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NuReDrain
European Regional Development Fund

EUROPEAN UNION

Webinar, 24 November 2022

Practical issues

- Please mute yourself.
- Feel free to ask questions in the chat.
- The webinar will be recorded.
- Handouts will be put available afterwards.

NuReDrain -> NureDrain 2.0

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- Nutrient Removal and Recovery from Drainage water
- 1/3/2017 – 30/9/2021 -> 30/6/2023
- Interreg North Sea Region
- Project cost: € 3.516.378 - Fund: € 1.758.187
- 11 partners in 3 countries -> 7 partners in 3 countries (BE, DE, DK)

Eutrophication status

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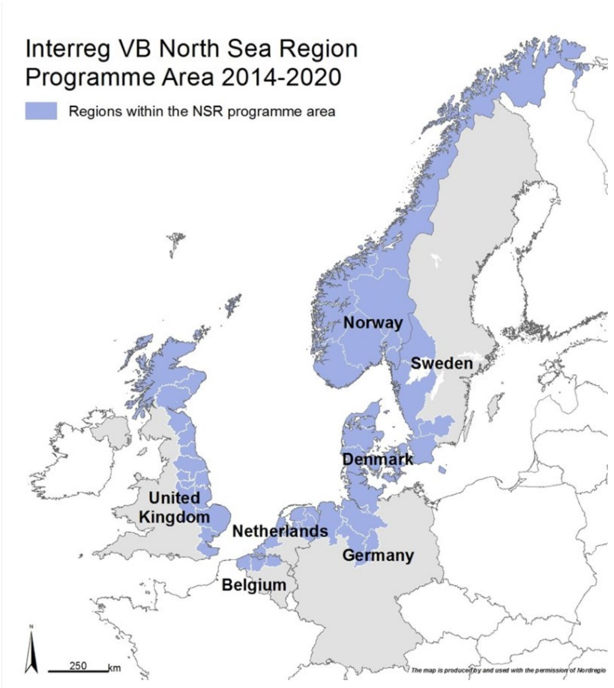

