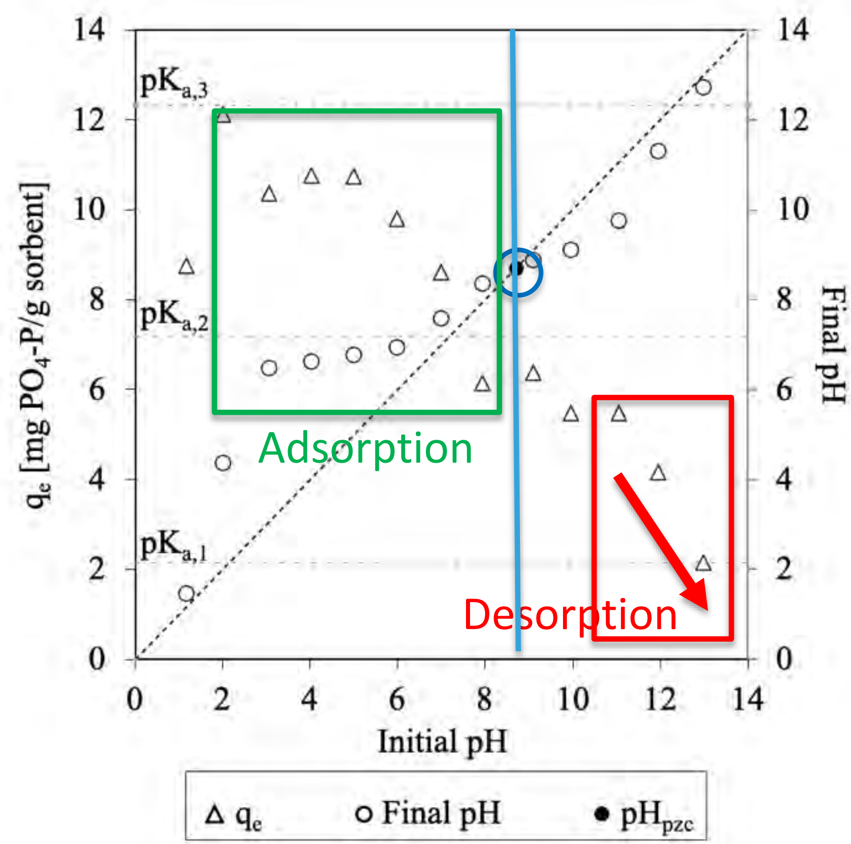
Iron Coated Sand (ICS)
DiaPure®
Vito A & B
FerroSorb SW

Introduction

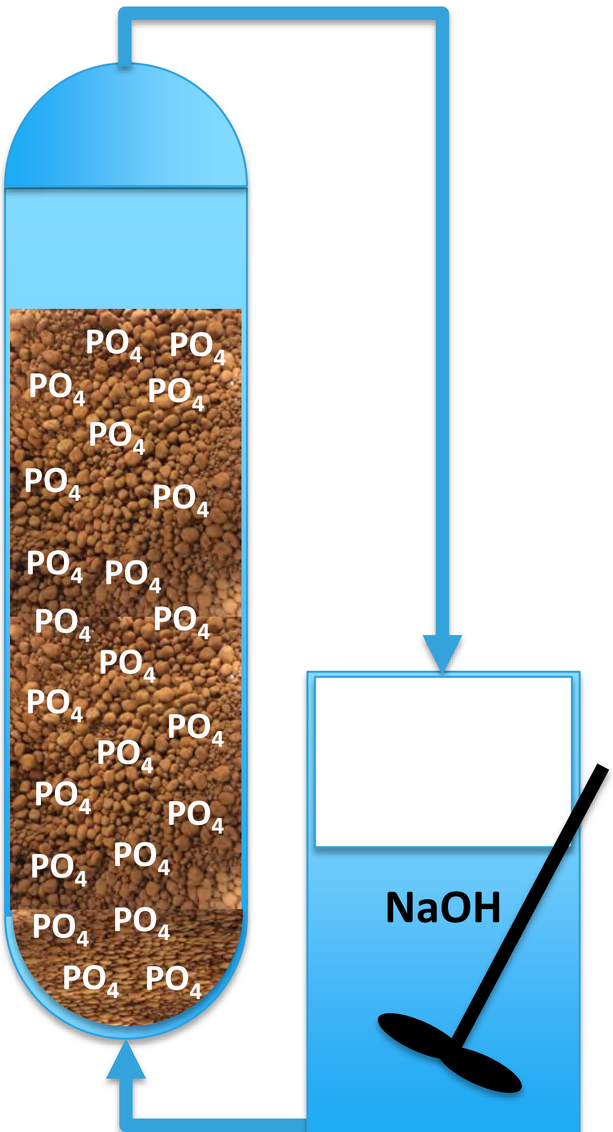
<u>Theoretical basis:</u>

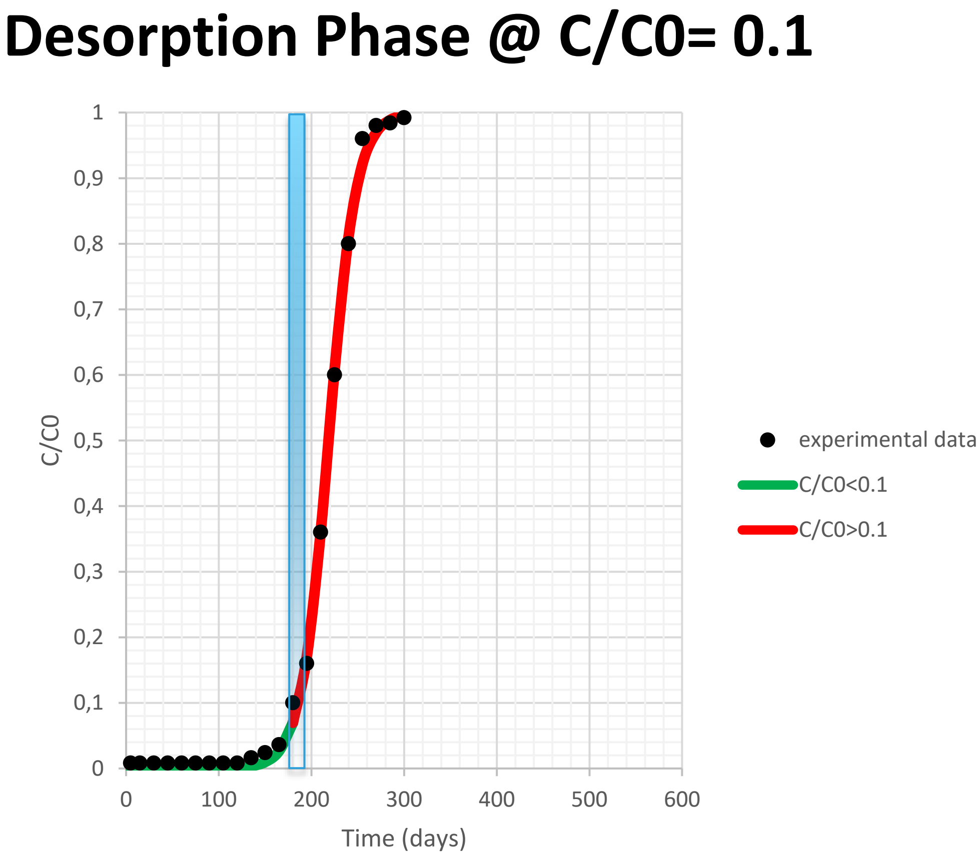
- The influence of initial pH on the adsorption capacity q_e for Fe and Al based adsorption materials
- Adsorption/desorption are **balancing processes** until an equilibrium is reached!

- pH 8.7 = pH_{PZC}
  = final pH is equal to the initial pH
- pH range 2 - 8.7: high q_e
- pH range 8.7 – 13: low q_e
- pH>11 the q_e drops considerably

