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# NuReDrain final conference webinar:

# Filter systems for nutrient removal from agricultural waters

1 June 2021

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# Eutrophication: too much of a good thing

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

# Plant nutrients: which nutrients?

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Macronutrients: N(itrogen),

P(hosphorus), K (potassium)

⟺

Micronutrients




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# “Open” vs. “closed” nutrient cycles

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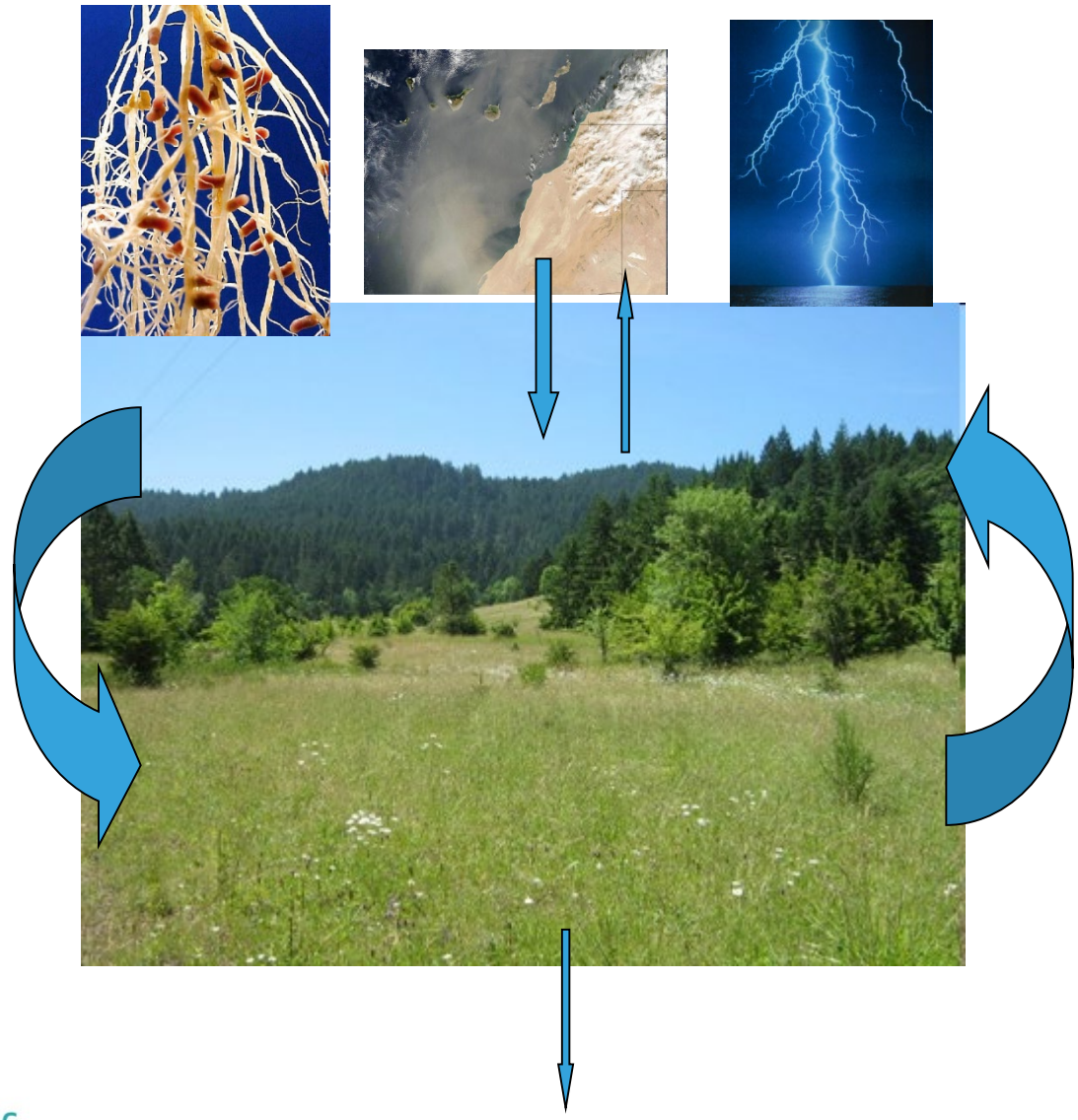
Pristine, natural ecosystems:

- very small nutrient inputs
- very small nutrient outputs

Closed nutrient cycle



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# “Open” vs. “closed” nutrient cycles

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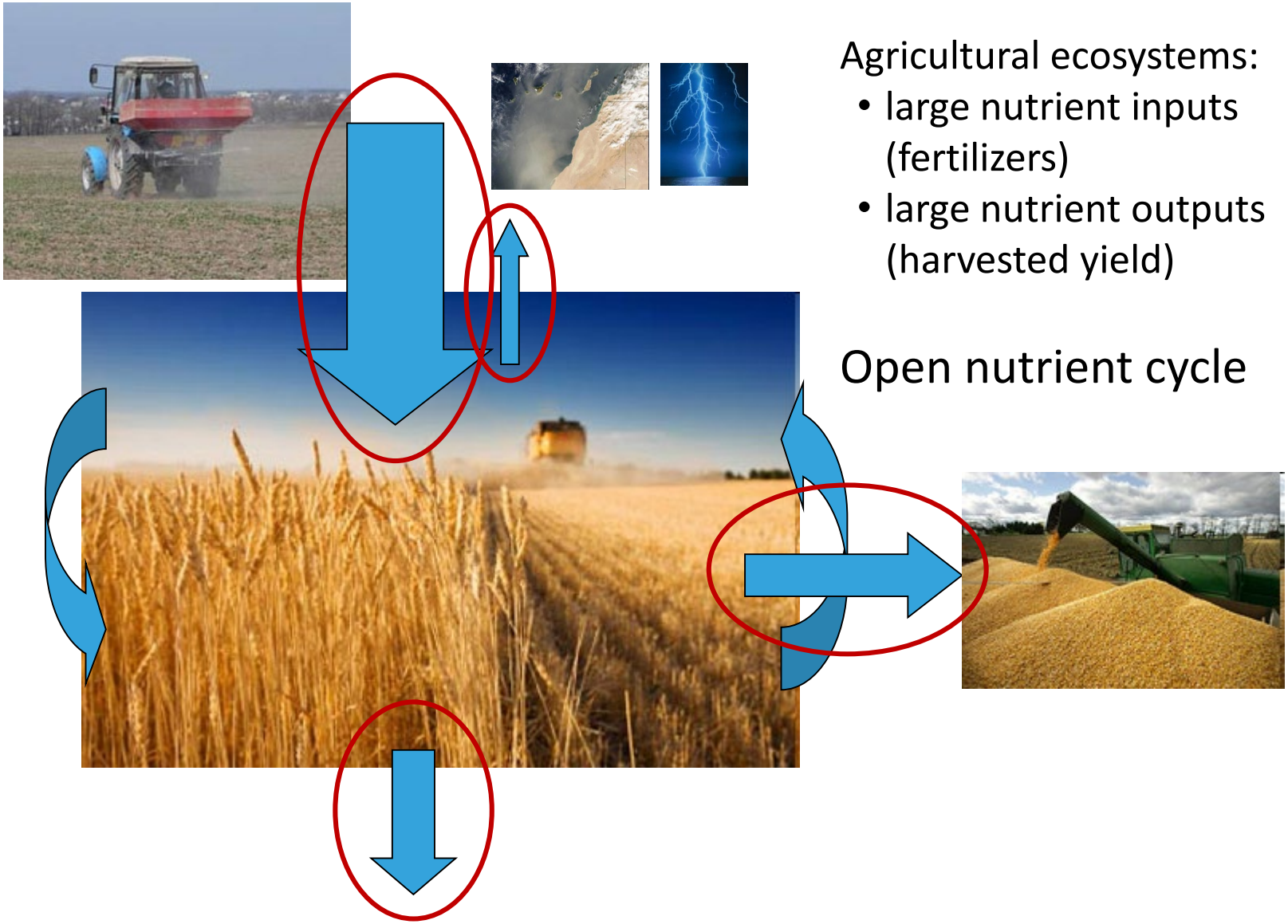

Agricultural ecosystems:

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

Open nutrient cycle

# Plant nutrients: which nutrients?

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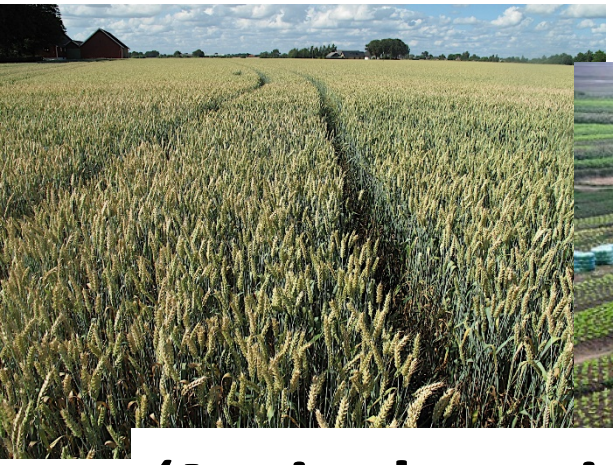
Macronutrients: N(itrogen),

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

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# Plant nutrients: from where?

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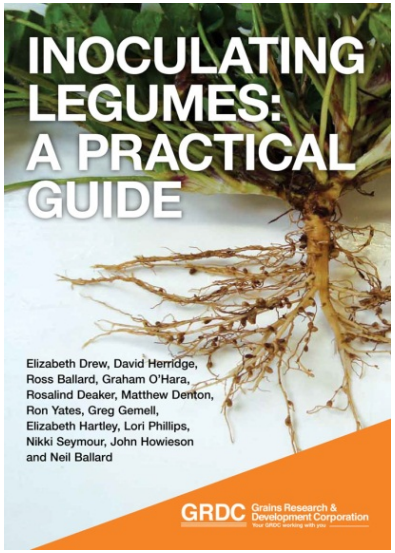
Nitrogen: fixation of (inert) atmospheric N2:




P, K, ...: mined from ores

Reserves are finite, and not in Europe!