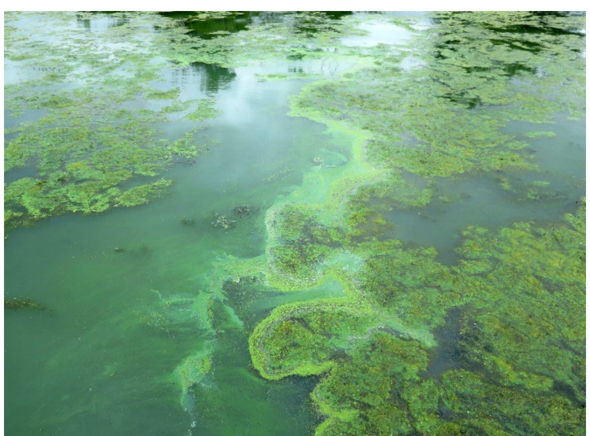

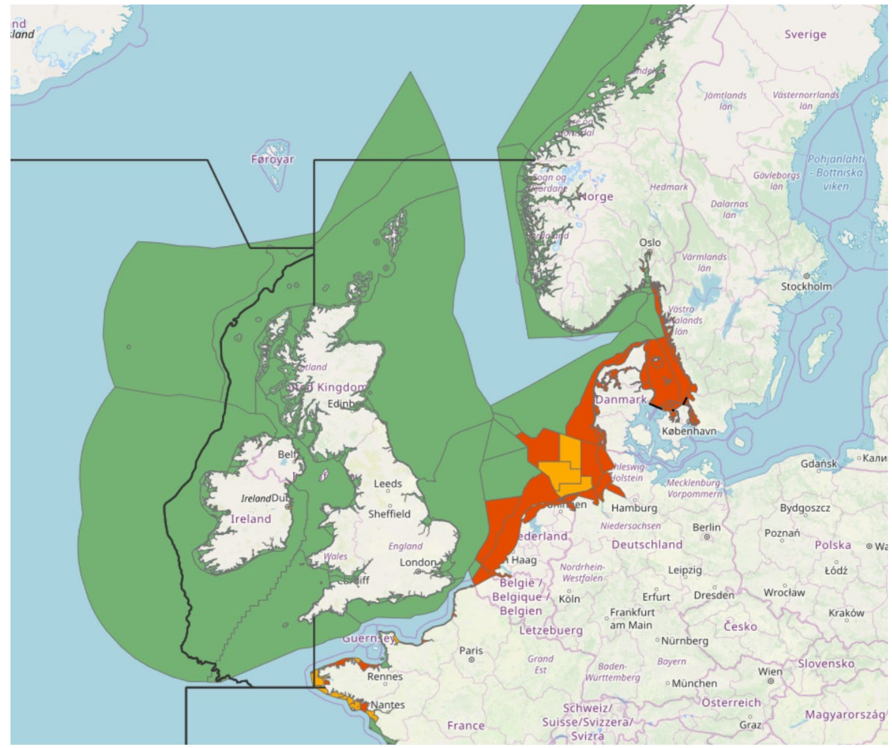

- Red : problem areas
- Orange : potential problem areas
- Green : non-problem areas

Source: OSPAR

Nutrient sources

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- **Point sources:**
  - Discharge municipal effluent
  - Discharge industrial effluent
- **Diffuse sources:**
  - Agricultural activities
  - Combined sewer overflow events

Pressure on surface water

Point sources: **18%**

Diffuse sources: **38%**

Source: European Environment Agency

Nutrient sources

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- **Point sources:**
  - Discharge municipal effluent
  - Discharge industrial effluent
- **Diffuse sources:**
  - Agricultural activities
  - Combined sewer overflow events

Pressure on surface water

Point sources: **18%**

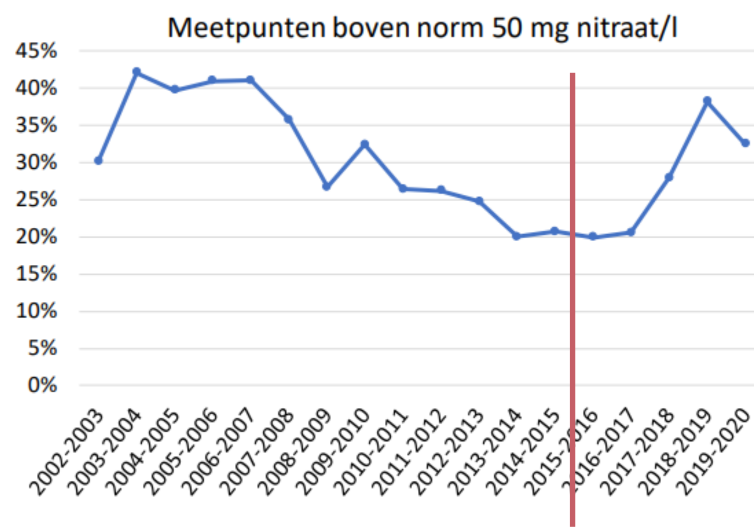
Diffuse sources: **38%**

Source: European Environment Agency

Actions to be taken

1. Source based measures

- Reduce nutrient input (optimize fertilization)
- Reduce losses from soil (adapt rotations, grow catch crops, manage crop residues, ...)