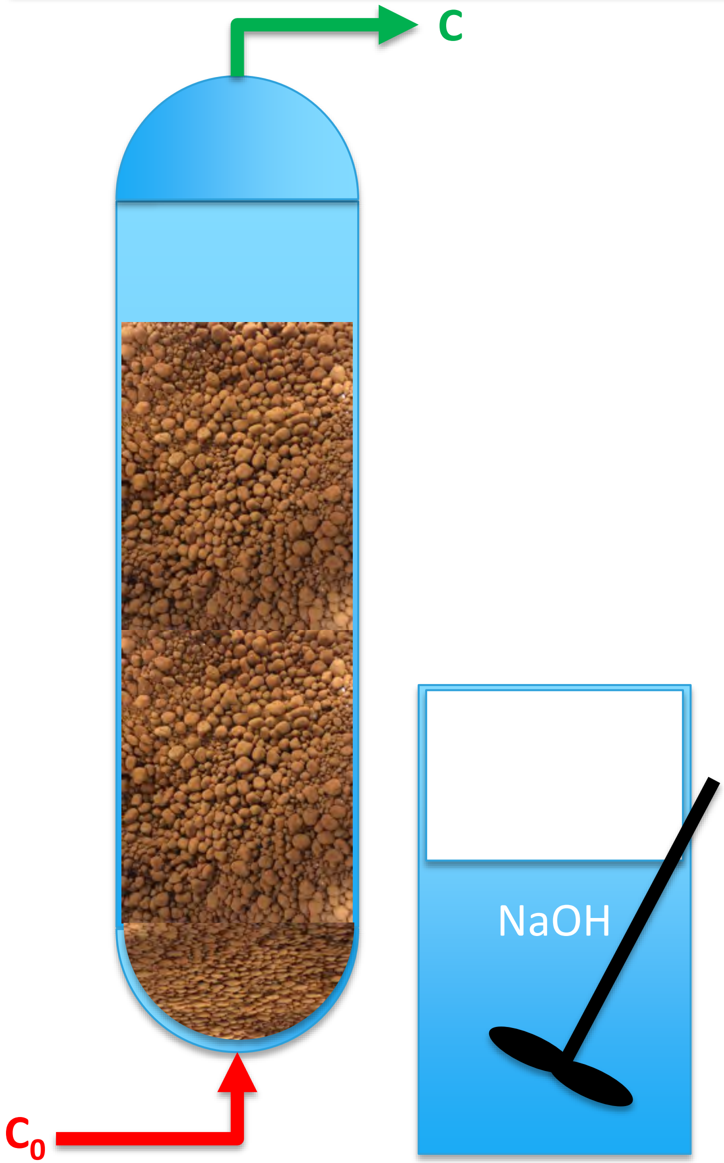


Concept of alkaline desorption



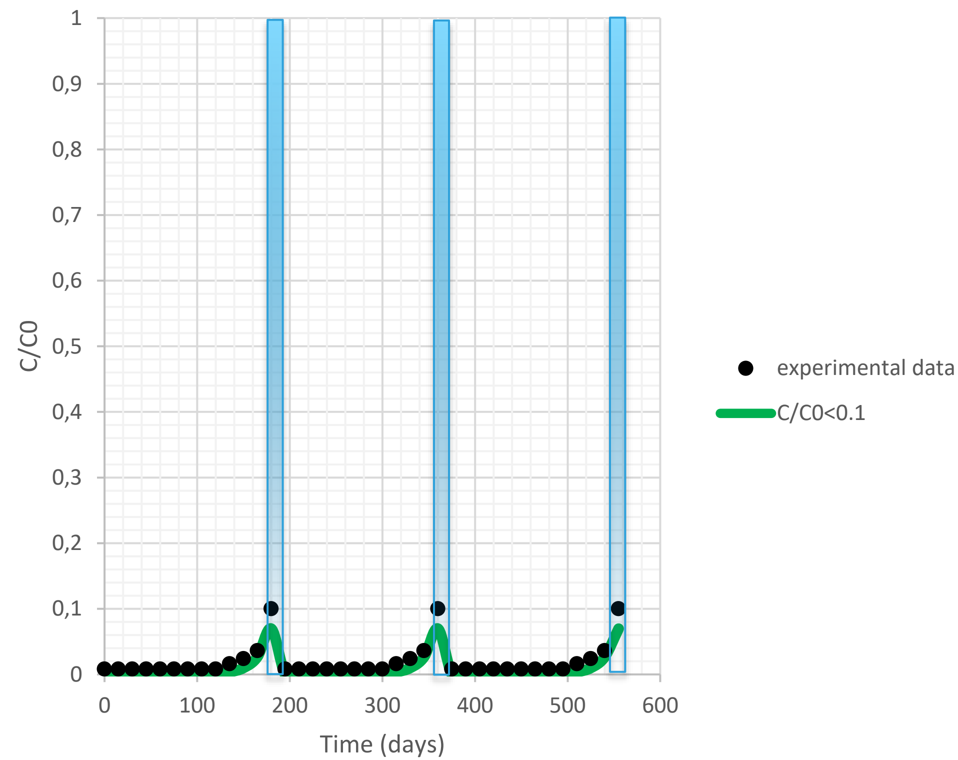


Concept of alkaline desorption



Regeneration of the saturated sorbent and recovery of phosphorus

Intermittent regeneration of ICS

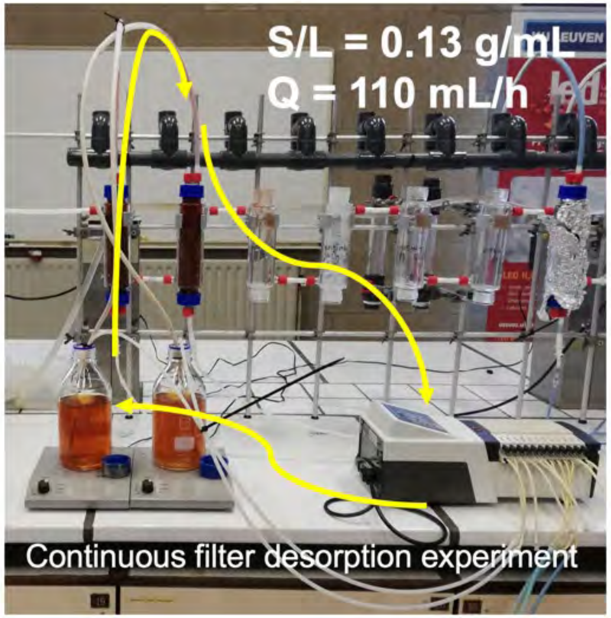


Materials & Methods

1. **Batch desorption experiments:** 5g of pre-dried saturated **ICS** was brought into contact with NaOH solution.

   Variable parameters:
   - NaOH concentration (1-0.5-0.1- 0.01- 0.001M),
   - Desorption time (5min-48h)
   - Solid/liquid ratio (S/L= 0.03-1 g/mL)

2. **Continuous filter ad- & desorption experiments:** 1 liter of NaOH solution was recirculated over an adsorption column filled with 150 cm^3 of saturated adsorption material.



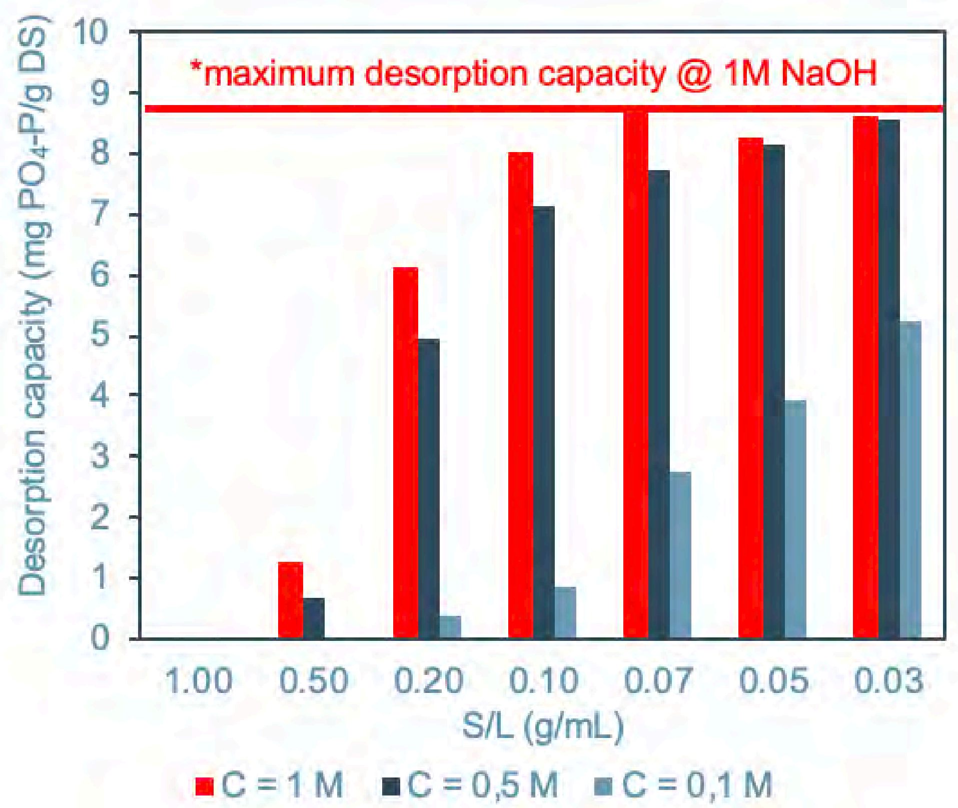
Continuous filter desorption experiment

3. **Analysis of the samples:** **Liquids**: PO_4-P determination by ion chromatography after .45 µm filtration. **Solid granules**: SEM-EDX.

Results & Discussion
Batch experiments

- The composition of 1 g of saturated ICS granules was determined by a complete destruction of the granules by Aqua Regia and ICP analysis:
  - Phosphorus: 15.30 +/-1.25 mg P/g DS **=1.5%P**
  - Iron: 590.7 +/-8.7 mg Fe/g DS **=59%Fe**

- Optimal NaOH concentration = 0.5 M
- Optimal contact time = 24 h or more
- Optimal S/L ratio = 0.10 - 0.05 g/mL
- P-desorption efficiency > 50% @ 0.5 and 1 M NaOH



Results & Discussion
Continious filter experiments: Adsorption

- The breakthrough curve of ICS column experiments with an Empty Bed Contact Time (EBCT) of **5.5 h** and **0.5 h** results in a breakthrough time of **180 days and 7 days** respectively.

Regeneration is highly appropriate in the case of a short EBCT

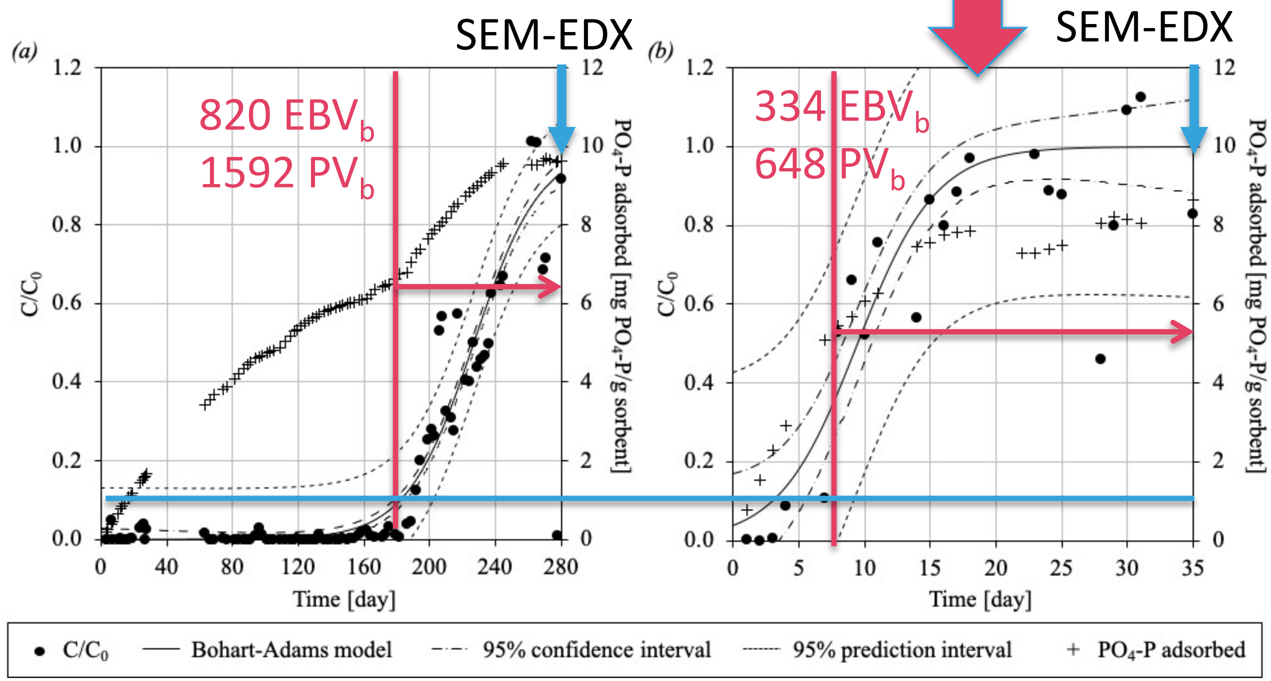
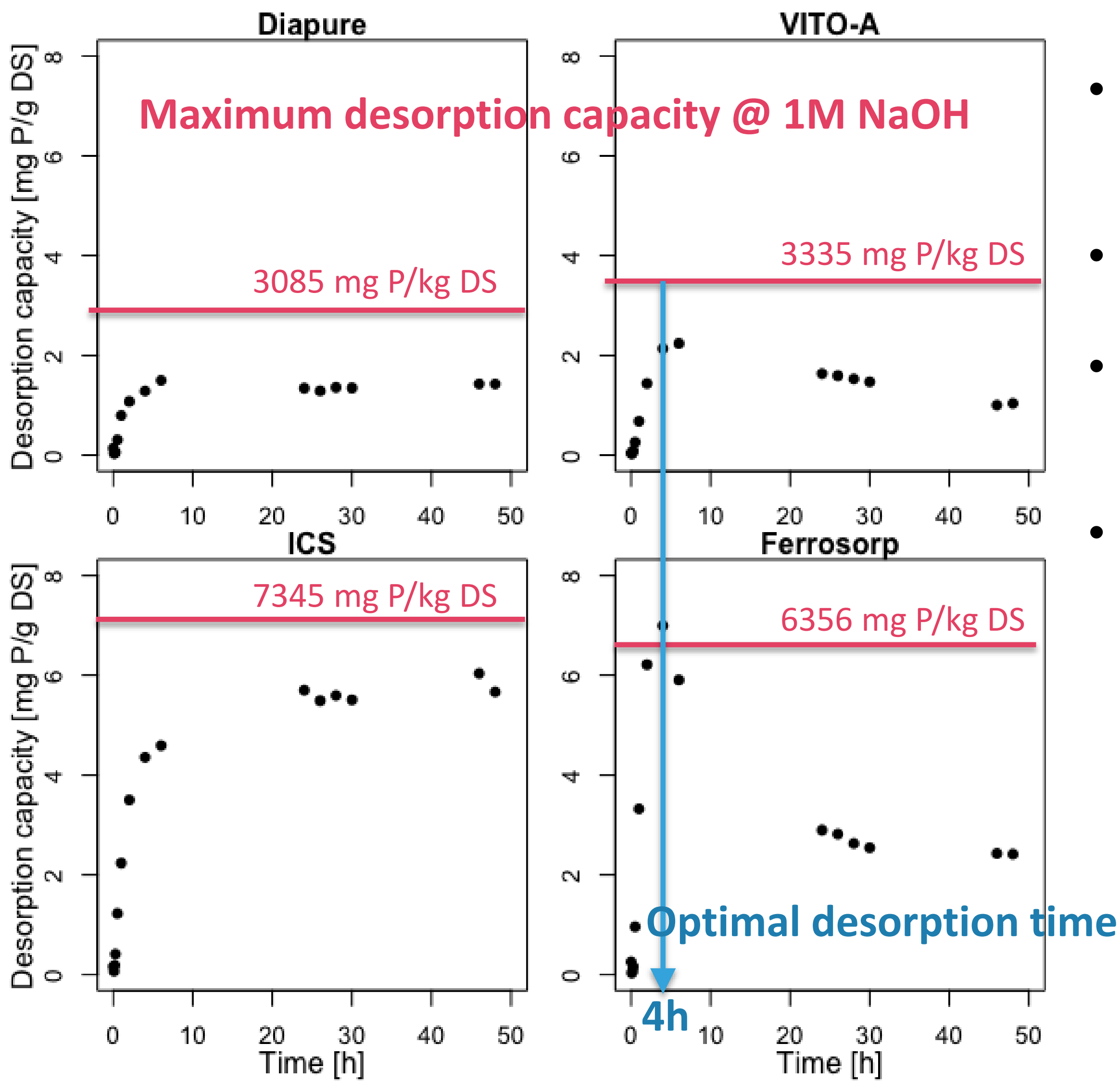