... P is a 'CRM'

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# Opening of planetary nutrient cycle

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**The true reason for nutrient excess problems!**

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# Consequences of too much

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$NH_3$ 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”

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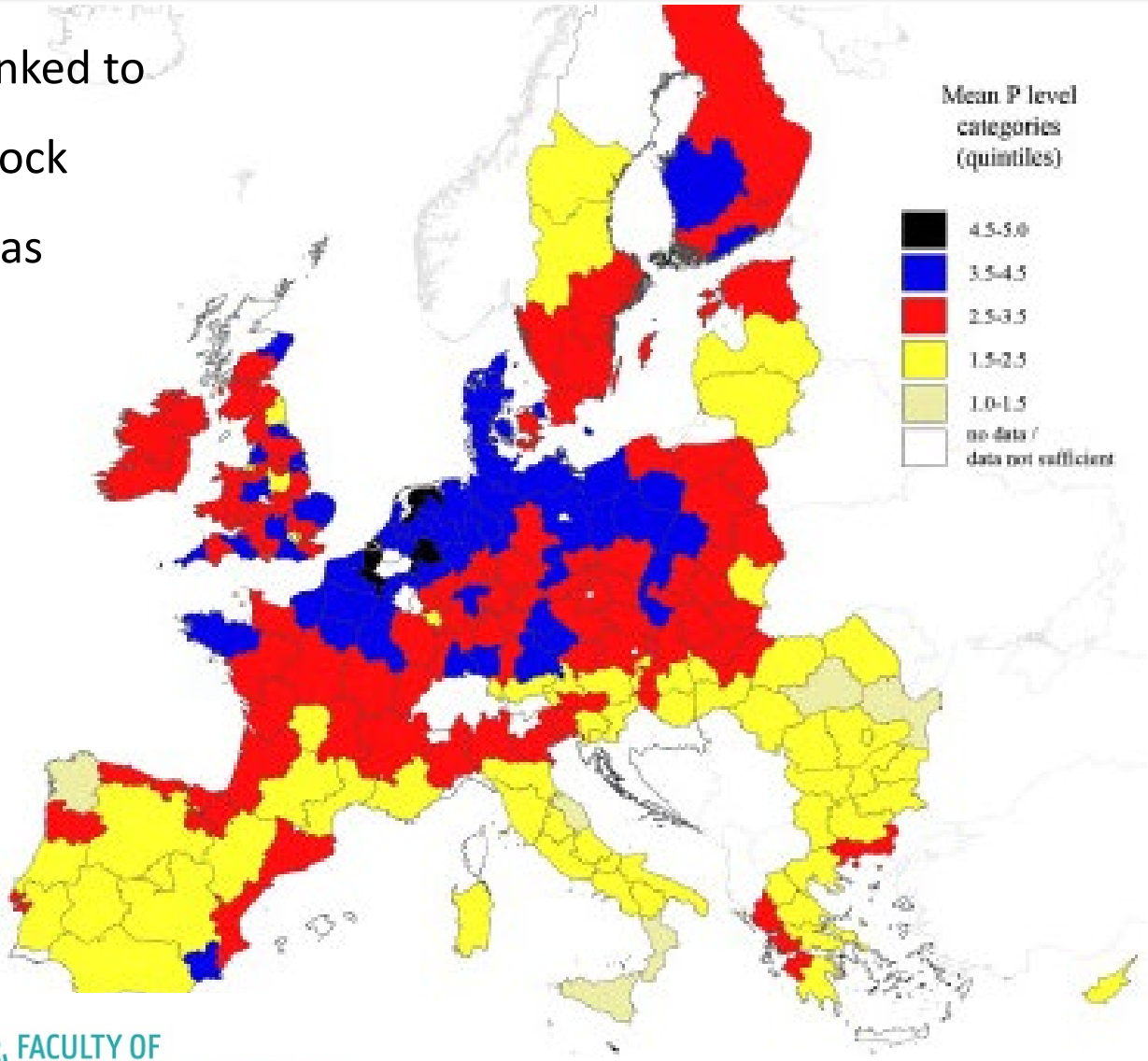
Hotspots are linked to intensive livestock production areas

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# 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, ...)

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# 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

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Nuredrain approach:

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

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# The Nuredrain approach

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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


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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?

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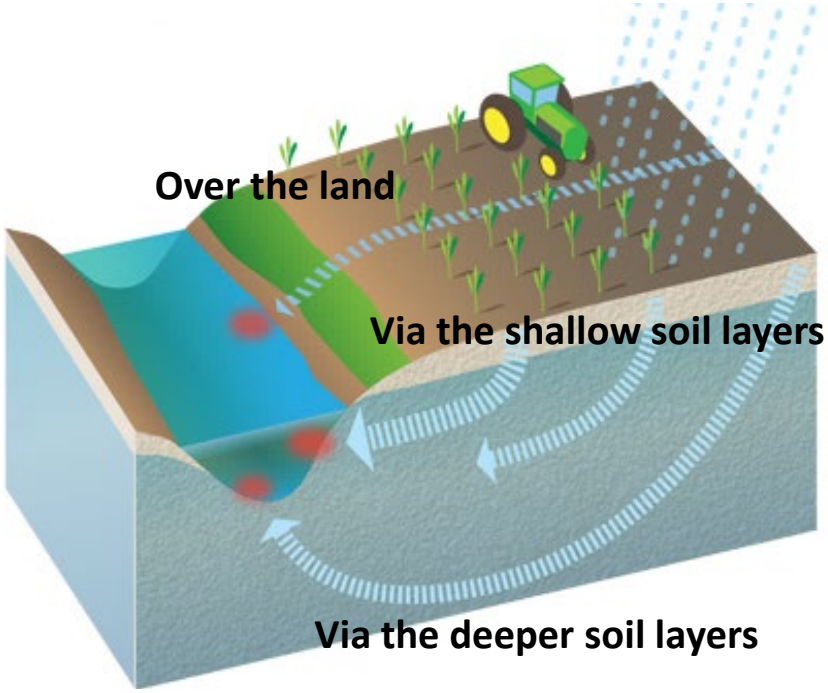
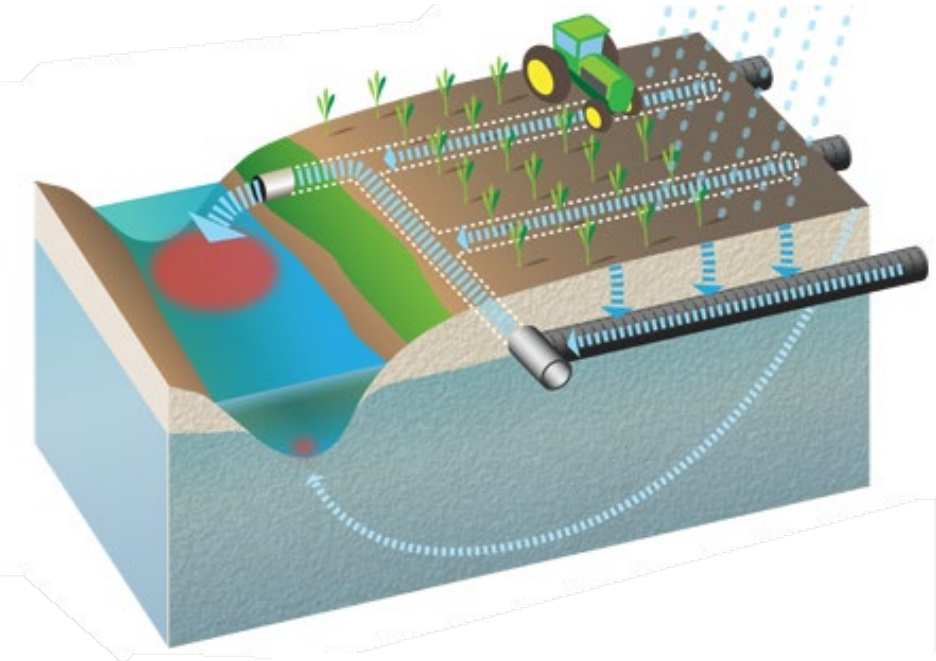



17—40% agricultural field is drained in NW Europe



Directly discharge of P towards the surrounding waters

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# What do farmers need?

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- 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

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# Phosphorus Sorbing Materials (PSM)

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## 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

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# Principle of PSM

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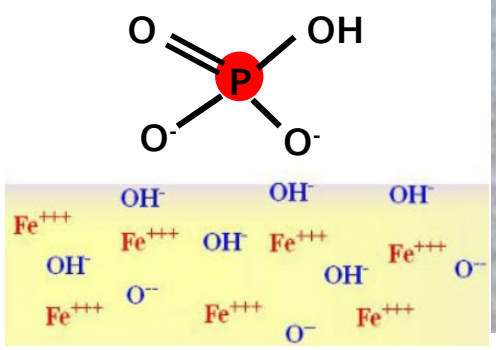
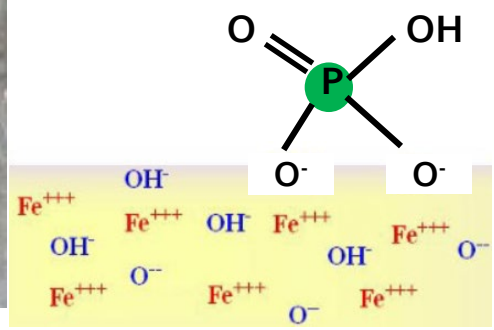
P is removed from water by absorbing into iron coated sand (ICS)

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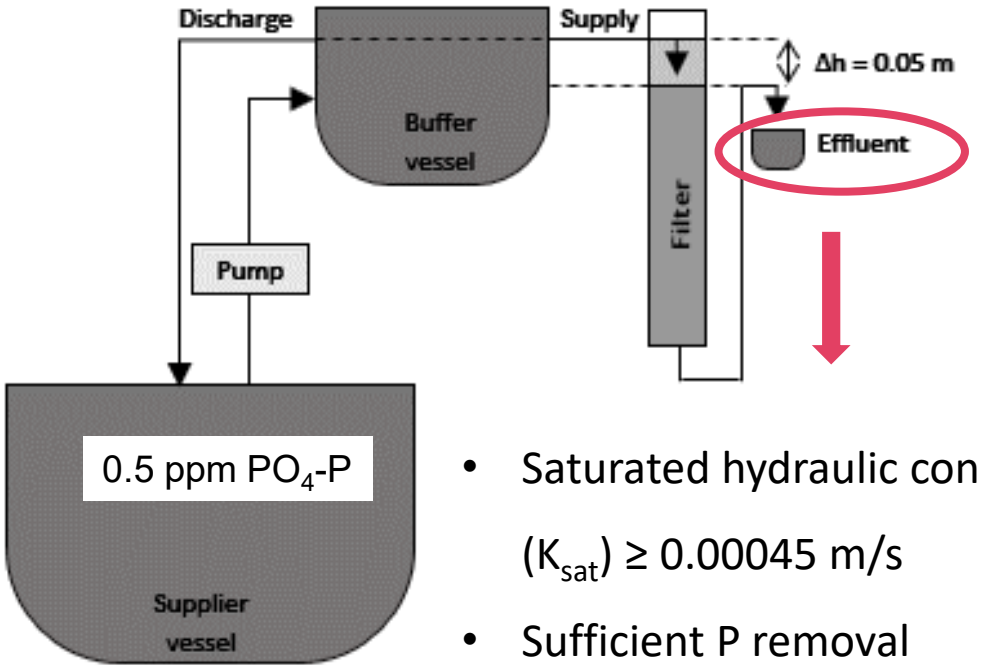
# Prepare and test filters at lab scale