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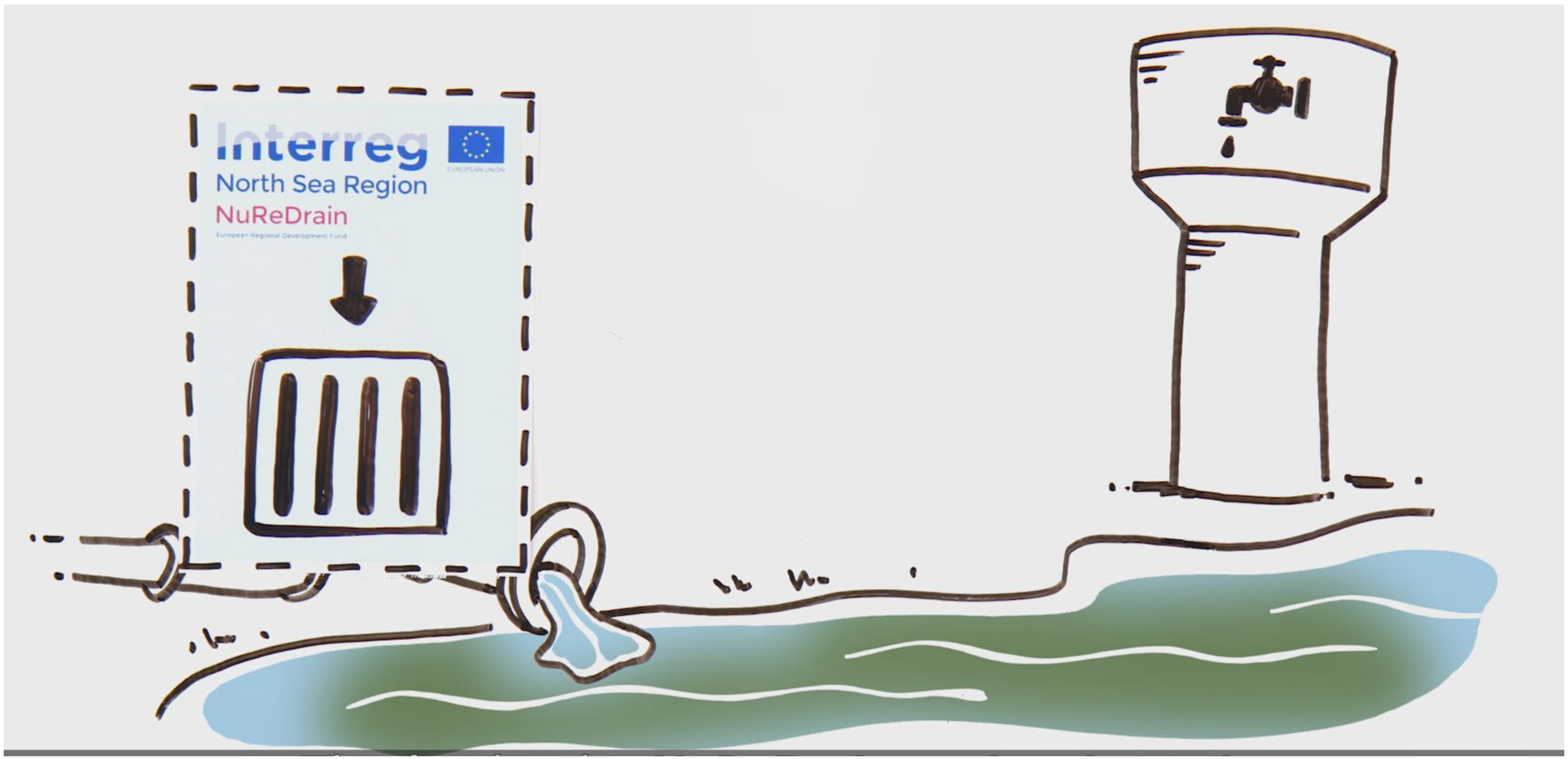
End-of-pipe filter systems