Figure: ICS adsorption column experiments on lab-scale (influent P concentration = 25 mg PO_4-P/L) with EBCT= 5.5 h (a) and EBCT= 0.5 h (b)

Results & Discussion
Continious filter experiments: Desorption



- Continuous desorption experiment in recycle
- NaOH concentration = 0.5 M
- Optimal desorption time = material dependent
- P-desorption efficiency > 50% @ 0.5 NaOH

Results & Discussion
SEM-EDX analysis @ EBCT of 0.5 h

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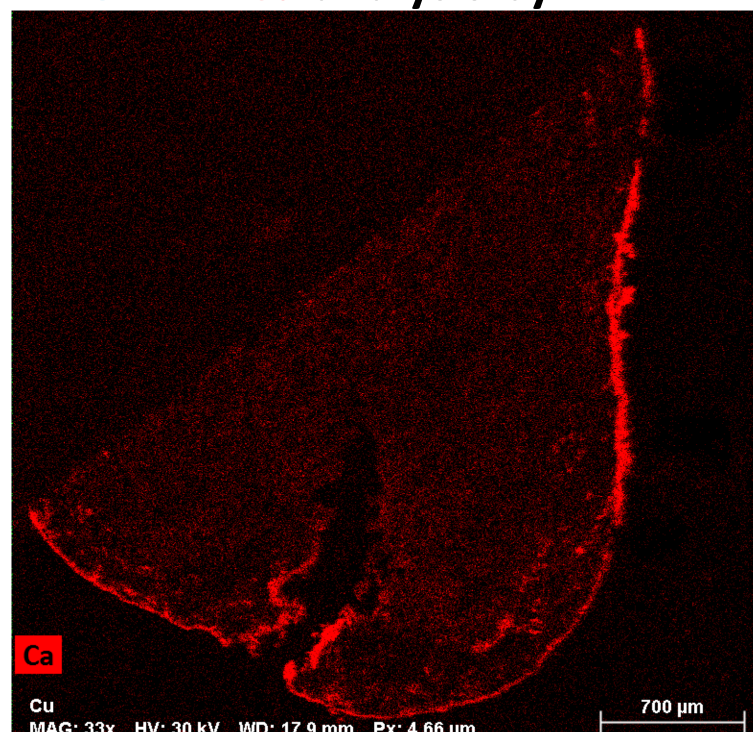
- SEM-EDX of saturated DiaPure® of column experiment with **EBCT of 0.5 h**.
  - The phosphate is mainly adsorbed at the outer layers of granules.
  - Calcium forms deposits on the adsorbent surface and disturb the alkaline desorption.
  - Acid regeneration step before alkaline desorption?

polished DiaPure® granule embedded in a resin

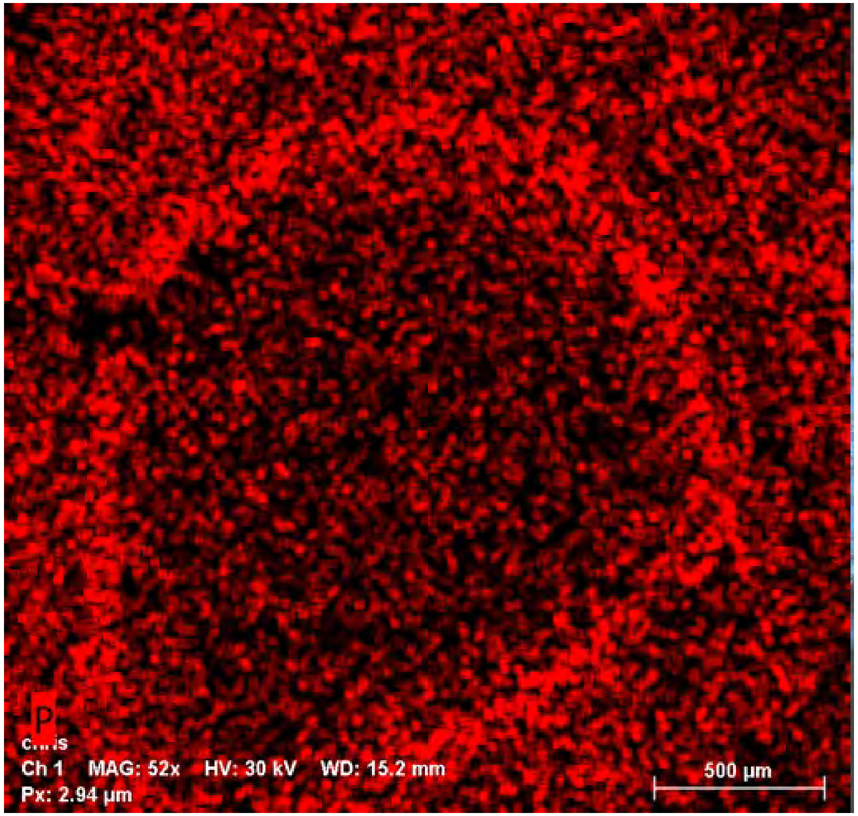
Fe – P – Ca analysis by EDX



Results & Discussion
SEM-EDX analysis @ EBCT of 5.5 h

- SEM-EDX of saturated ICS of column experiment with **EBCT of 5.5 h**.
  - Phosphorous is accumulated at the sand core of the granule.
  - Phosphorous migrates towards the core of the granule.

Si – Fe – P analysis by EDX



Conclusions

- Optimal NaOH concentration = 0.5 M
- Optimal desorption contact time = material dependent
- P-desorption efficiency > 50% @ 0.5 M NaOH
- Leaching of Fe during the desorption process is a problem
- Desorption of P from the inner layers of the granule will be difficult
- Calcium deposits should be avoided by an acid wash

Q & A

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Part IV: Nutrient removal modelling

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Nutrient reduction potential using end-of-pipe solutions for an entire catchment

Andreas Bauwe, Bernd Lennartz – University of Rostock

#EUGreenWeek

2021 Partner Event

+++ Filter systems for nutrient removal from agricultural waters +++

1 June 2021

The Warnow river basin

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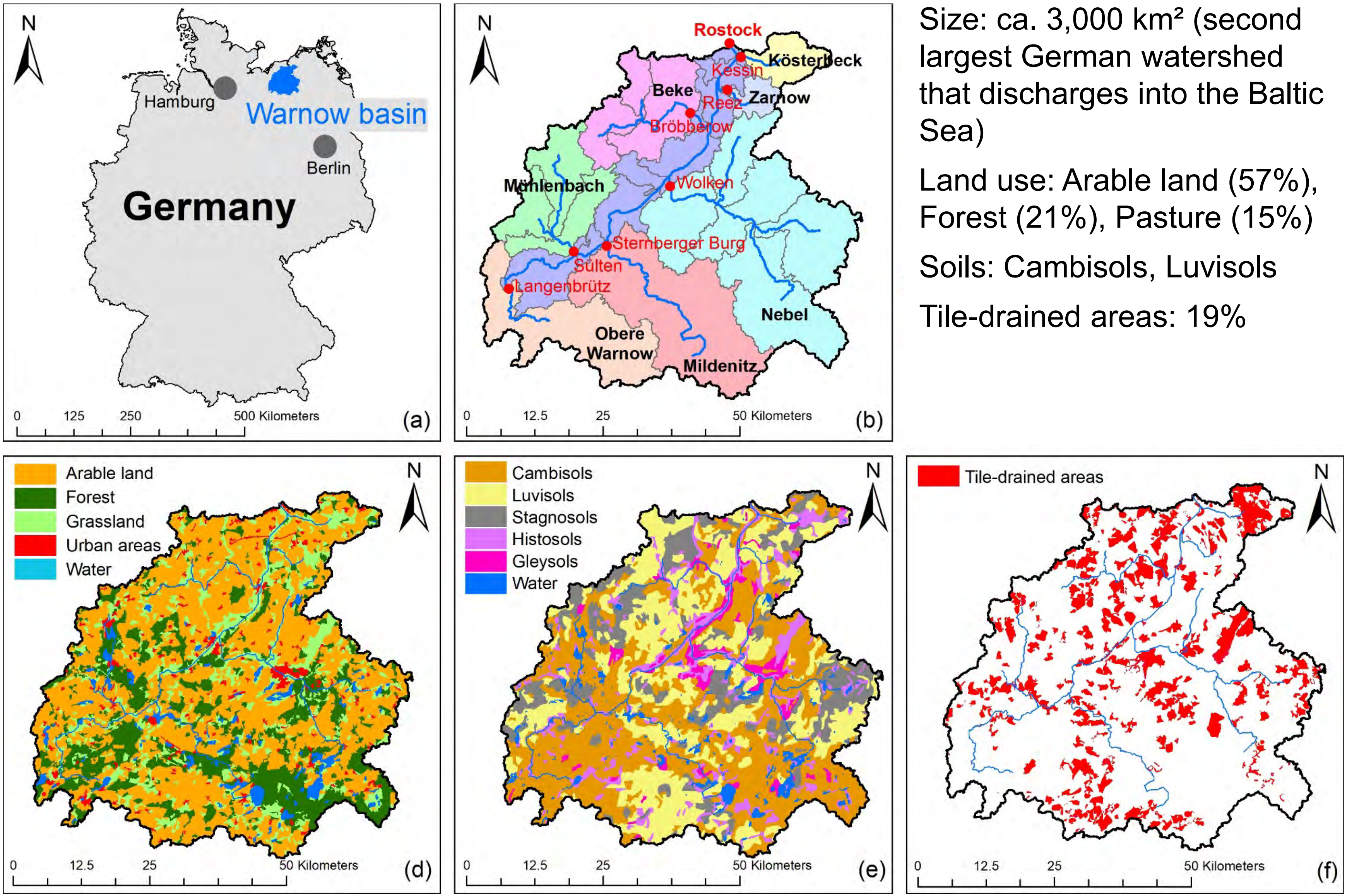