- 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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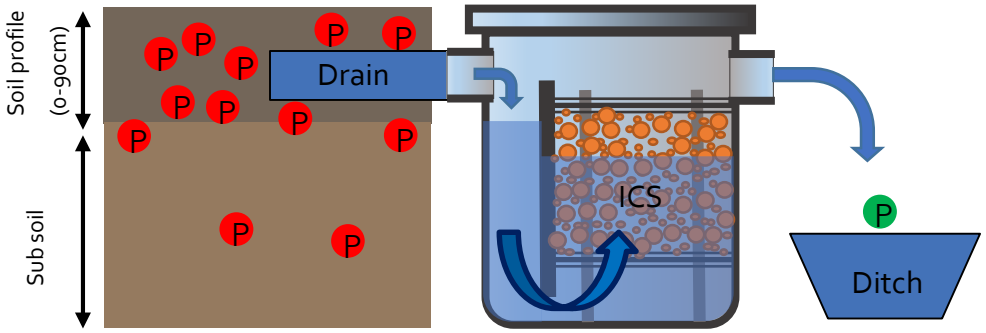
**Key features**:

upward oriented outlet

mesh netting at bottom

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# Performance of prototype

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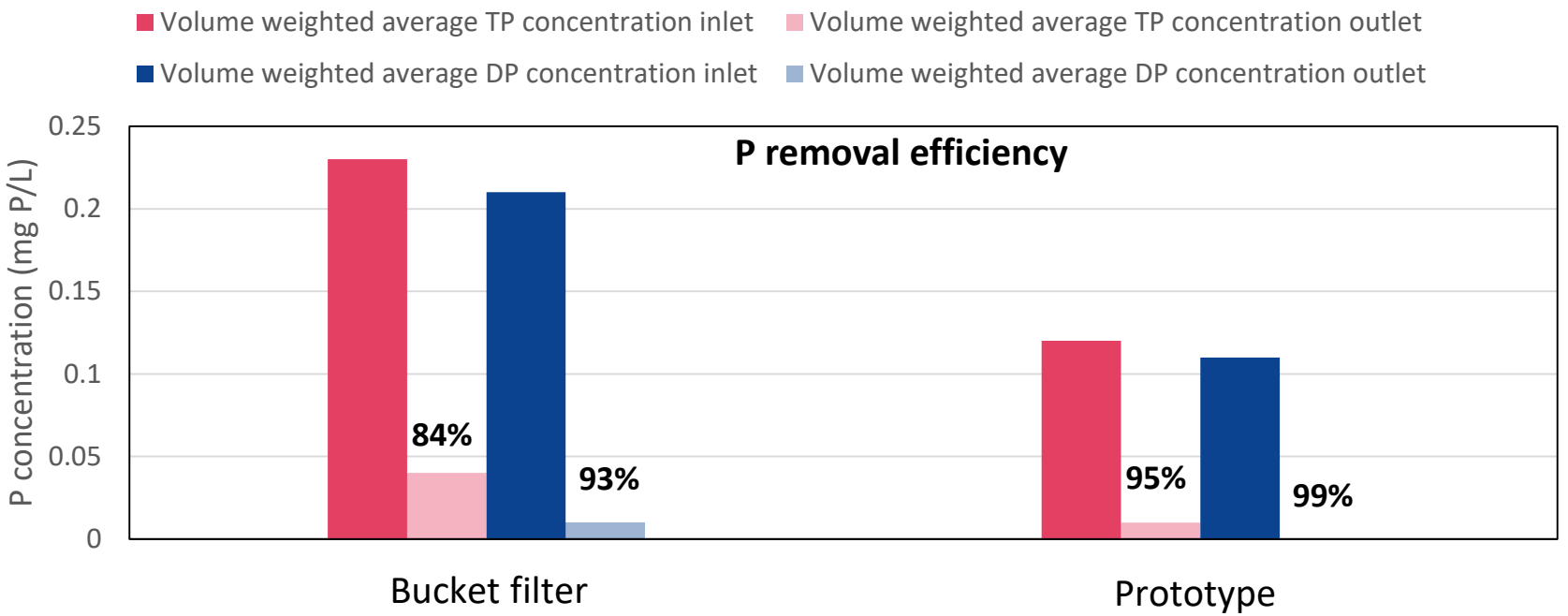
Simple bucket VS Prototype




**Water flow:** **0.04-4.3 $m^3$/day** **0.04-3.6 $m^3$/day**

**TP**: Total phosphorus
**DP**: Dissolved phosphates

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# Performance of prototype

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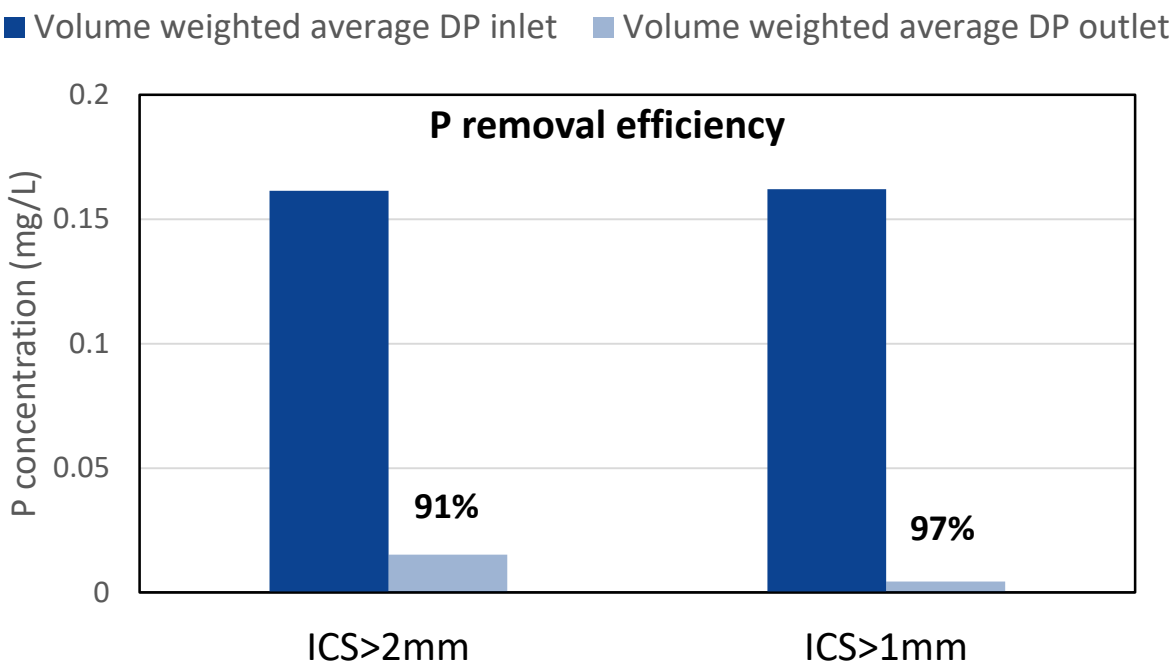
ICS >2 mm **VS** ICS >1 mm




**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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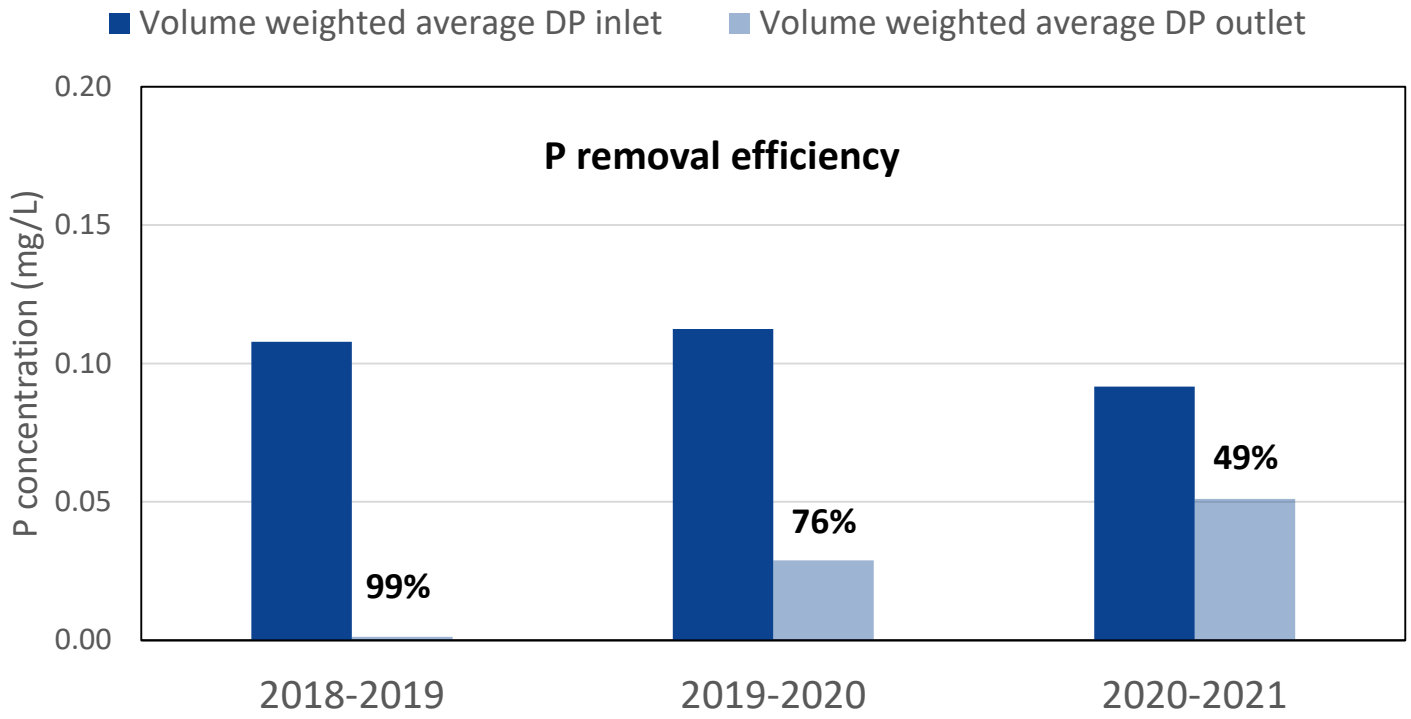
**With 35L/50 kg of ICS → max 8 $m^3$/day & 0.5 mg/L $P\text{-}PO_4$**




| | | | |
|---|---|---|---|
| **Water flow:** | **0.04-3.6 $m^3$/day** | **0.1-7.2 $m^3$/day** | **0.1-2.5 $m^3$/day** |