2 water types

1. Drainage water

Bigger volumes

Low N and P concentrations

Rain dependent

Periodic

2. Greenhouse effluent

Smaller volumes

High N and P concentrations

Controllable

Continuous or periodic

Field cases

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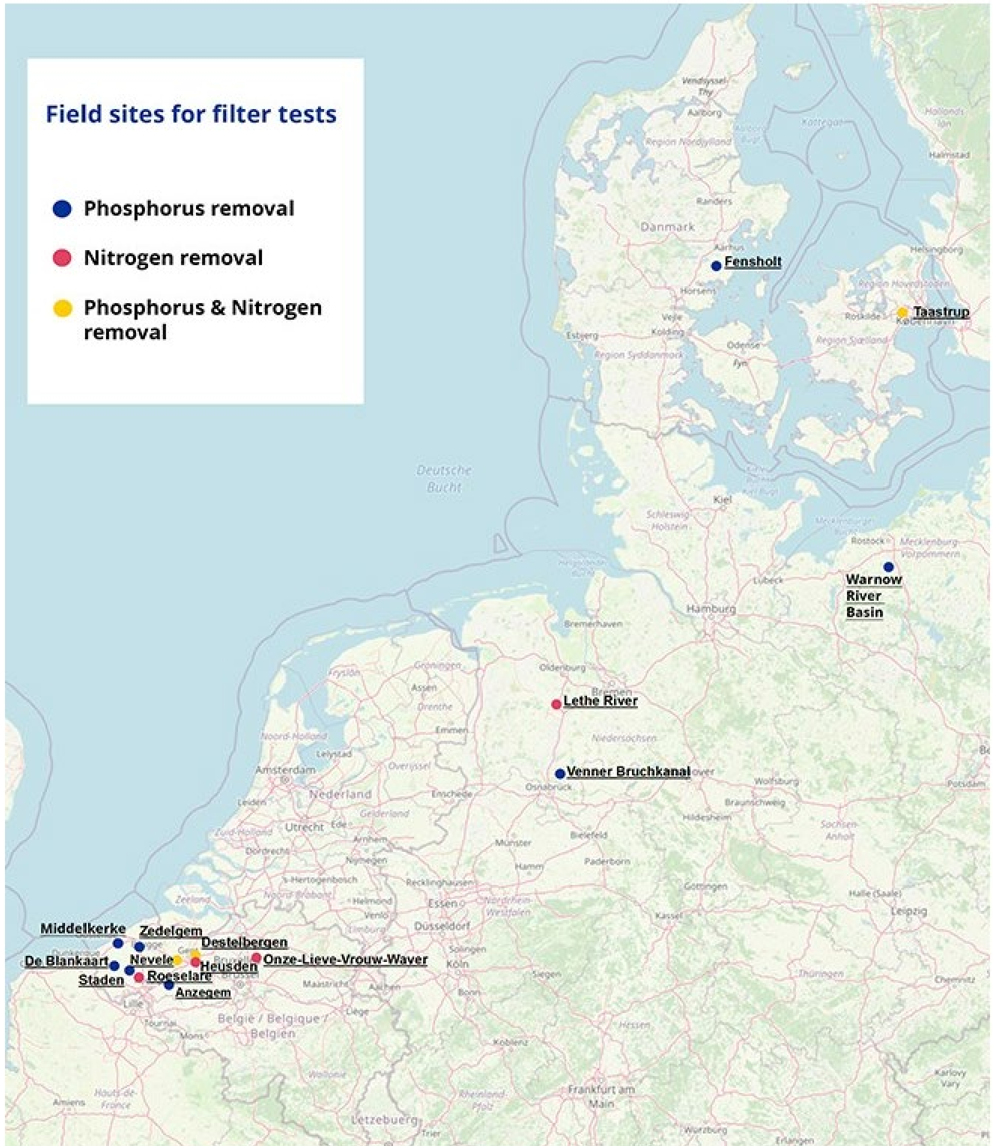

Programme

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1. **Long term evaluation and upscaling of iron coated sand filters for P removal from agricultural drainage water**
   Junwei Hu (Ghent University)

2. **Can filter materials be regenerated and reused?**
   Jef Bergmans (VITO)

3. **Combining filter systems for N and P removal from greenhouse wastewater**
   Els Pauwels (PCS Ornamental Plant Research)