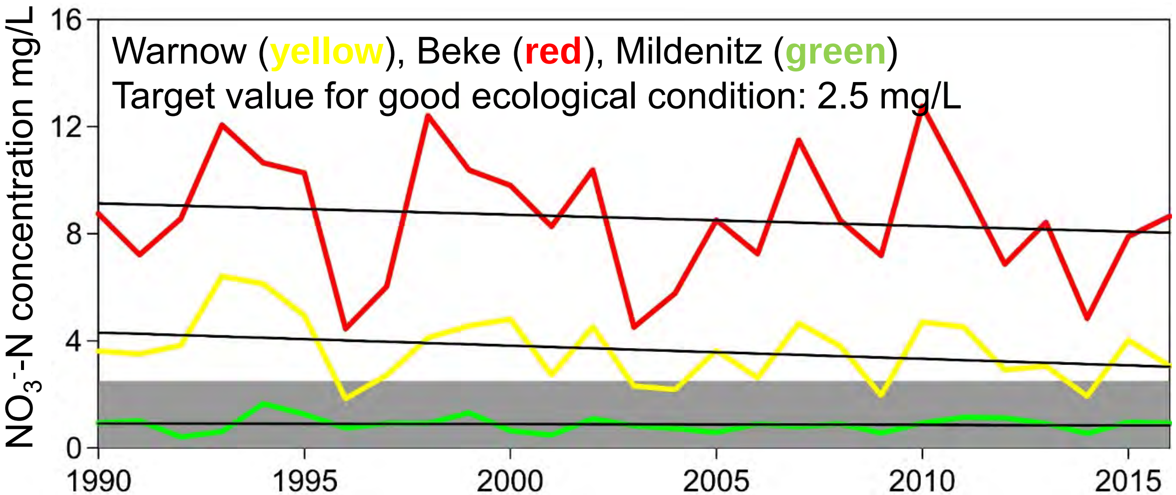
Size: ca. 3,000 km² (second largest German watershed that discharges into the Baltic Sea)

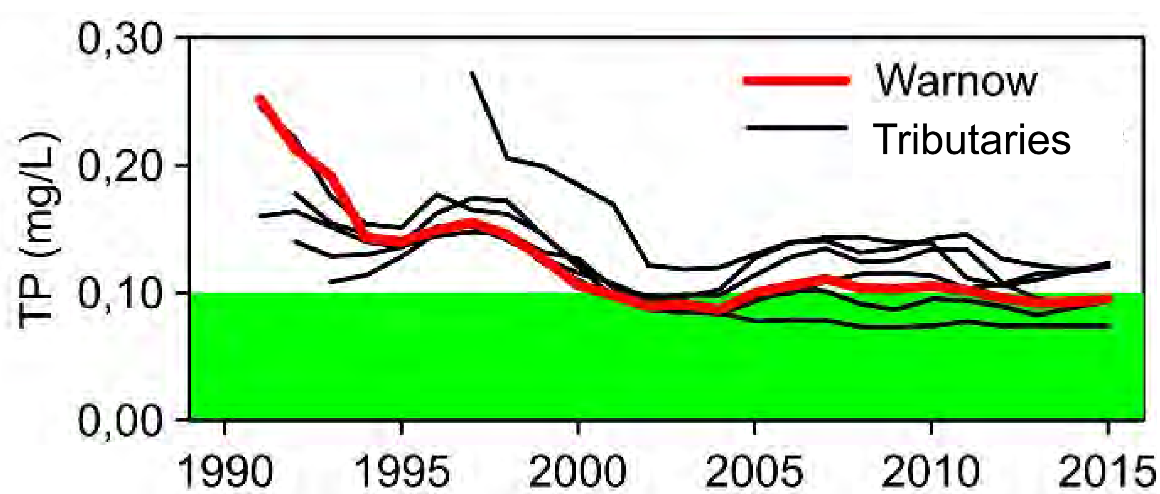
Land use: Arable land (57%), Forest (21%), Pasture (15%)

Soils: Cambisols, Luvisols

Tile-drained areas: 19%

Background





- Slow decrease of NO_3^--N concentrations during the last 30 years
- Large differences in NO_3^--N concentrations among the sub-basins depending on land use
- Mitigation measures needed for sub-basins dominated by agriculture
- Strong decrease of TP concentrations in the early 1990s mainly due to improved treatment of wastewater
- Target values for TP are complied in most sub-watersheds
- However: HELCOM demands a reduction 110 t TP/a for Germany

Reduction measures needed for N + P (end-of-pipe)

Methods

End-of-pipe solutions to reduce nutrient loads in tile-drained areas

Phosphorus
Filters

Nitrogen
Constructed wetlands

Modeling the reduction potential using the SWAT model

Model input

- Digital Elevation model,
- Weather data
- Land use
- Soil data
- Land management
- Vegetation
- ….

Modelling approach

1. Calibration and validation of stream flow
2. Calibration and validation of P and N loadings
3. Implementation of filters and constructed wetlands in the model

Reference simulation

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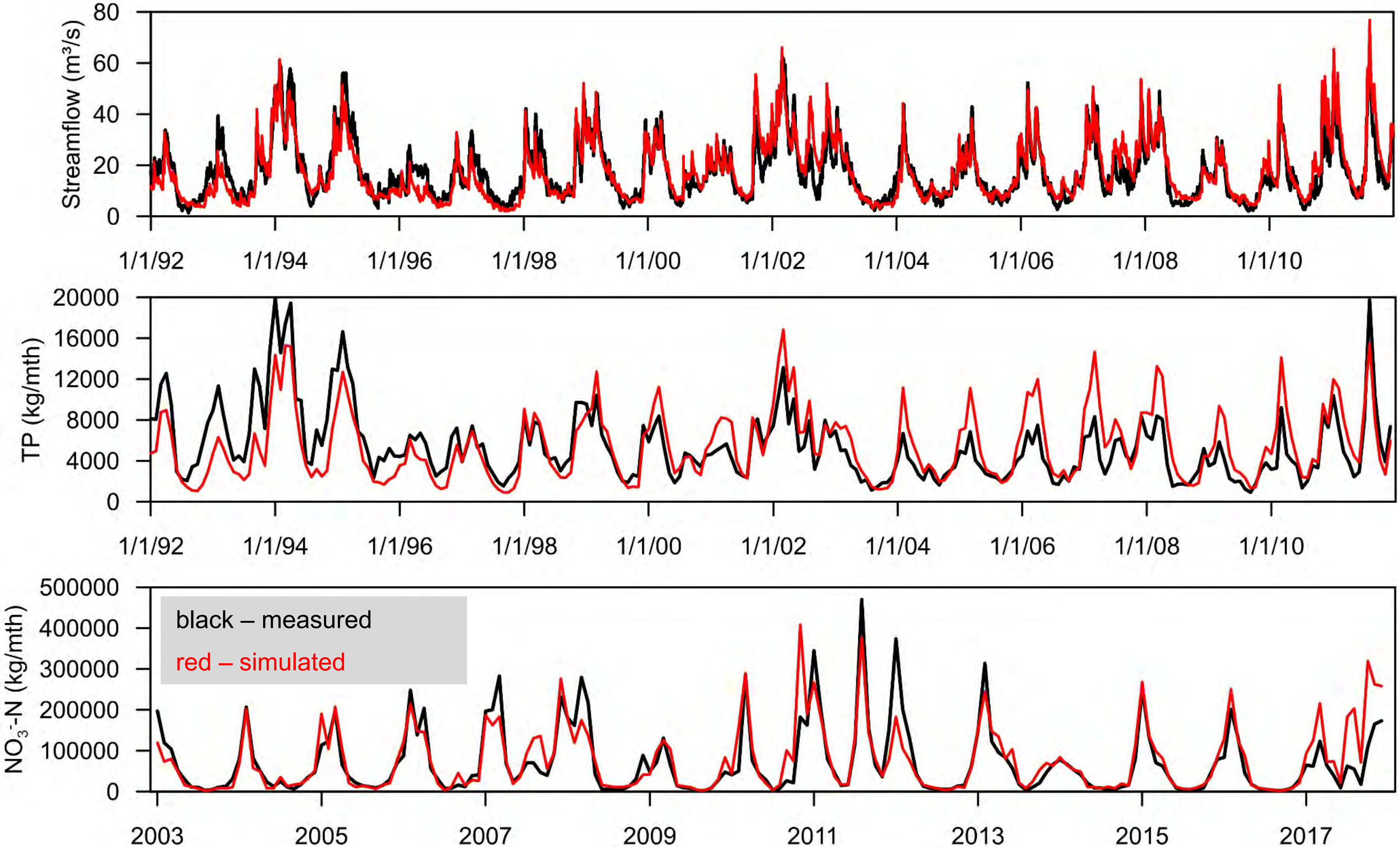

P reduction scenarios

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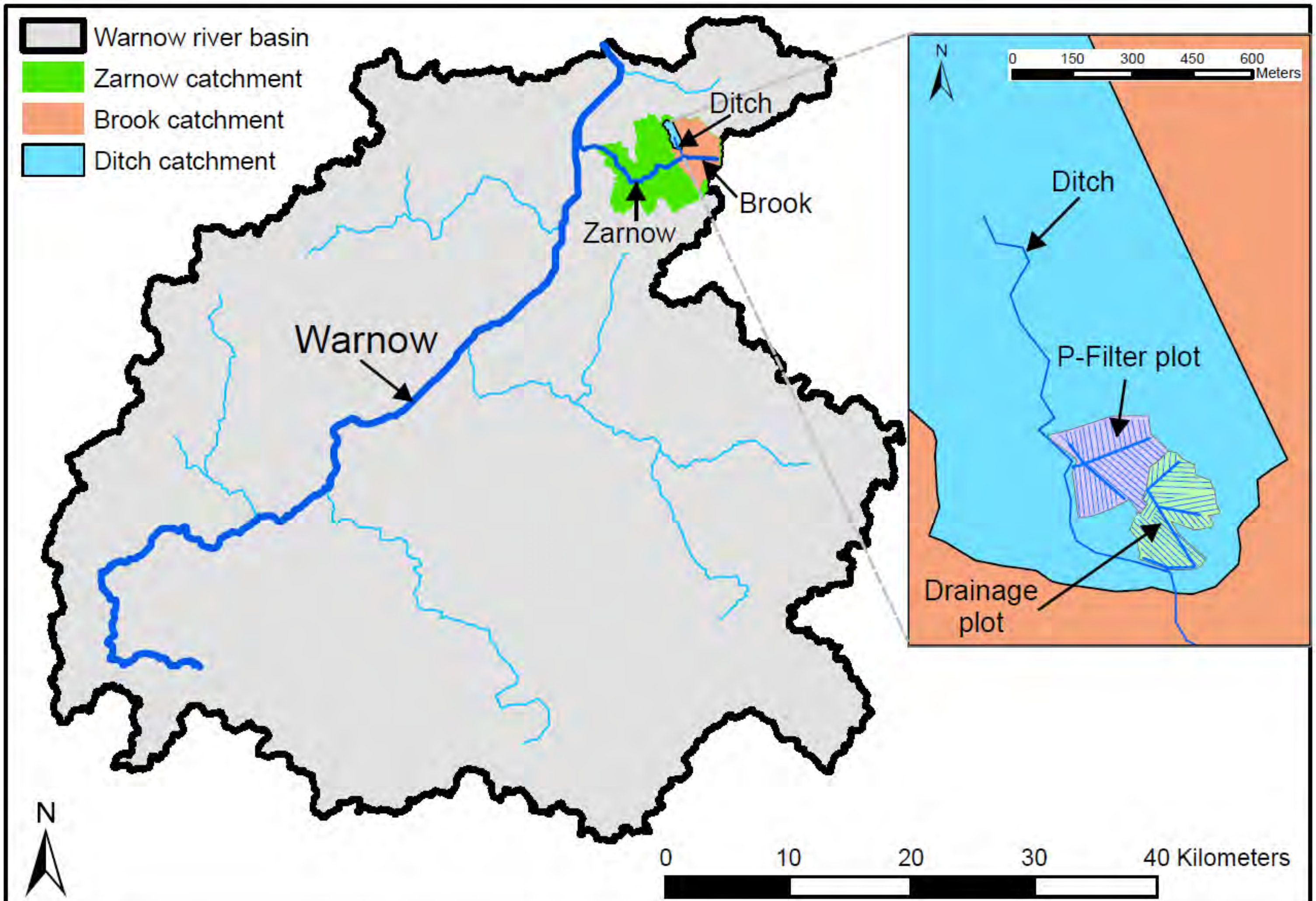
Evaluation of P filters in tile-drained areas at different spatial scales