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# Cost estimation

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| | 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** | |

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# 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)

## 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

With 2-3 $m^3$ of ICS

→ Max 1 $m^3$/day

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

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d after 4 years

ICS

PCS proefcentrum voor sierteelt

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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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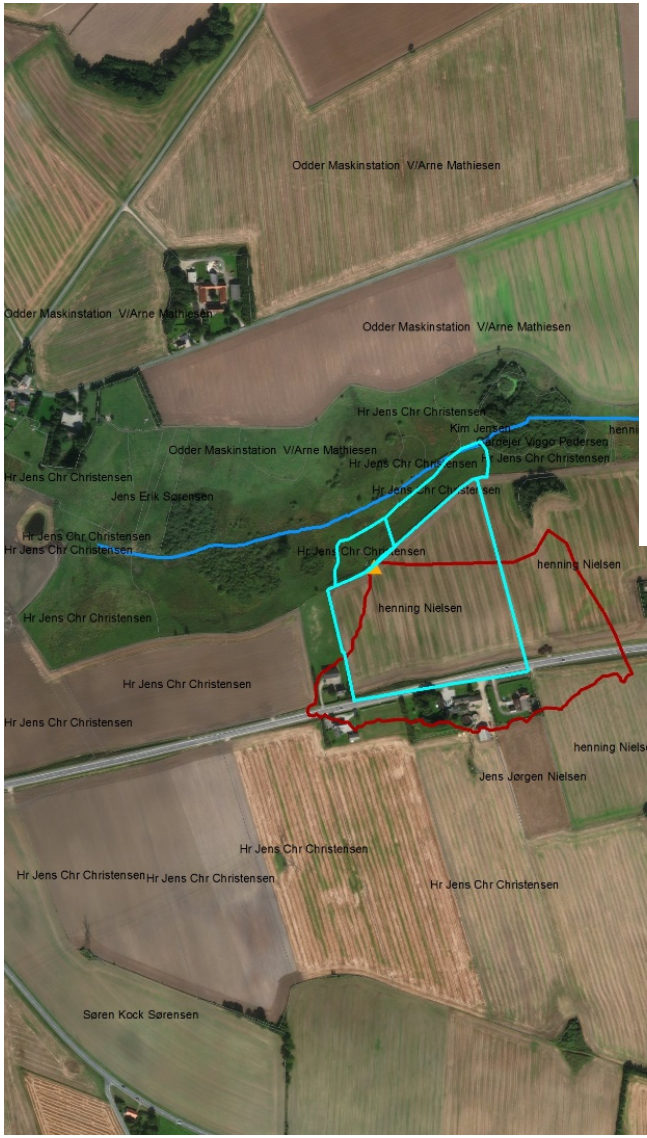


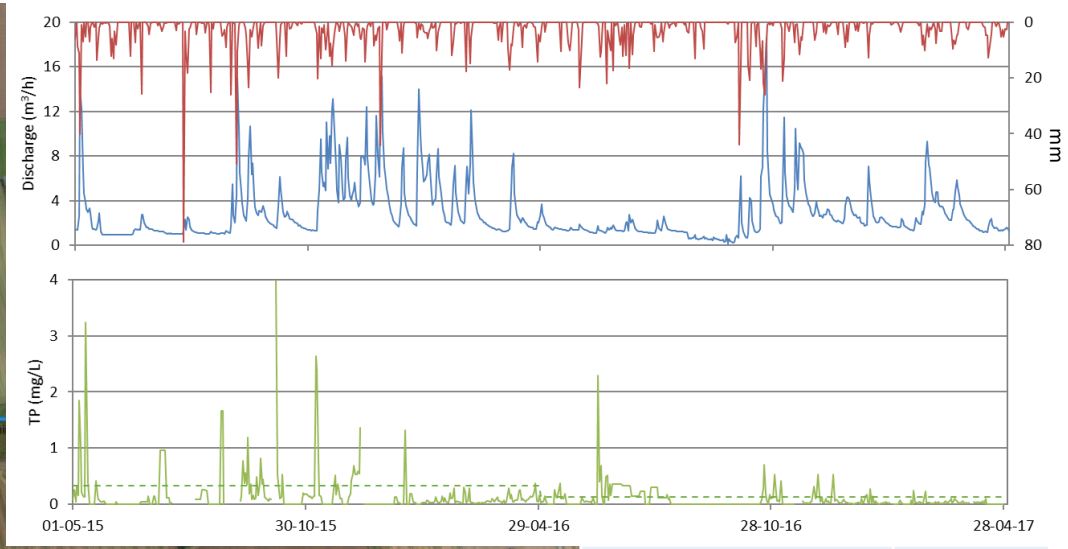


| | | |
|---|---|---|
| Catchment area (ha) | | 8.4 |
| May 2015/16 | Q (mm) | 349 |
| | Q/P (-) | 0.30 |
| | TP (kg/ha) | 1.1 |
| | Flow weighted average TP (mg/L) | 0.32 |
| May 2016/17 | Q (mm) | 246 |
| | Q/P (-) | 0.28 |
| | TP (kg/ha) | 0.3 |
| | Flow weighted average TP (mg/L) | 0.13 |