4. **Cost effectiveness of nutrient removal filters at a catchment scale**
   Andreas Bauwe (Rostock University)

5. **Nutrient filter systems in practice: construction manuals, fact sheets and cost assessment**
   Charlotte Boeckaert (VLAKWA/VITO)

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Long term evaluation and upscaling of iron coated sand filters for P removal from agricultural drainage water

Junwei Hu, Hui Xu, Stany Vandermoere, Stefaan De Neve
Department of Environment
Ghent University

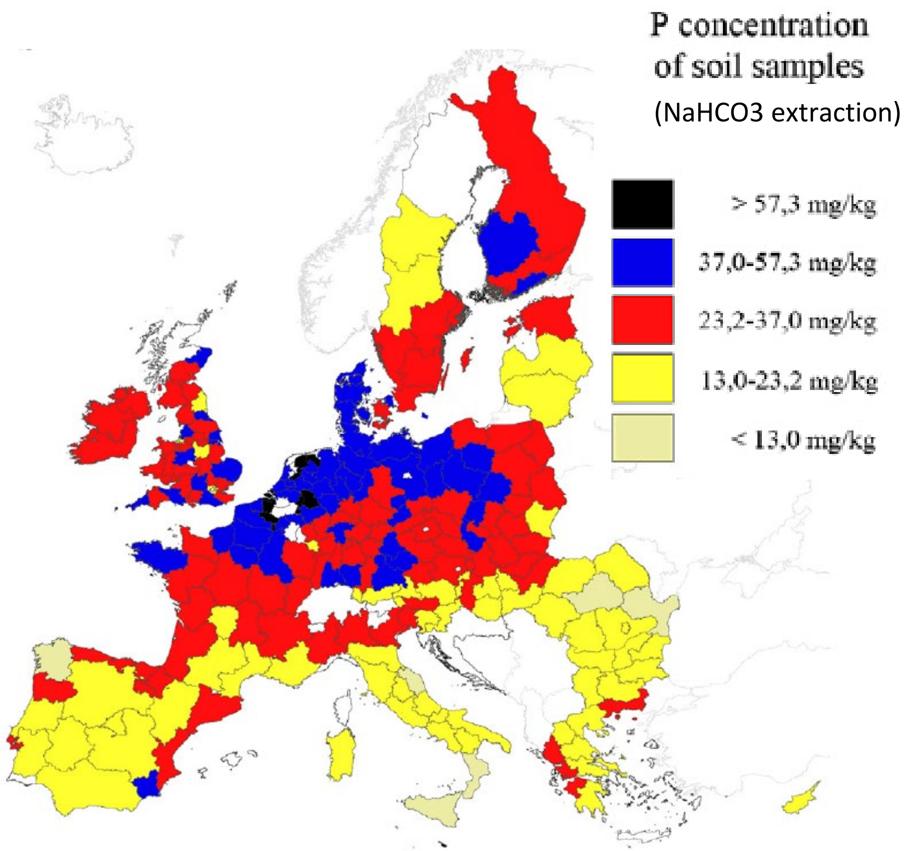
GHENT UNIVERSITY

FACULTY OF BIOSCIENCE ENGINEERING

inagro
RESEARCH & ADVICE IN AGRICULTURE & HORTICULTURE

Why is P removal important?

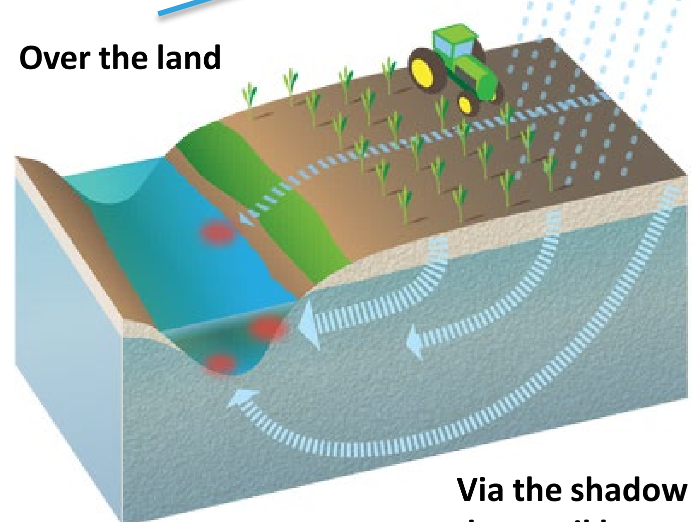
Agricultural intensification resulted in high soil P content