P reduction scenarios

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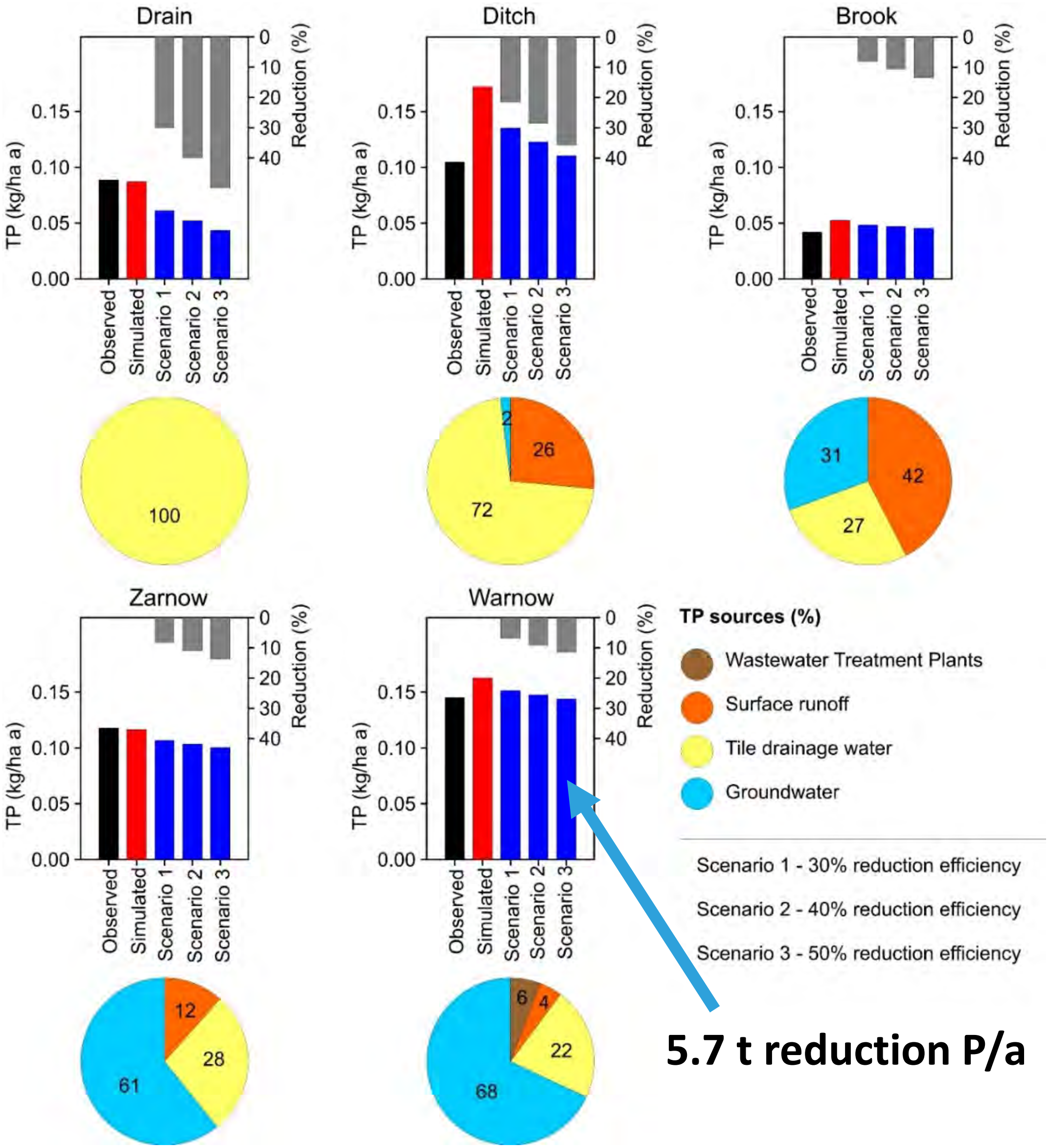
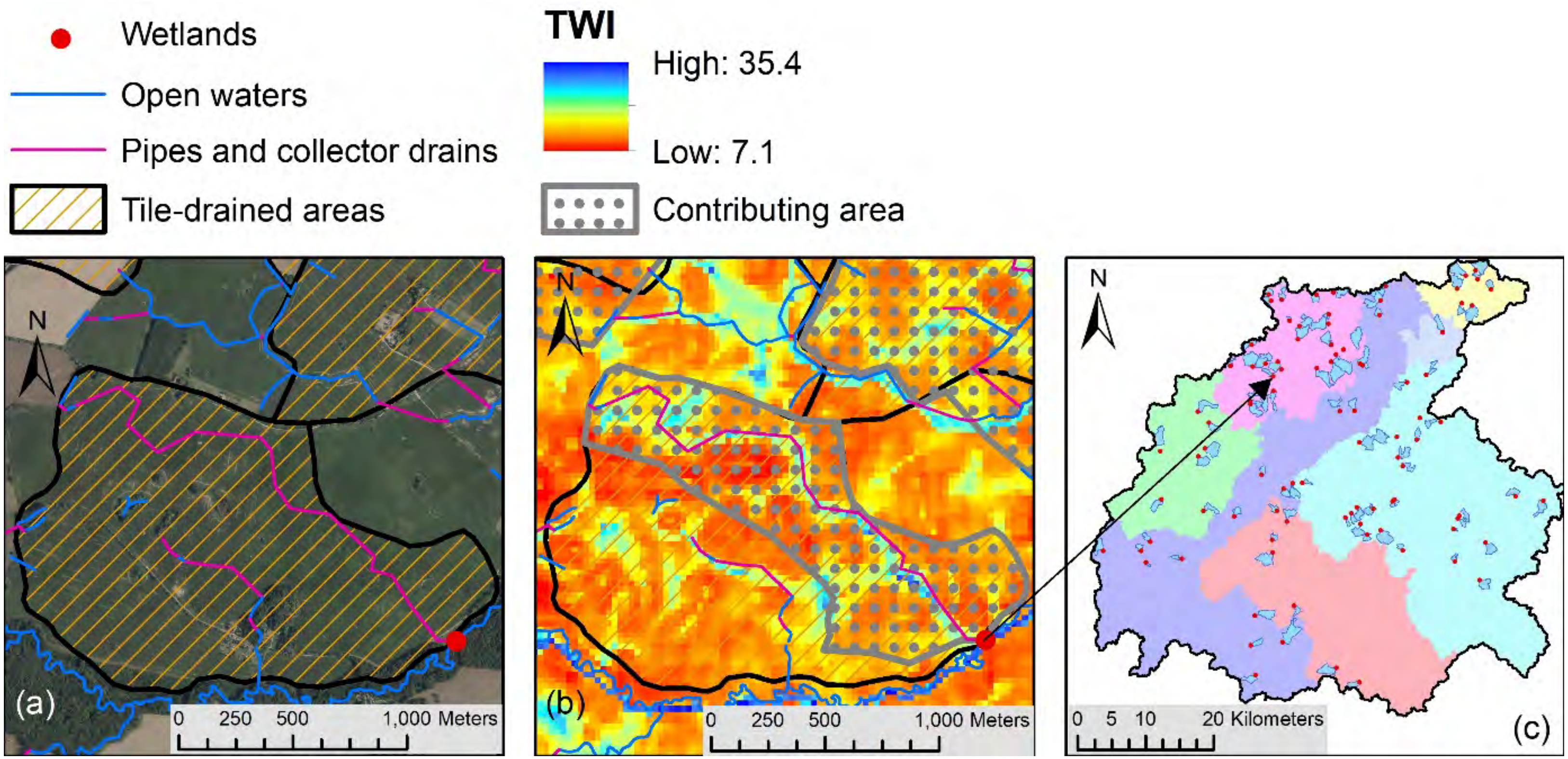


- Good fit of measured and modeled values at different spatial scales.
- Effect of P filters at catchment scale depends on proportion of tile-drained areas.
- P filters could contribute to reduce P losses notably in the Warnow river basin.

N reduction scenarios

Evaluation of constructed wetlands in tile-drained areas



- Contributing areas were identified by using maps of tile-drained areas, running waters (open or as pipes) and aerial photographs.
- Constructed wetlands (CWs) were placed in moist areas according to topographic wetness index (TWI).
- 97 suitable spots for CWs were identified.

N reduction scenarios

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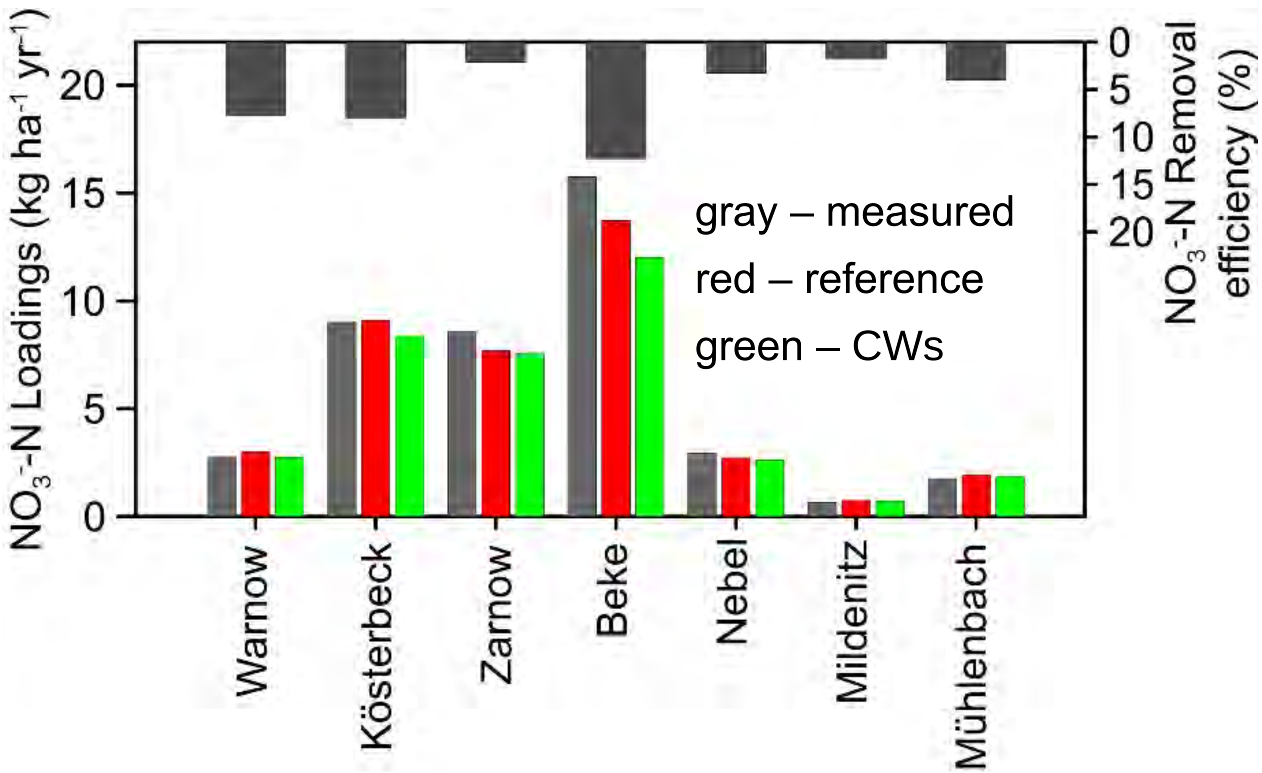

- Measured NO_3^--N loadings were reproduced well by the model.
- The implementation of constructed wetlands had positive effects on the surface water quality with an overall NO_3^--N removal efficiency of 7.8%.
- The NO_3^--N removal efficiency depended on subbasin characteristics (number of CWs, ratio between contributing area and subbasin area).