# System design

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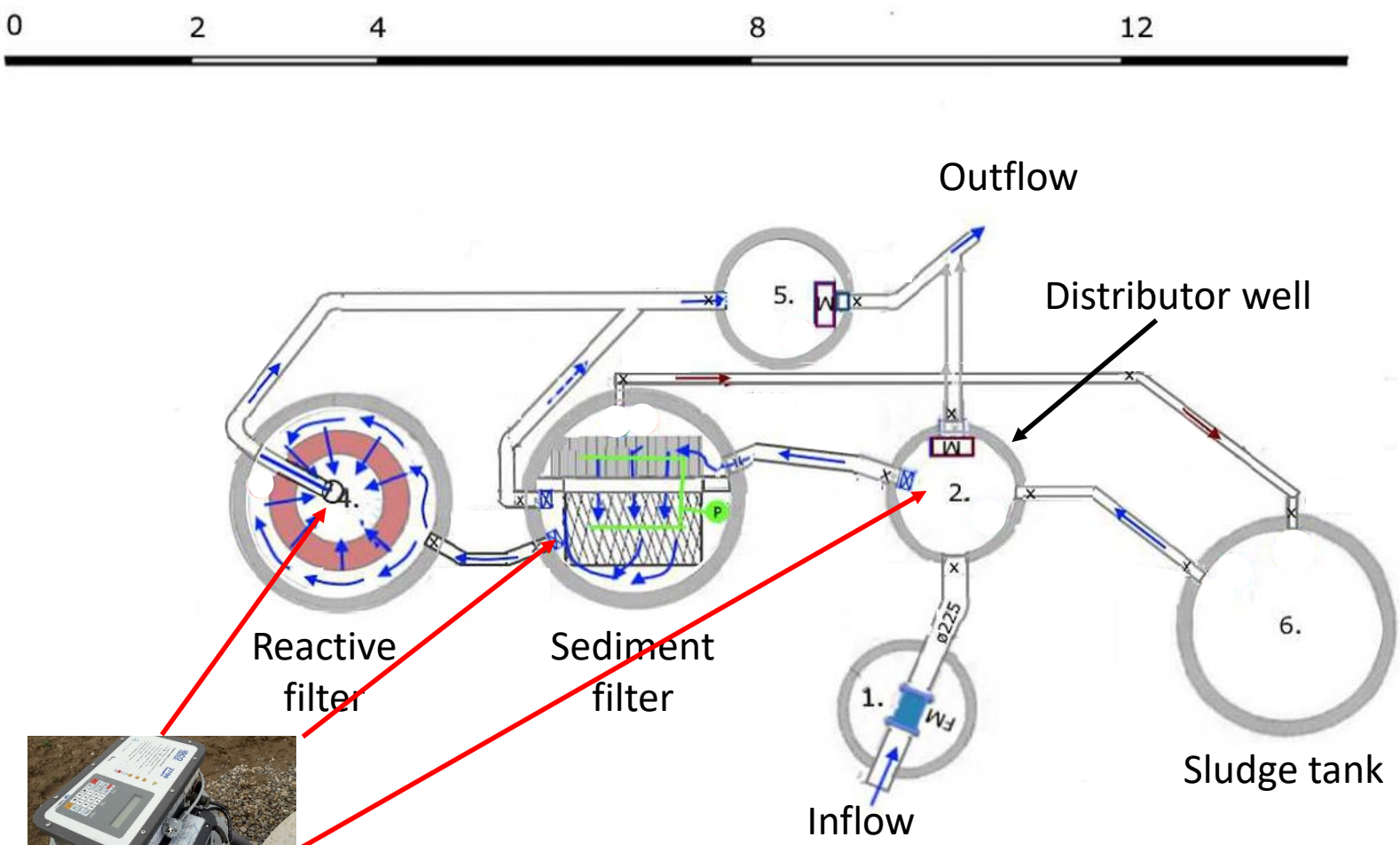
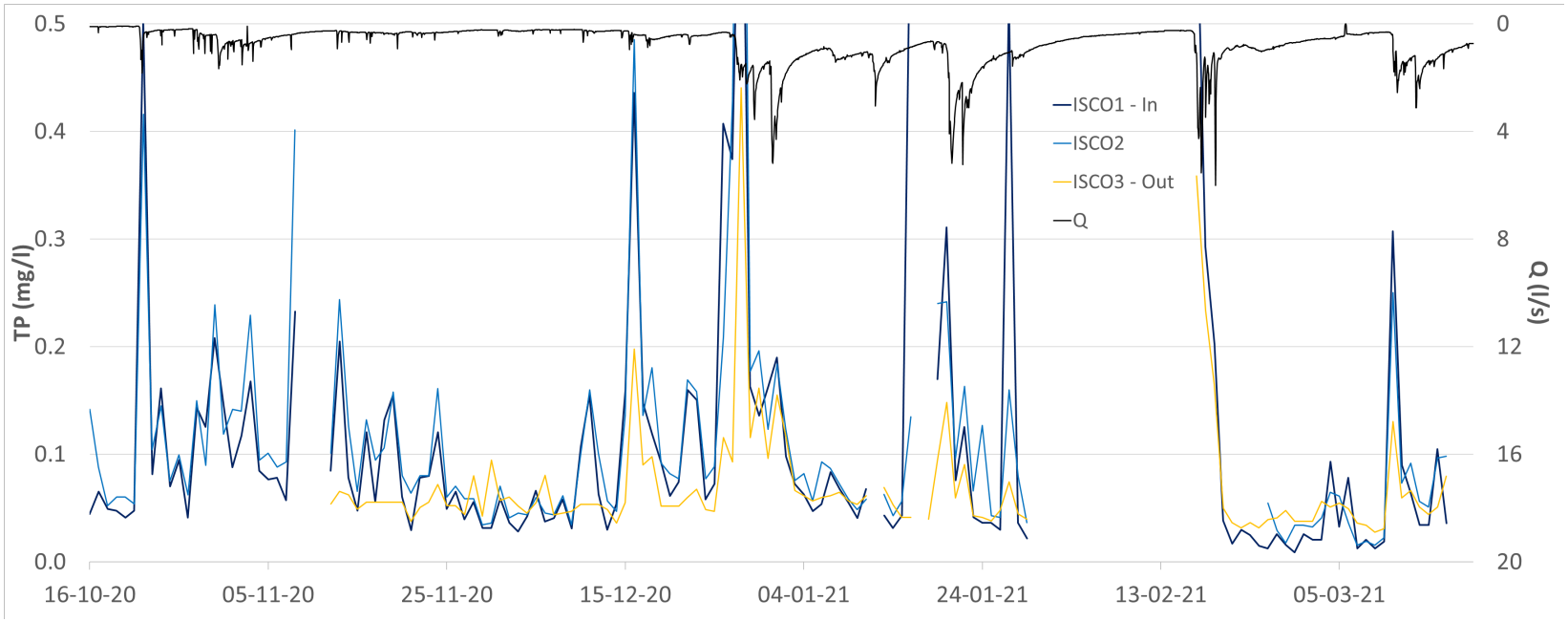
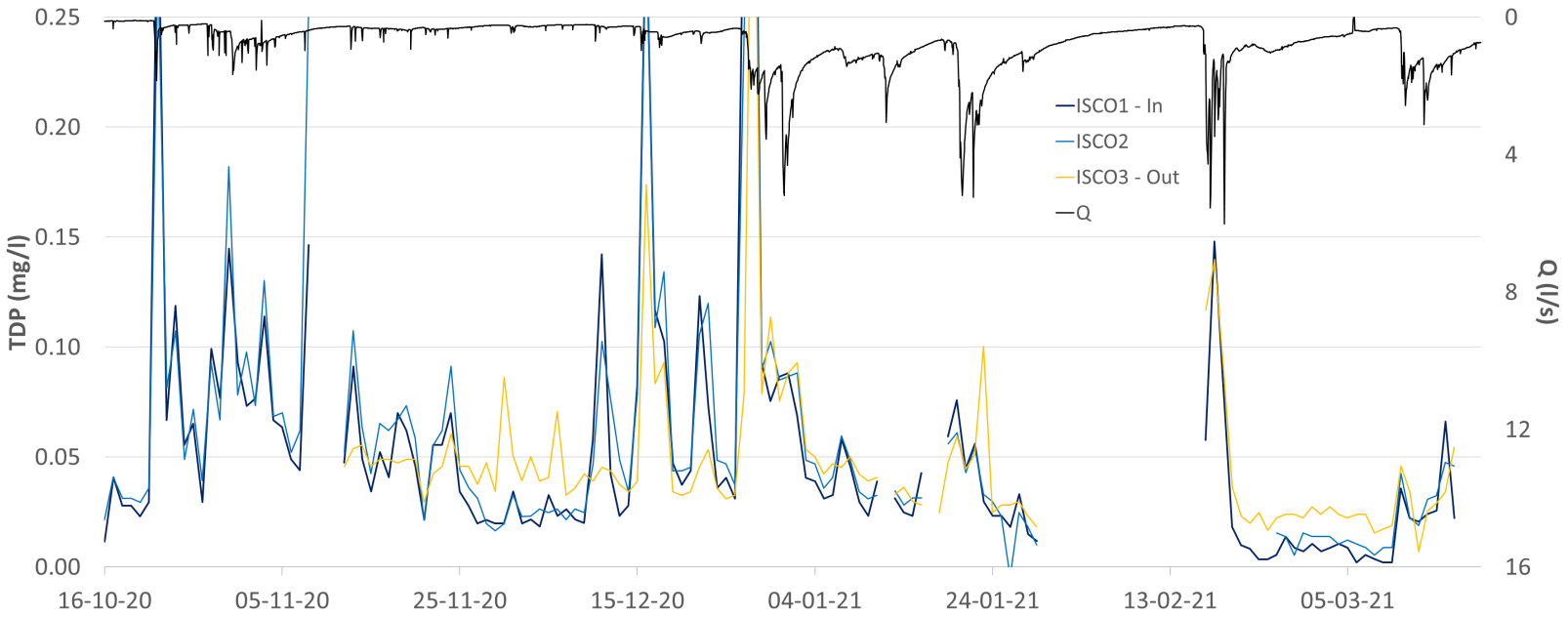


# TP – Fensholt D8



# TDP – Fensholt D8



# 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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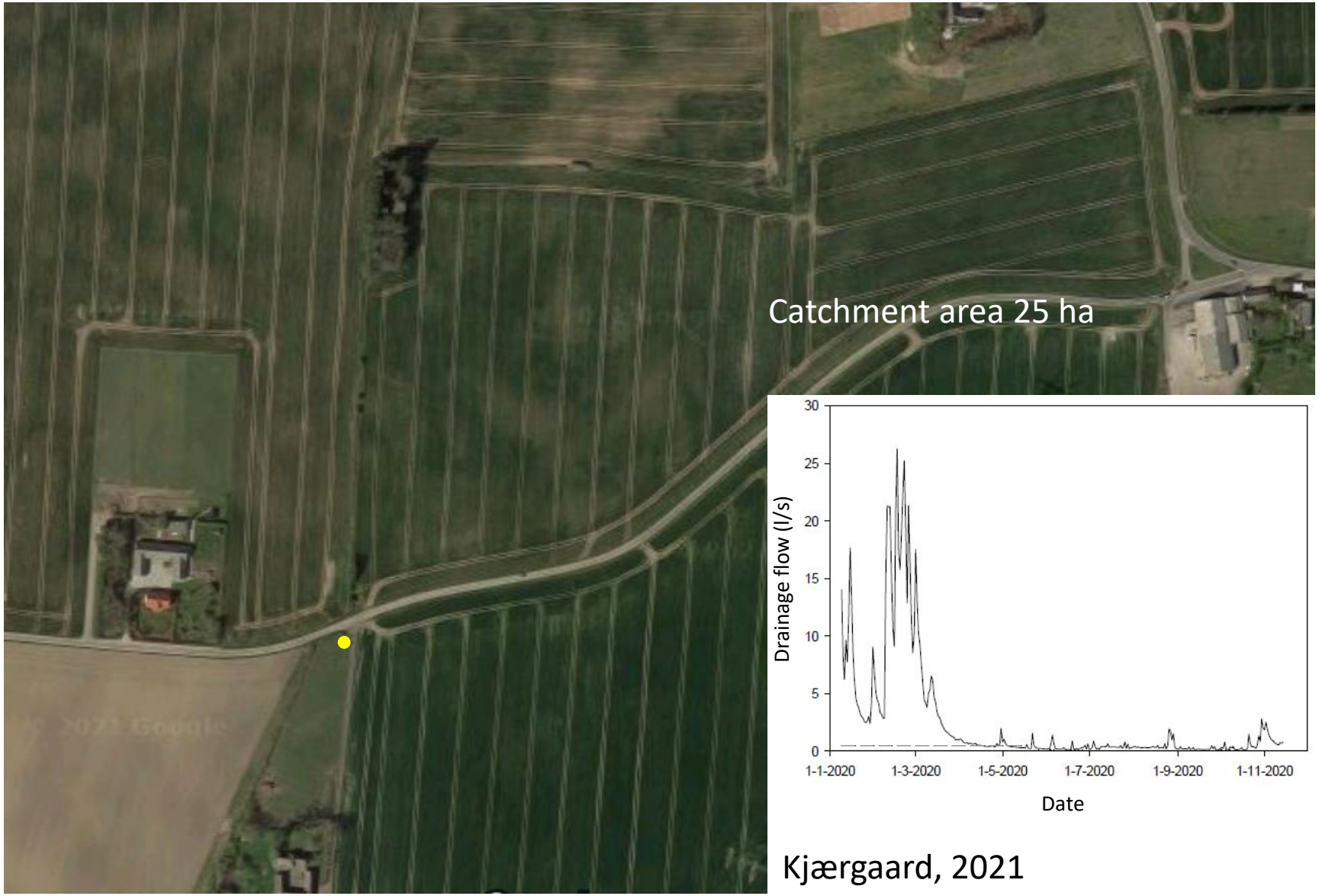