In Northwest Europe, agricultural P losses are a major cause of eutrophication problems in surface water

catch crops
buffer strips
reduced tillage

Over the land

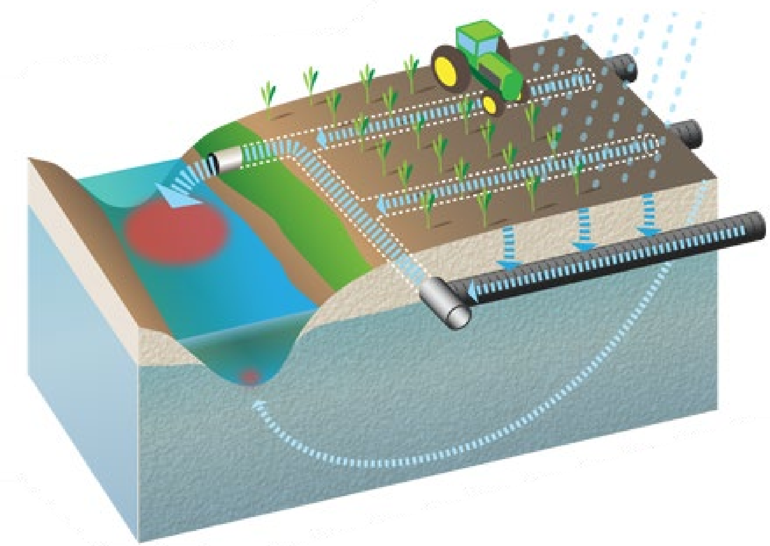


Via the shadow and deep soil layers

phytomining
reduced fertilizer
(only to be possible on the long run)

What do we need?

There are no efficient management practices to reduce P leaching on the short term.



17—40 % is drained in NW Europe
a large mitigation potential

installing P filters at the end of the drains could be potential solution

- Reduce P loads as much as possible (< 0.1 ppm, Water Framework Directive)
- Process discontinuous and peak flows
- Low cost and easy to be installed

Phosphorus Filter Development

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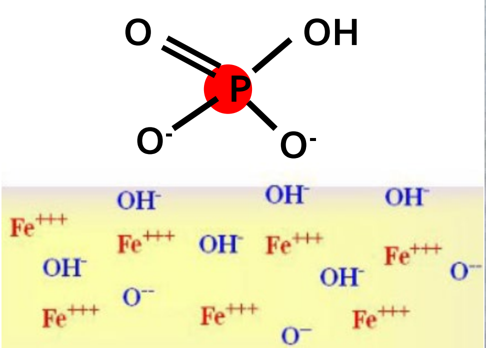
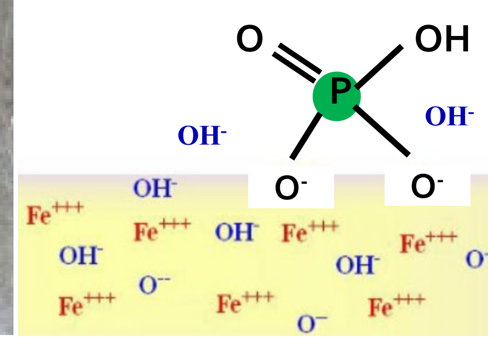
Phosphorus Sorbing Materials: Iron coated sand (ICS)

Lab scale
P sorption capacity and speed:
ICS > bauxite > glauconite > olivine = biotite.