N reduction scenarios

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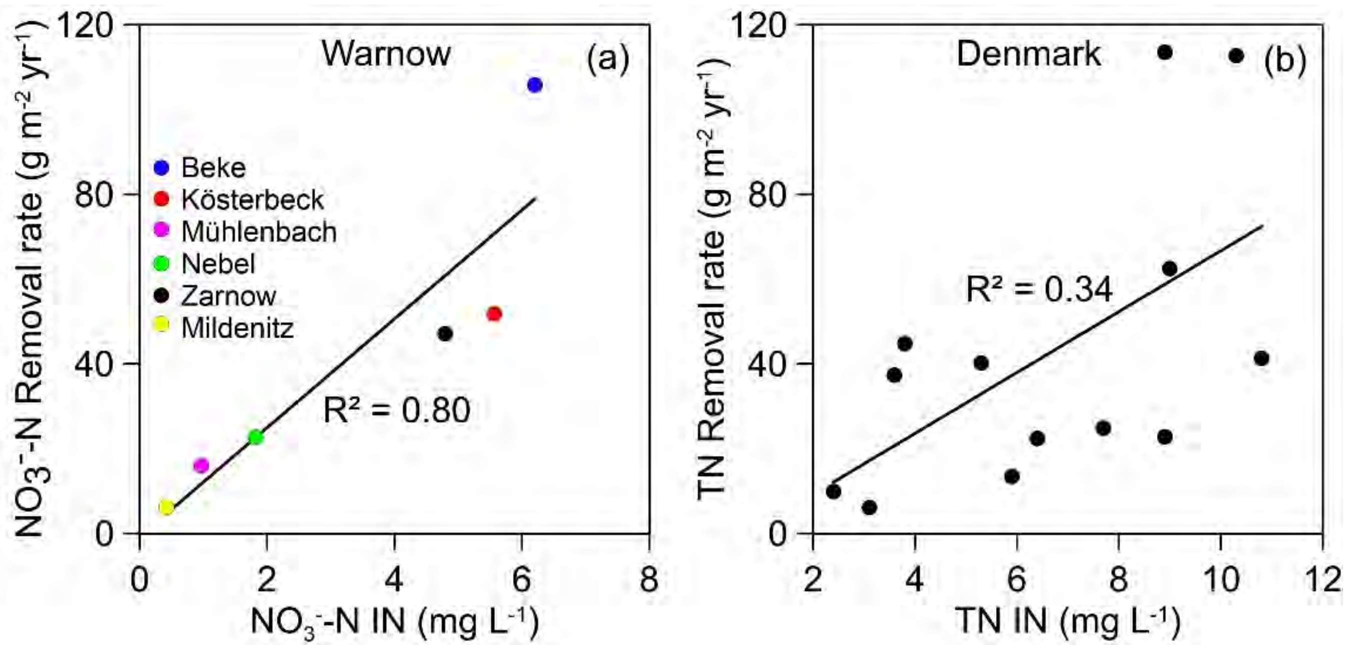

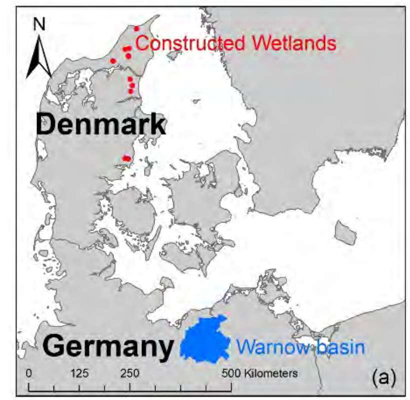

- The scenario results were verified by comparing simulation data with recordings of 13 existing CWs in Denmark (thanks to the Danish partners for providing the data!).
- The NO_3^--N removal rates for the Warnow basin and CWs in Denmark were similar.
- Both for the Warnow basin and the CWs in Denmark, there was a significant positive relationship between input concentration and removal rate.
- Due to site-specific characteristics, this relationship was weaker for the Danish CWs.

Summary

- Through the widespread installation of filters in tile-drained areas, the TP loads in surface waters could be reduced by 5.7 t yr^{-1}, which corresponds to an overall reduction of ca. **10%**.
- The effect of P filters on a catchment scale depends on proportion of tile-drained areas.
- NO_3^--N loads could be reduced from 900 t yr^{-1} to 840 t yr^{-1}, which corresponds to an overall reduction of ca. **8%**.
- NO_3^--N removal rates varied strongly among the subbasins ranging from 6 to 106 g m^{-2} yr^{-1} and they were positively correlated with the input concentrations.
- The installation of filters for P reduction and constructed wetlands for N reduction should be prioritized, focusing on hot-spot areas, in which the largest benefit is expected.

Thank you!

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Cost-effectiveness of the filters and the farmers' opinion

Charlotte Boeckaert, Vlakwa

P removal

Drainage water

P filterbox

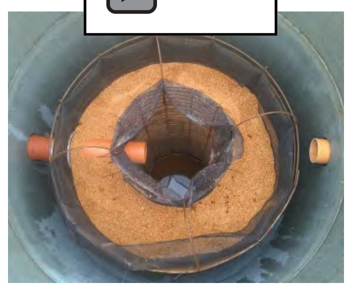
80 – 100%

Inline P filter

Organic matter

50 – 80%

Sediment + rea ter



Sediments

ongoing

0,1 – 0,5 mg P/l

Greenhouse effluent

DIY

99%

Company

99%

10 – 20 mg P/l

Cost P filter

Water	Filter	CAPEX	OPEX	Yearly cost	Total P removal (kg P)	Cost effectiveness (€/kg P)
Drainage (0,25 mg P/l)	P filterbox	€ 635	€ 19	€ 78,2	0,06	**1 264**
	Drainage water (0,46 mg P/l)				0,19	409
	Drainagewater (0,12 mg P/l)				0,02	4 938
Greenhouse (15 mg P/l)	DIY	€ 690	€ 95	€ 164	1,94	**85**

Cost effectiveness P-filter

FL – Measures Cost Model

Measure	€/kg P
DIY	85
Non-turning soil tillage	174
Green cover	284
Municipal WWTP	363 - 1006
P filterbox	1264
Buffer strips	2160
Individual WWTP	5235 - 5913

N removal

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Drainage water

MBBR Subsoil

60%

MBBR Containerized

75%

ZVI

90%

10 – 40 mg N/l

Greenhouse effluent

DIY

85%

50 – 100 mg N/l

Cost N filter

	Application	CAPEX	OPEX	Yearly cost	Total N removal (kg P)	Cost effectiveness (€/kg N)
DIY	Greenhouse effluent	€ 2 700	€ 1 400	€ 1 600	12.44	128.76
Subsoil	Drainage	€ 30 000	€ 2 900	€ 5 550	52.84	105.06
Containerized	Drainage Off-grid	€ 50 000	€ 2 700	€ 7 180	71.11	101.01
	Drainage	€ 40 900	€ 3 800	€ 7 460	71.11	104.97

Cost effectiveness N-filter

FL – Measures Cost Model

Measure	€/kg P
Green cover	3
Municipal WWTP	59(-163)
Reduced fertilization	70
MBBR	101-129
Individual WWTP	378-427

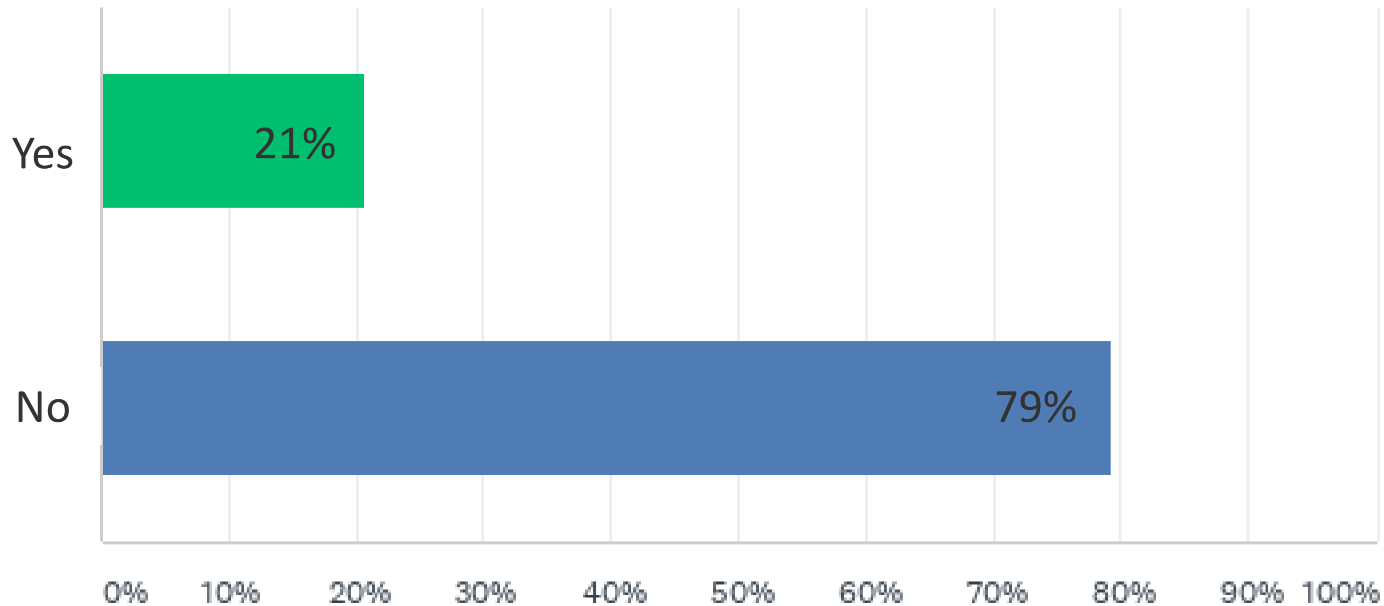
Farmey Survey – FL - Greenhouses

- Which requirements should the filter have?
- Are individual or collective filters recommended?
- Who should pay for these filters?