Kjærgaard, 2021

# System design

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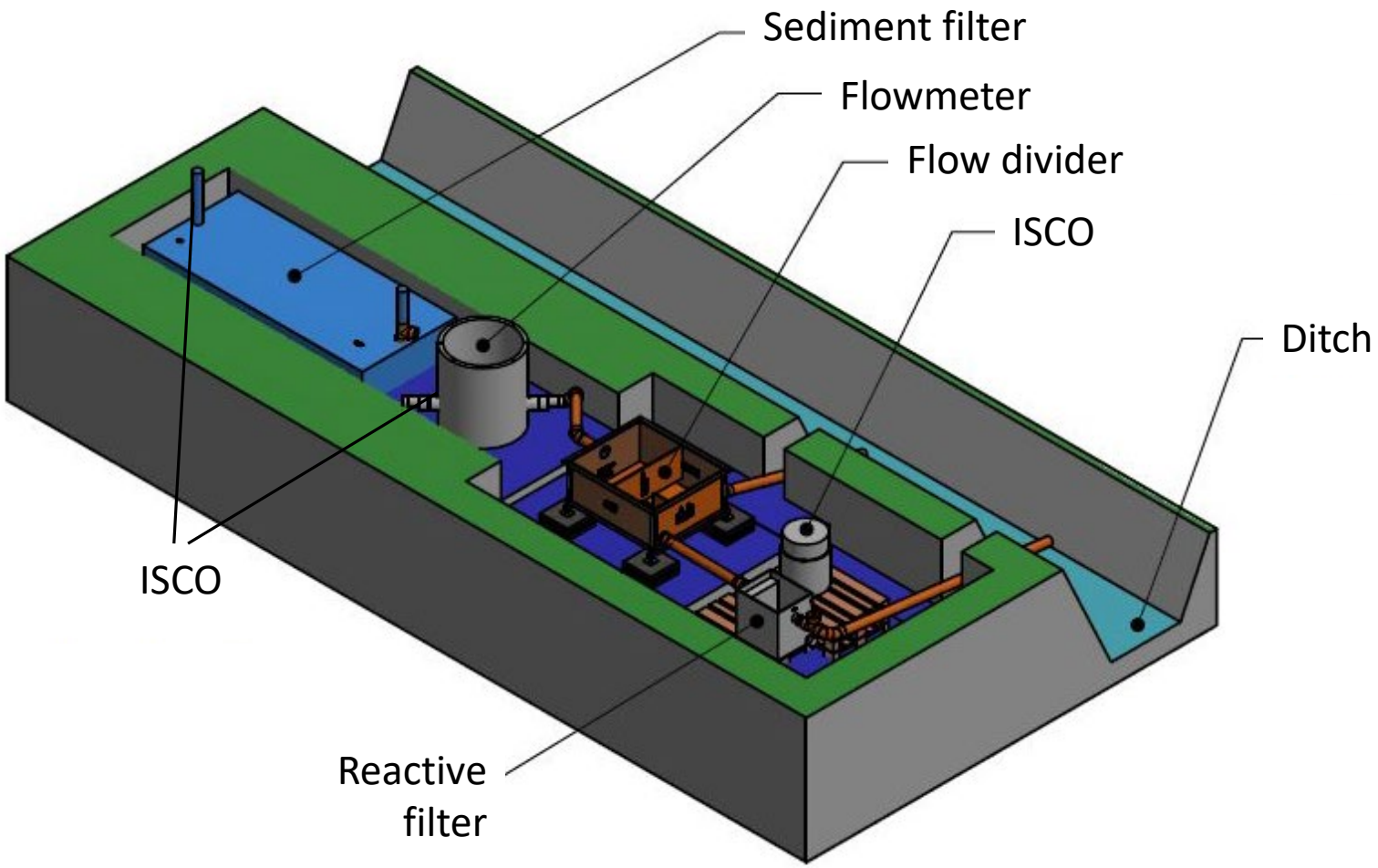

# TP – Fensholt D3

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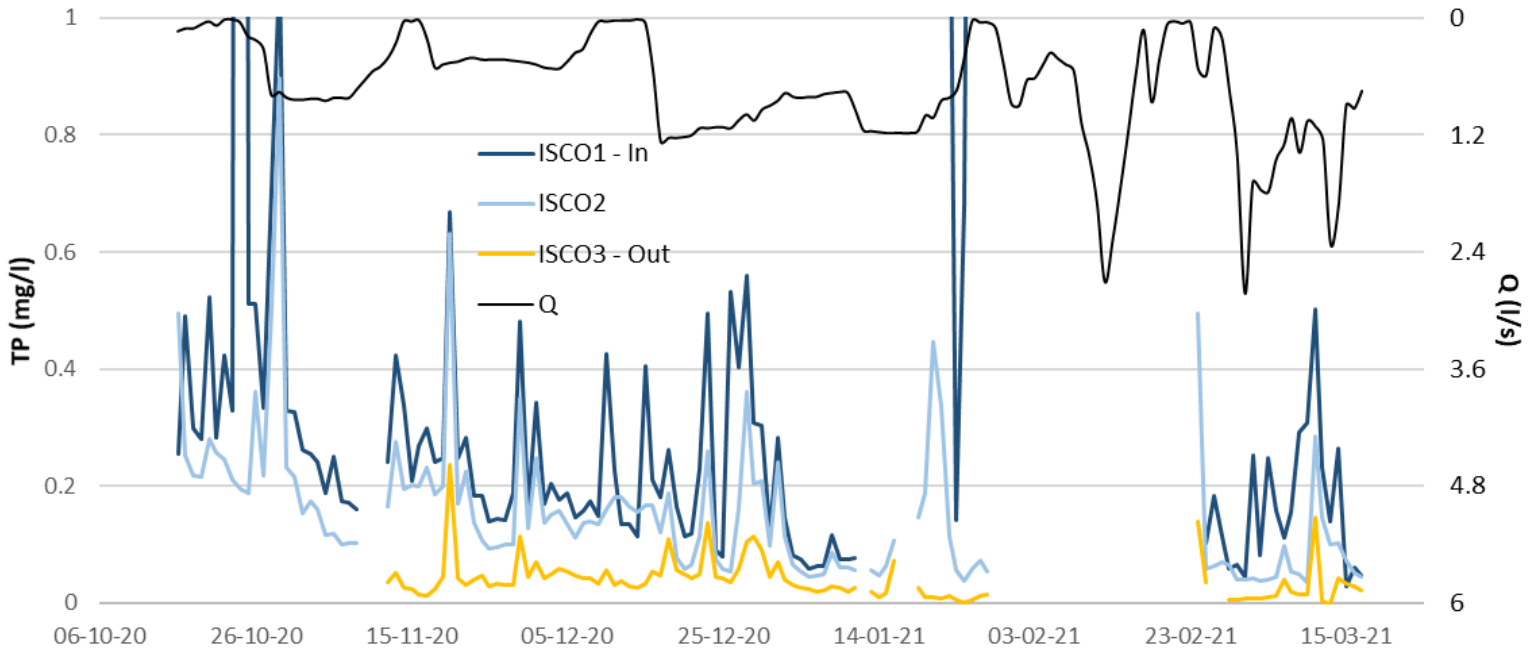

# TDP – Fensholt D3

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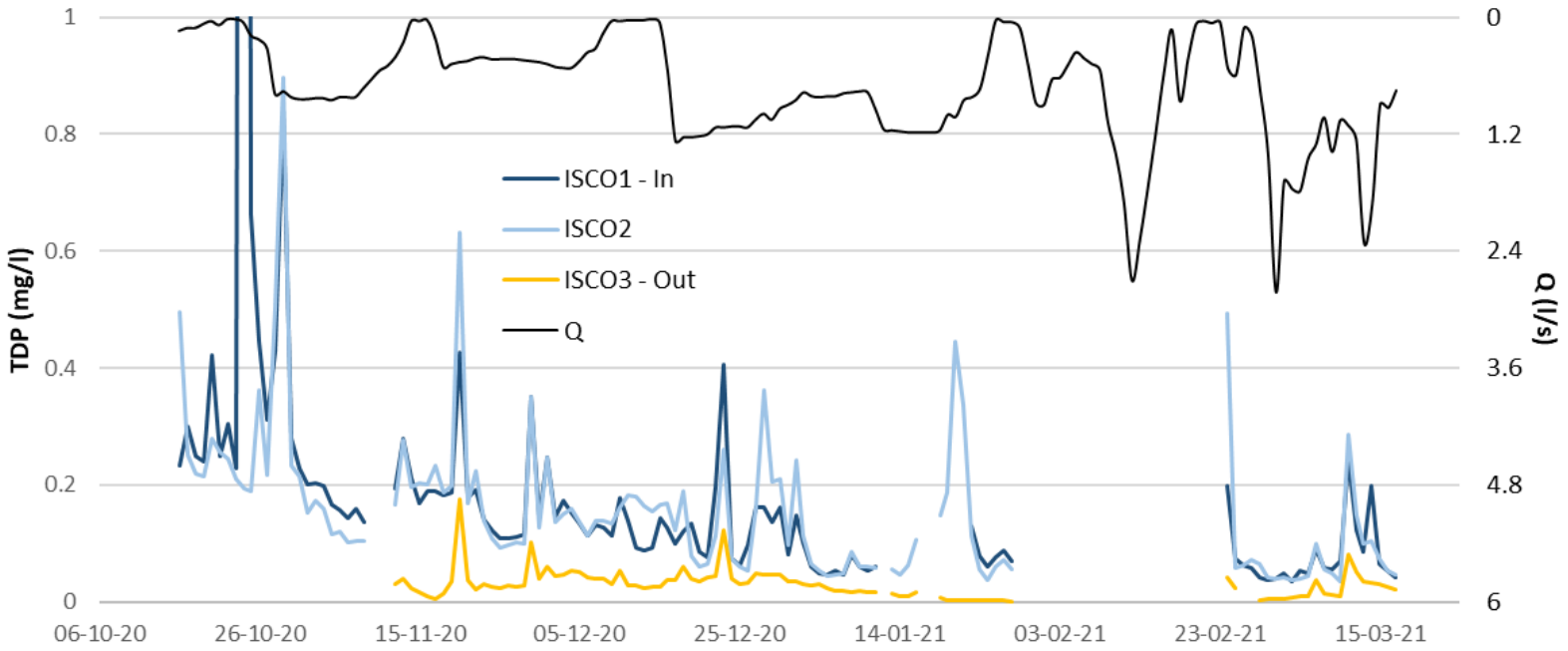

# Monthly data overview

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| Month | Sediment filter | | | | | Reactive filter (ICS) | | | | | Overall system |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q ($m^3$) | TP load (g) | TP removal (%) | TDP load (g) | TDP removal (%) | Q ($m^3$) | TP load (g) | TP removal (%) | TDP load (g) | TDP removal (%) | 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

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- 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