- Saturated hydraulic conductivity (K_{sat}) ≥ 0.00045 m/s
- Sufficient P removal (≥74%)





By-product from drinking-water industry

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.

Simple bucket filter and prototype

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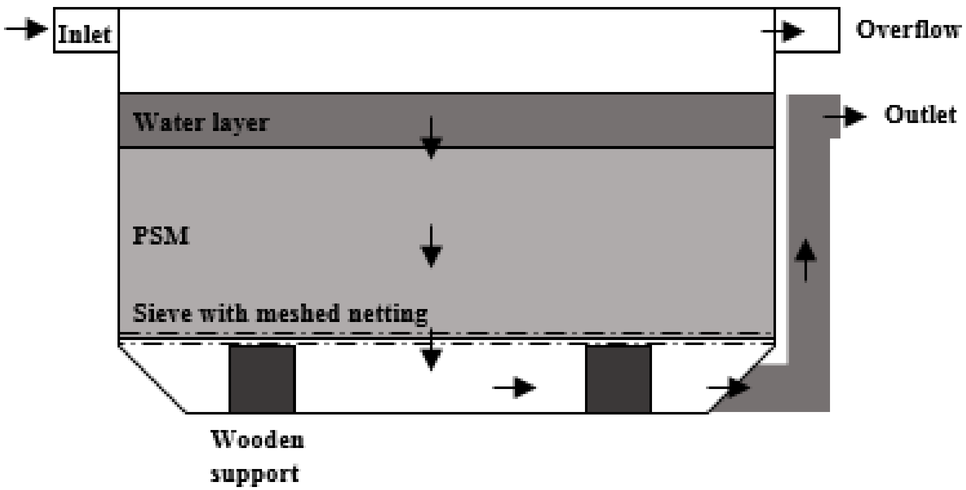
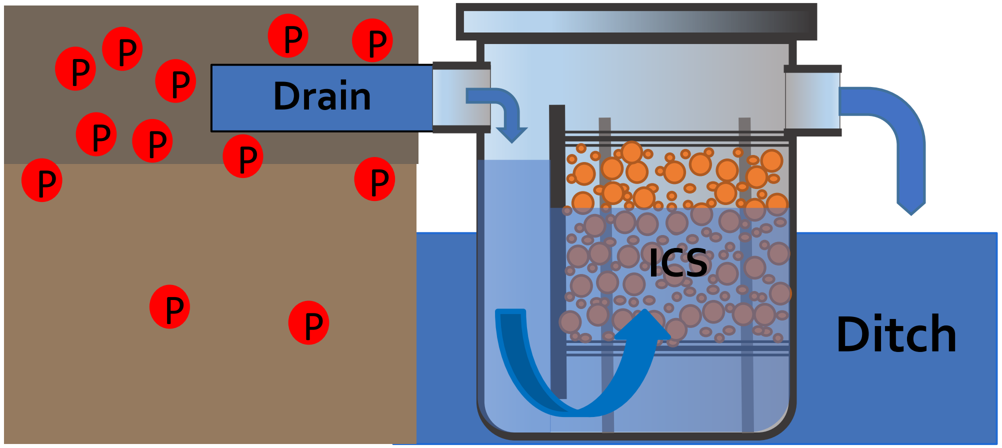
Simple bucket filter