→ 29 answers

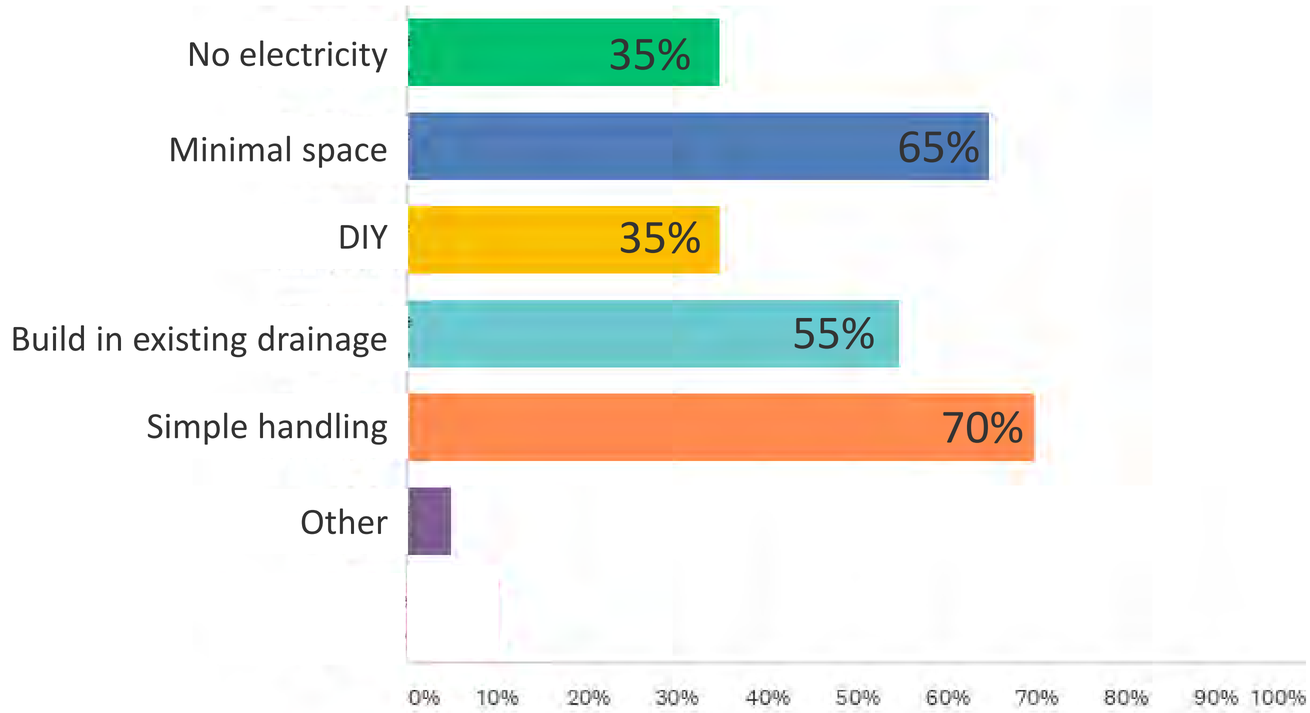
Are you familiar with end-of-pipe technology to remove nutrients from agricultural waters?

Beantwoord: 29   Overgeslagen: 0



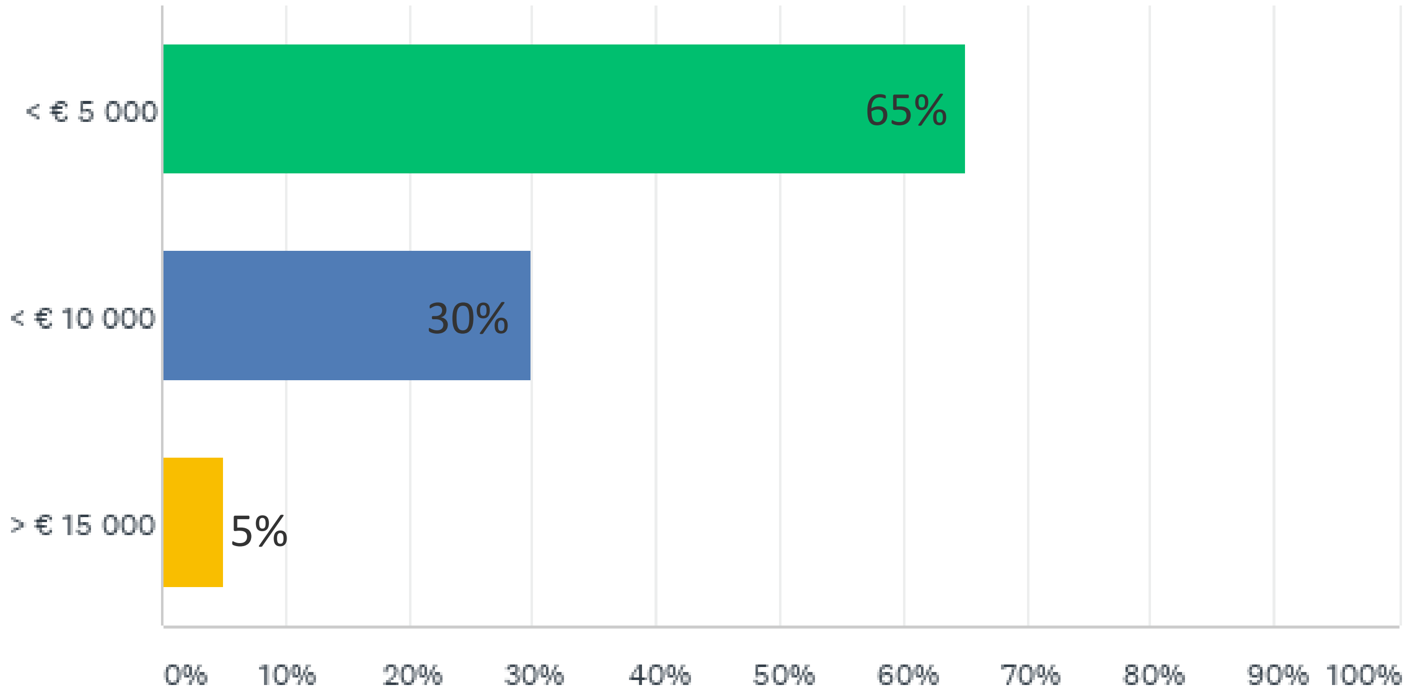
Preferential requirements for the filter are:

Beantwoord: 20 Overgeslagen: 9



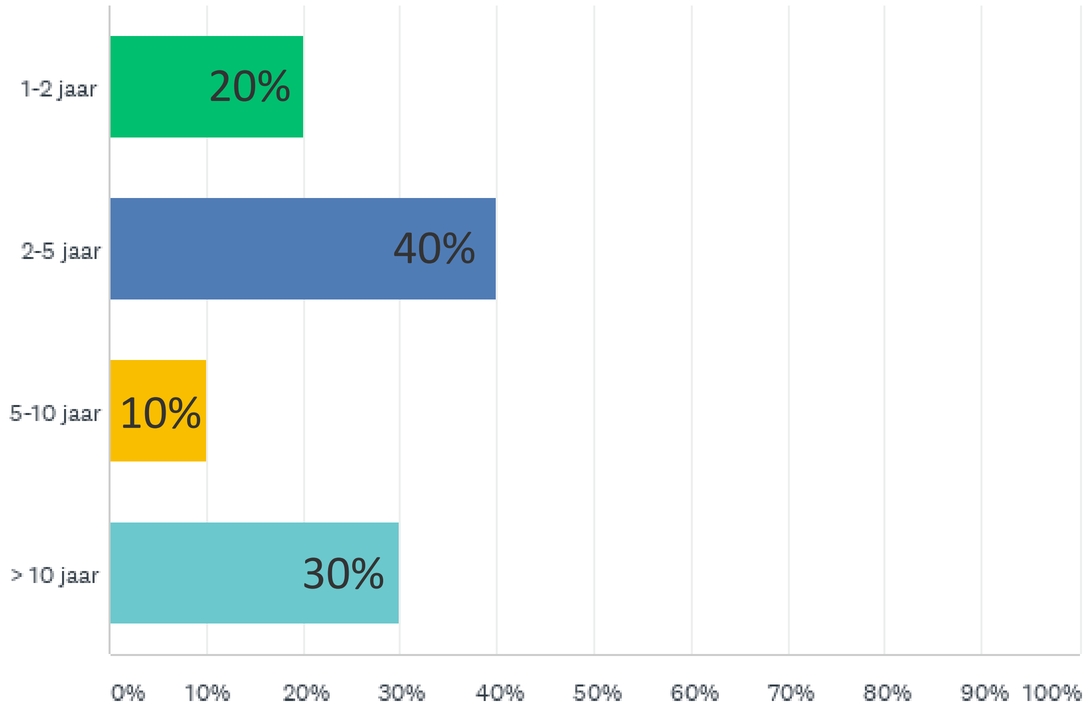
Which investment cost is acceptable?

Beantwoord: 20   Overgeslagen: 9



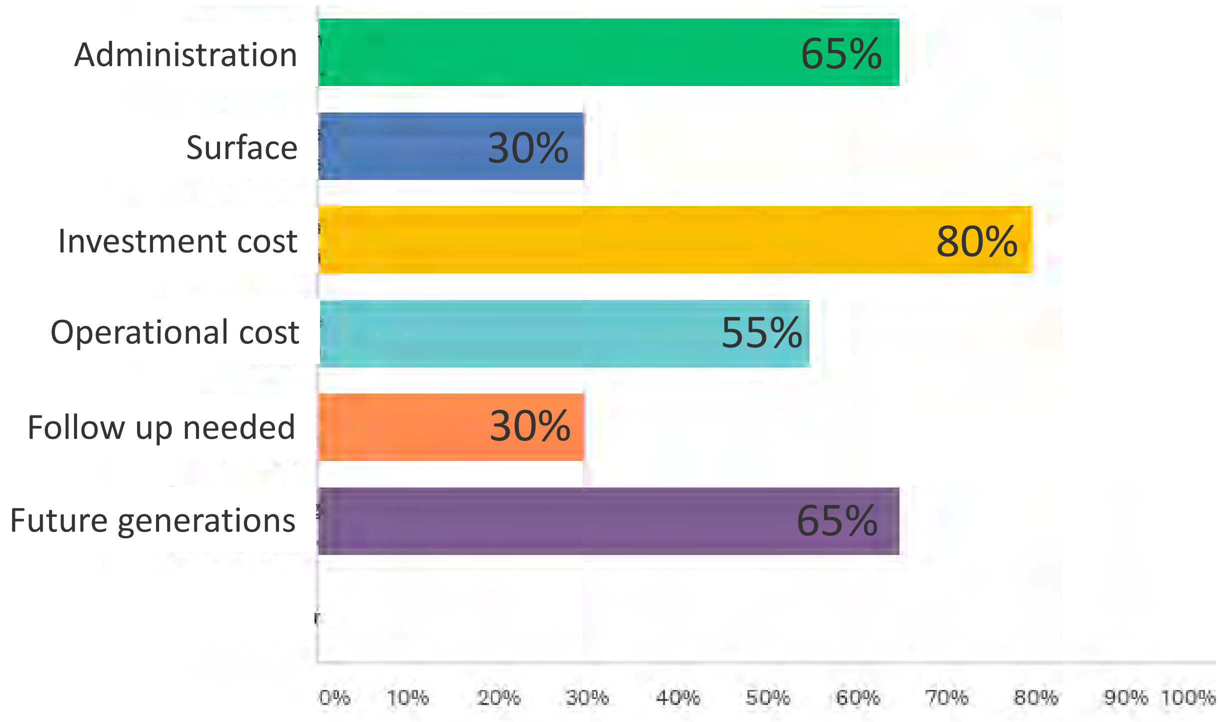
Within which time frame would you consider this investment?