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- 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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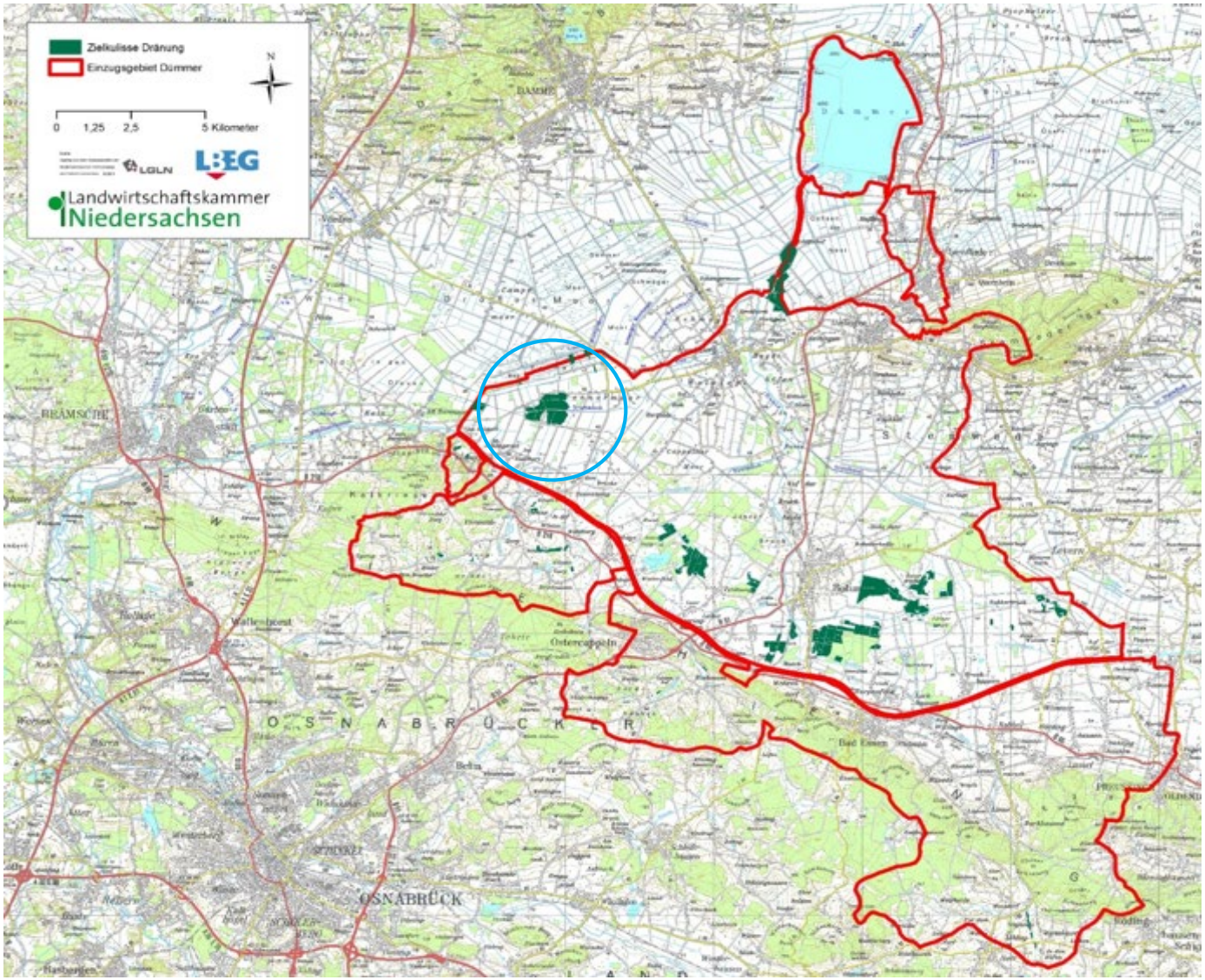
# Experimental Inline Phosphorus Filtration in a Drained Arable Field

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

# High P losses in drained fields



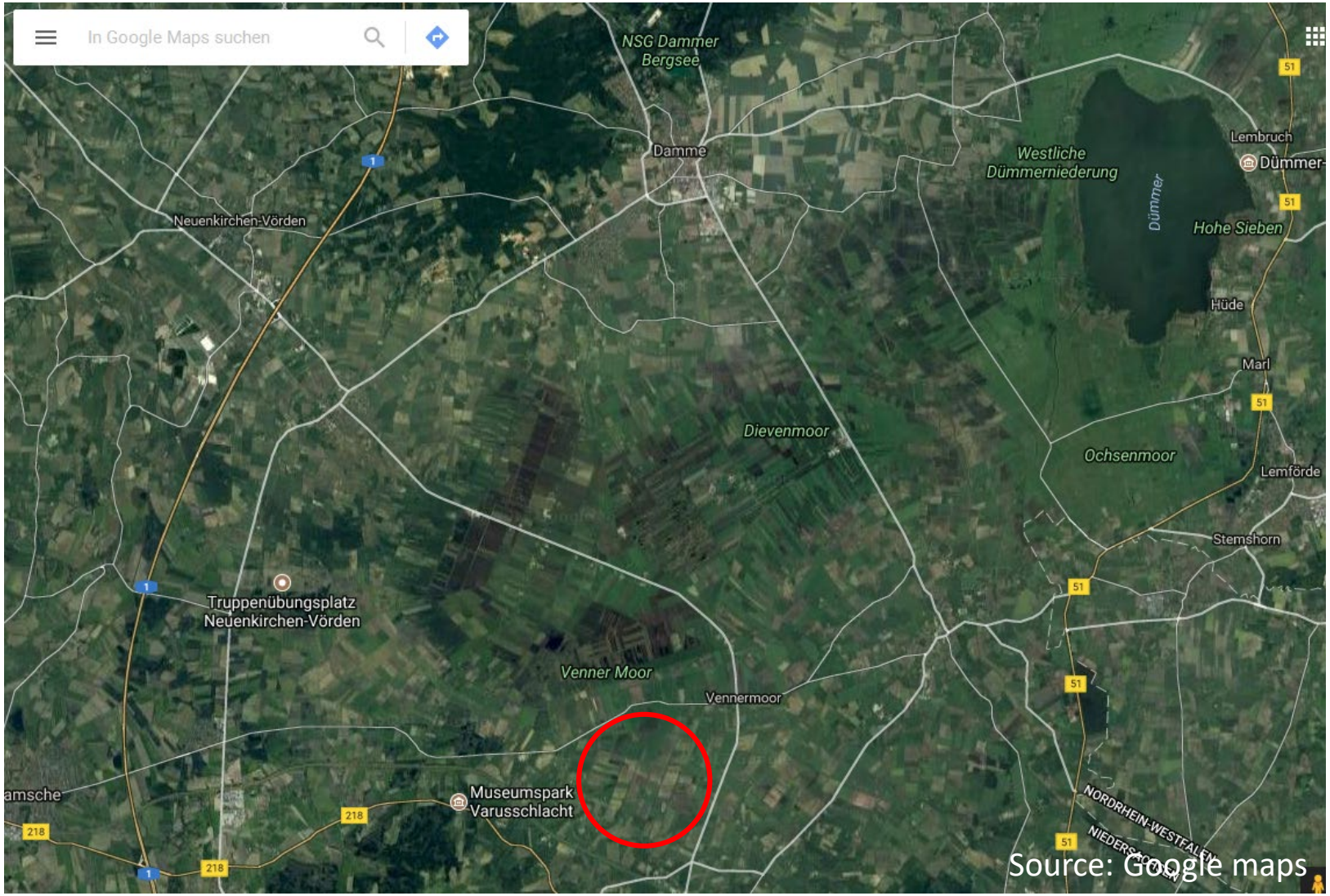


**"Hot Spots"**

↑ P concentration

↑ drainage flow

# Lowland and peat soils



# Test site specification




**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

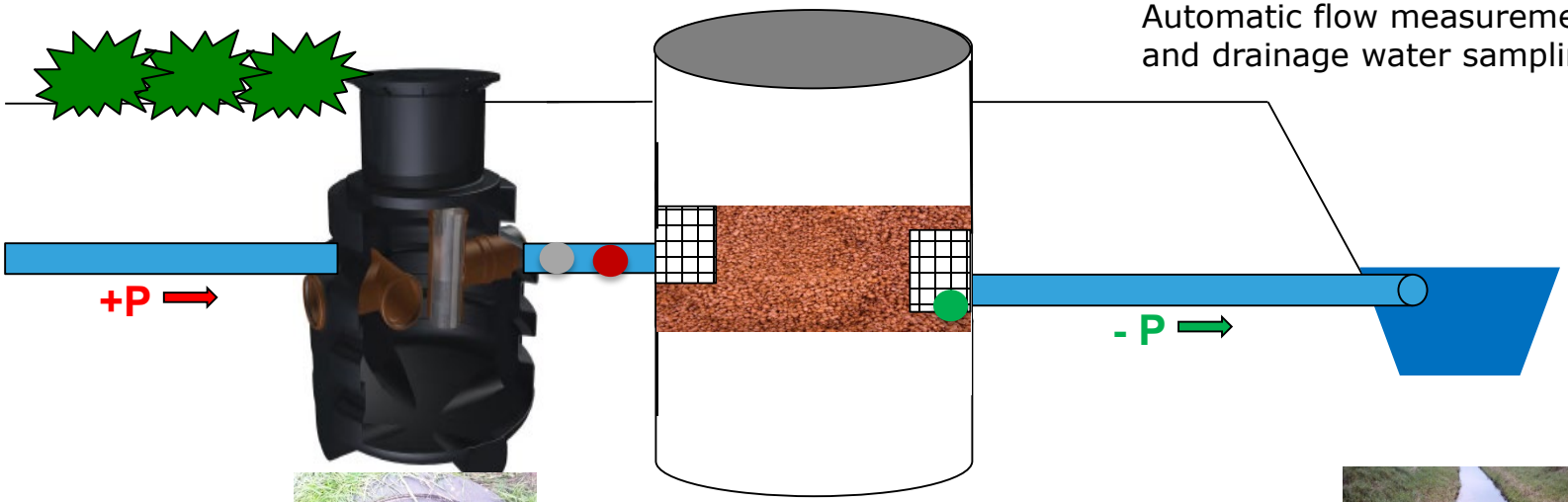
# Location challenges


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




# Setup experimental Inline P filter


Automatic flow measurement
and drainage water sampling




Flow direction ⇨

Pre-Filter

P-Filter

Venner Bruchkanal

# Drainage water samples

| | 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

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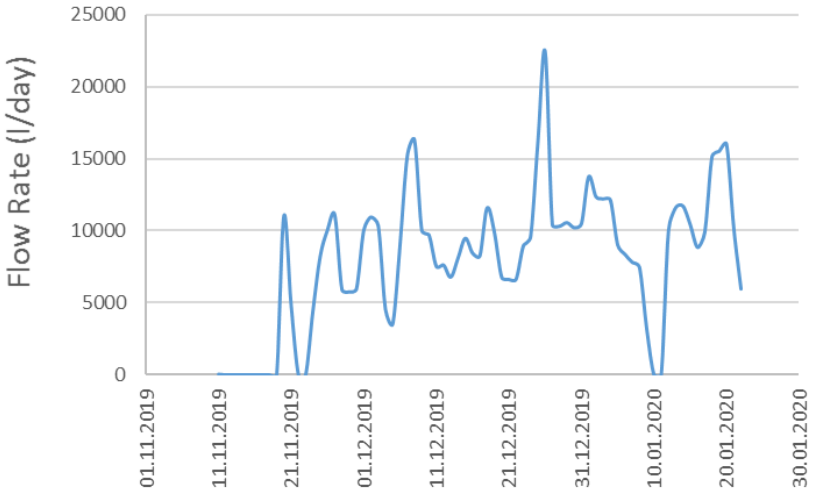
## Manual flow measurement