Beantwoord: 20   Overgeslagen: 9



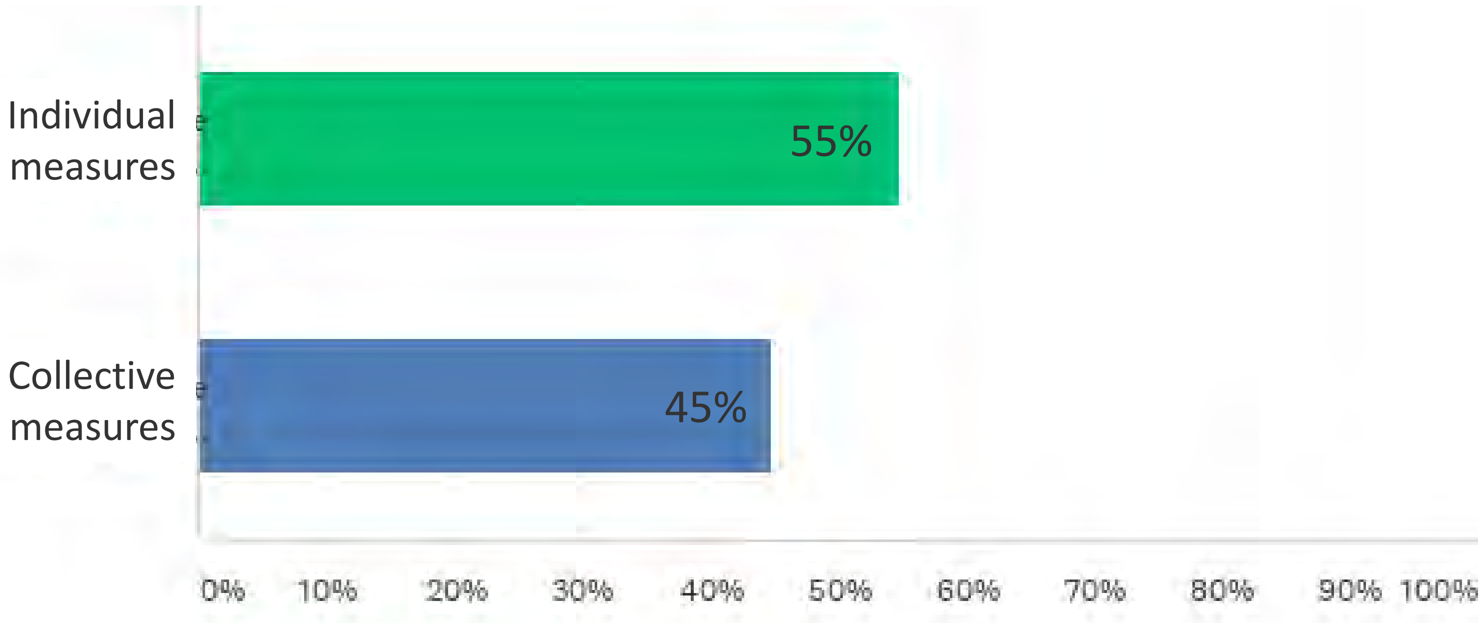
Which factors influence your choice for a certain technology?

Beantwoord: 20 Overgeslagen: 9



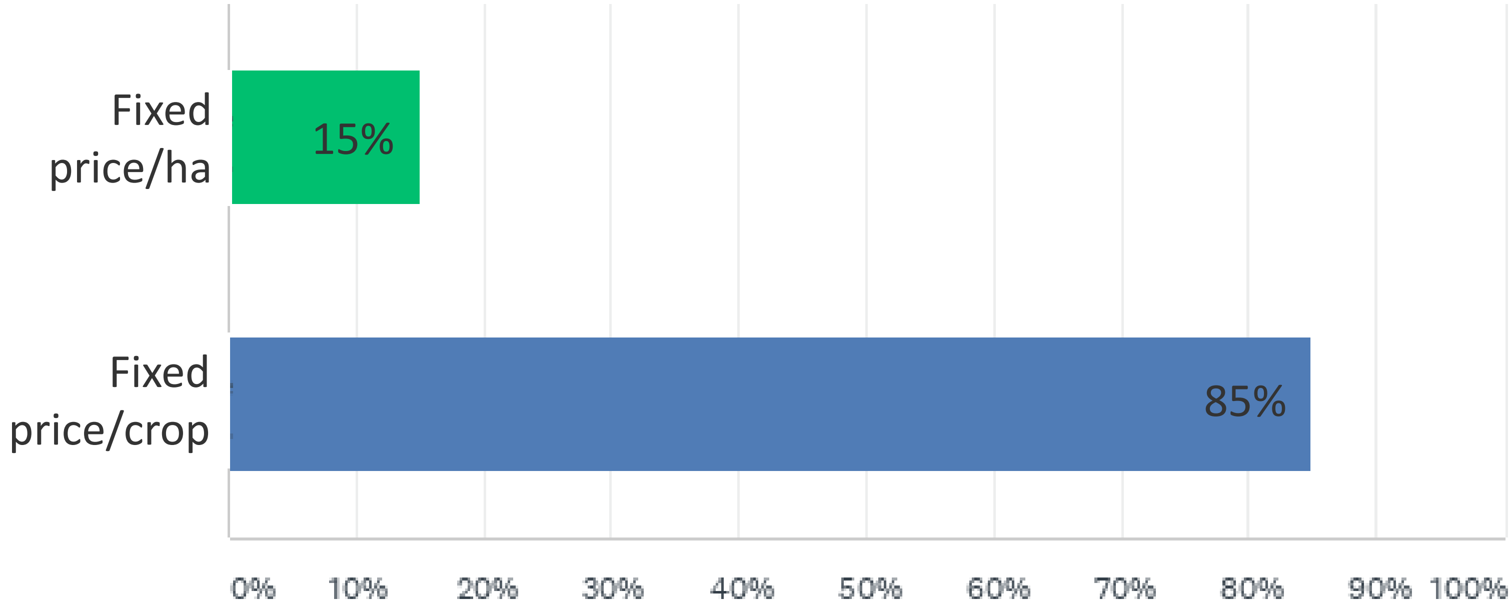
I prefer:

Beantwoord: 20 Overgeslagen: 9



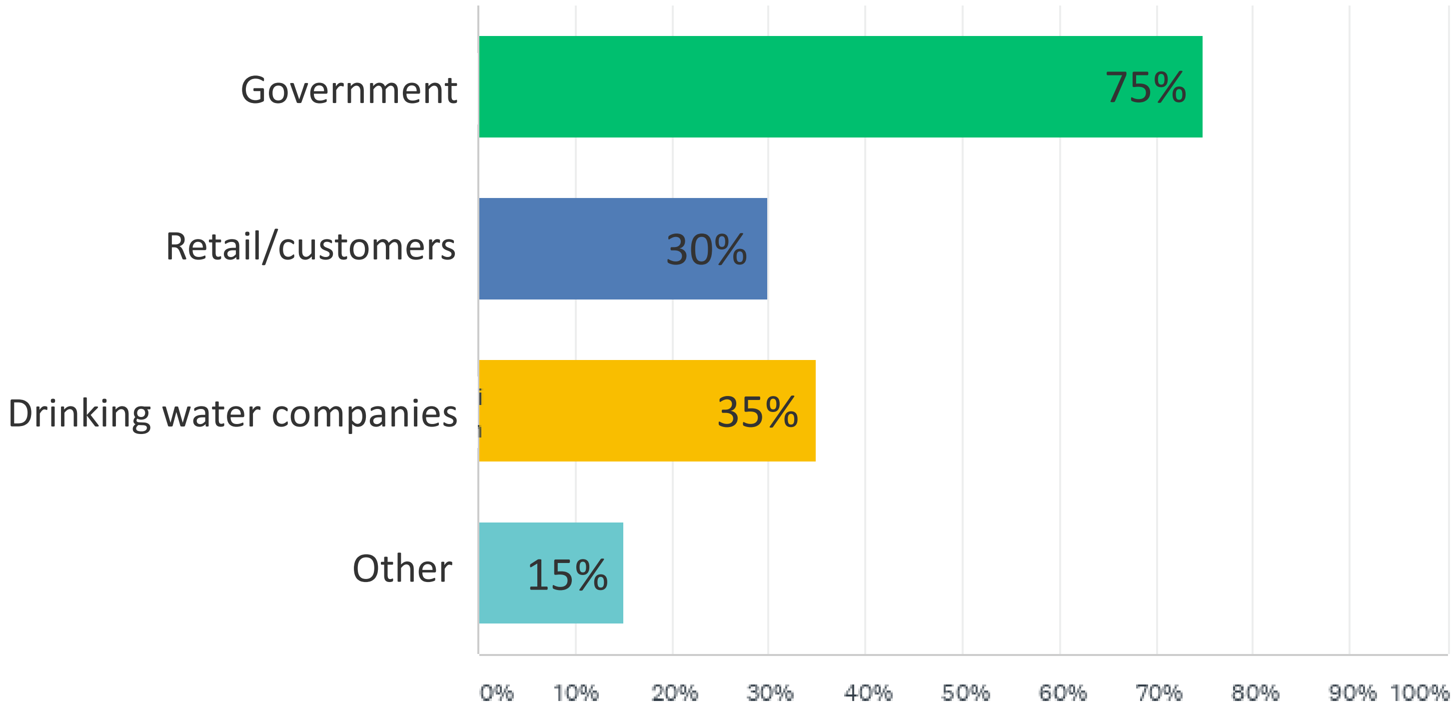
In case of collective measures, which financing system is preferential?

Beantwoord: 20   Overgeslagen: 9



In case of collective measures, who else should pay?

Beantwoord: 20   Overgeslagen: 9



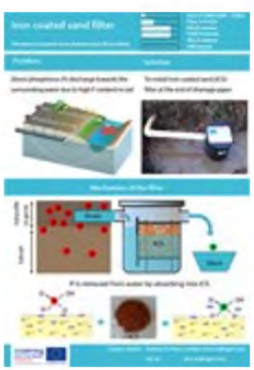
Farmers' opinion

- Simple technology required minimum of space
- Cost < € 5000
- Investments within 2-5 years
- Individual measures <-> collective measures
- Fixed price/crop

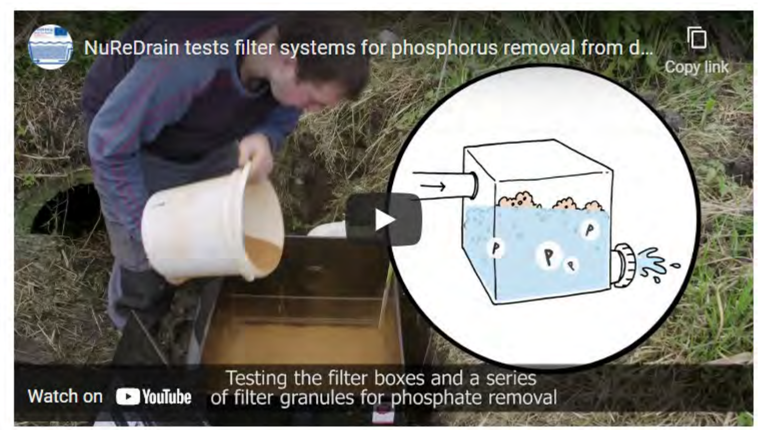
Nuredrain information

- [NuReDrain, Interreg VB North Sea Region Programme]()
- Scientific articles
- Filter fact sheets
- Videos
- MBBR manual: working principle, calculation tool, DIY build instruction

Filter Fact Sheets



Filter Construction Manuals



Field visits with sun

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Field visits with rain

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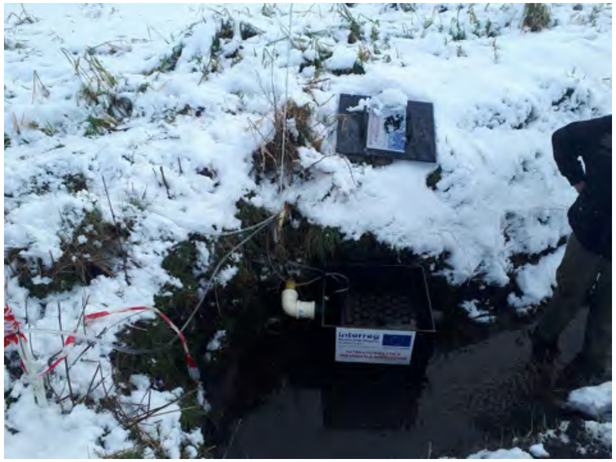
Field tests in summer

Field tests in winter



Acknowledgements

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vito
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Ghent University
Aarhus University – Department of Agroecology
University of Copenhagen
Universität Rostock – Traditio et Innovatio
PCS – proefcentrum voor sierteelt

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Provincie Antwerpen
Provincie Oost-Vlaanderen – Voor ieder van ons
west-vlaanderen – de gedreven provincie

Q & A