Day in season 2020/2021


## Automated flow measurement

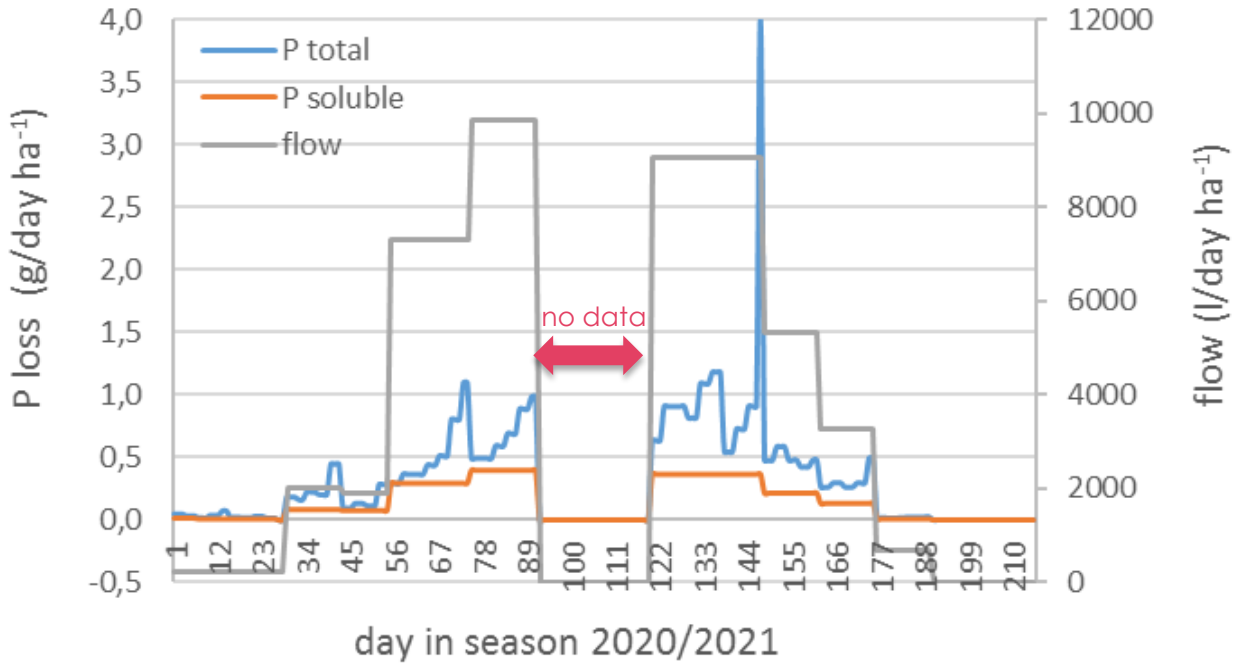



Date in season 2019/2020

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

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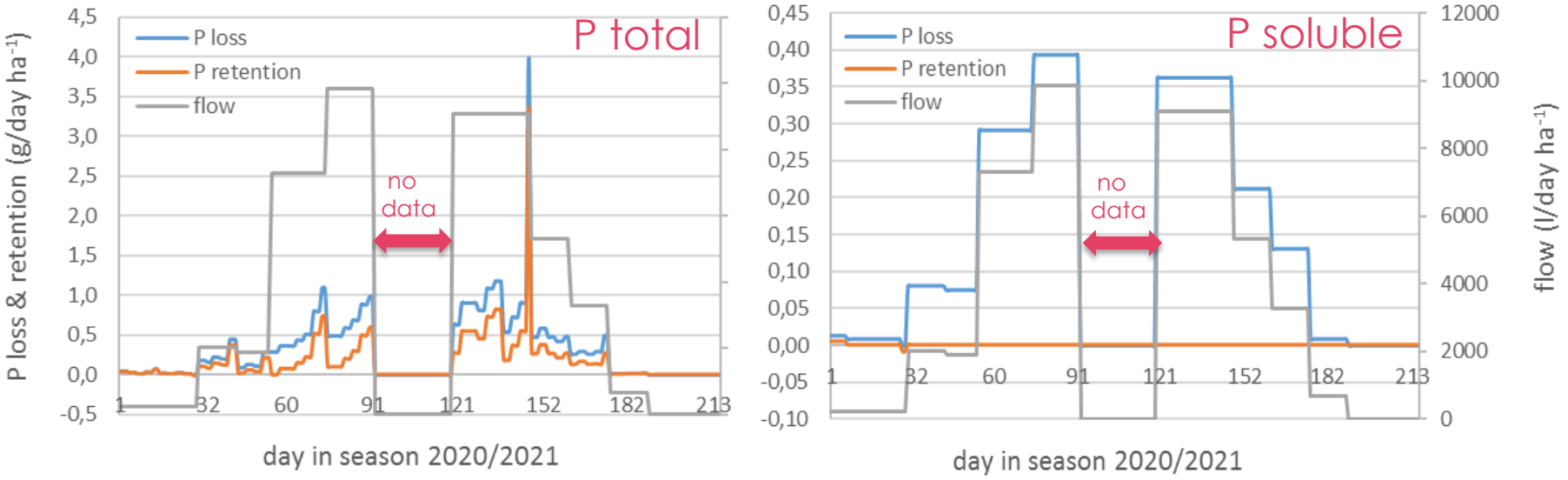
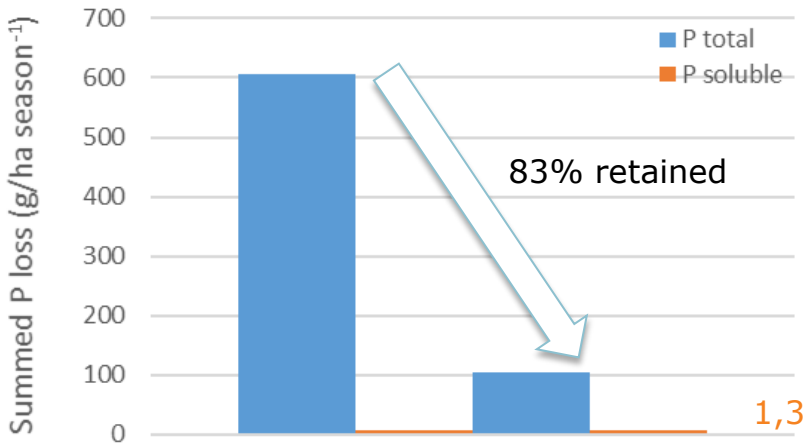
## 2020/2021




- **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).

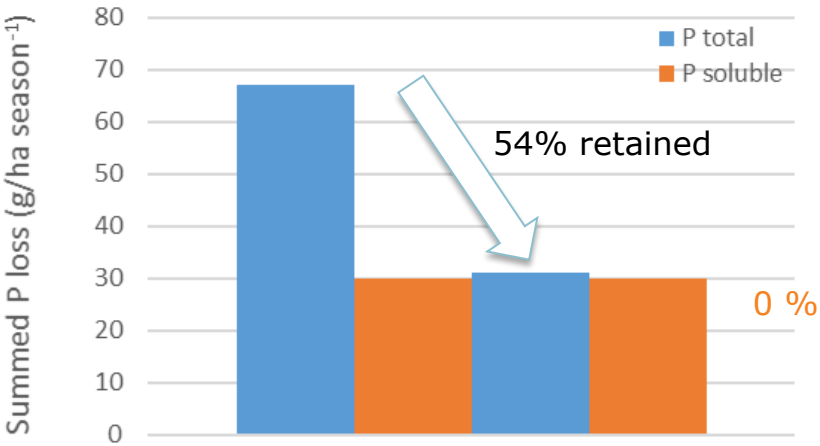
# Impact P loss on algae growth

## 2019/2020




1,3 % retained

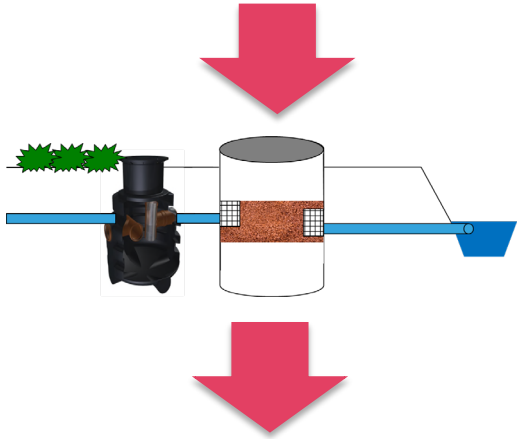
## 2020/2021




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

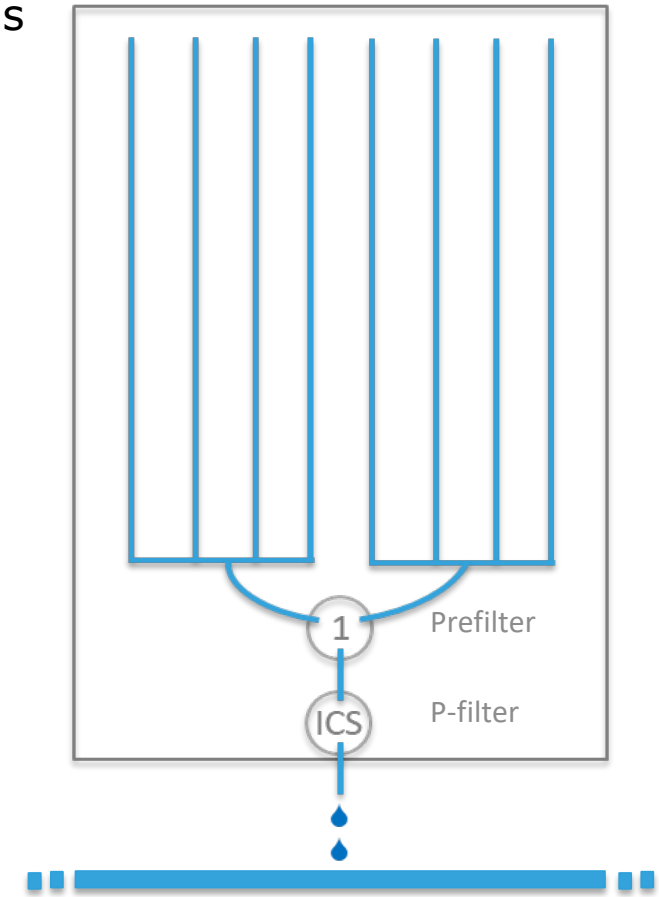
**New** installation
**Extension** of existing drainage collector systems

## 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

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