Prototype



Filter performance

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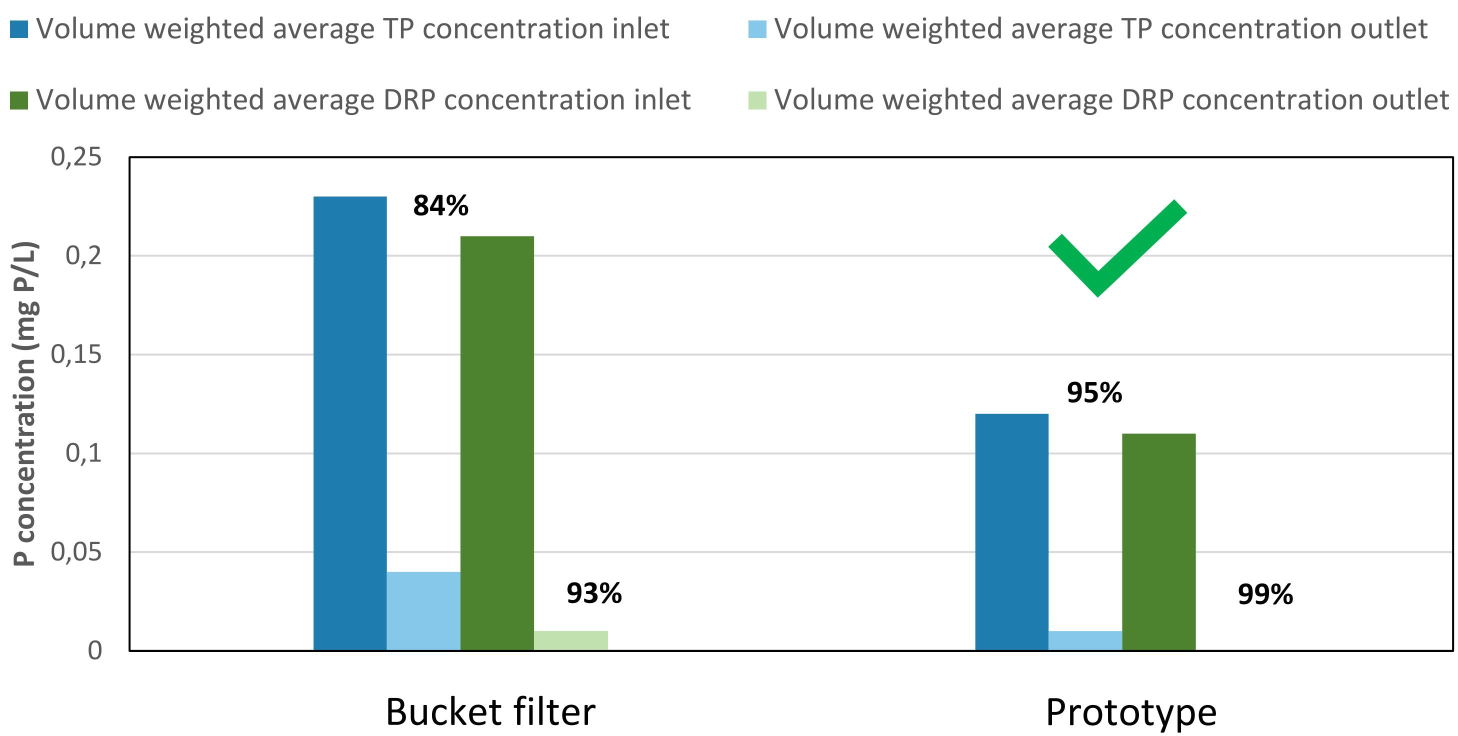
P removal efficiency



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

TP: total phosphorus
DRP: dissolved reactive phosphorus

Cost estimate

	Price [€]	Life span [years]
Filter bucket	600	15
ICS materials	50	2
Labor for installation	50 (self-installation) /100 (external-installation)	2
Total [€/year]	**90-115**	

Evaluation of the filter

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

+ Only applicable for individual drain
+ Mostly remove dissolved reactive P

Recent Progress

Long term performance of filter box for single drain

Dig-in filter box for single drain

Upscaled filter box for larger volume of water

Long term performance

- 4 existing P filter boxes

Anzegem, 2018-11-29

Zedelgem, 2018-11-30

Zedelgem 1mm (2), 2020-1-10

Zedelgem 2mm (3), 2020-1-10

Long term performance

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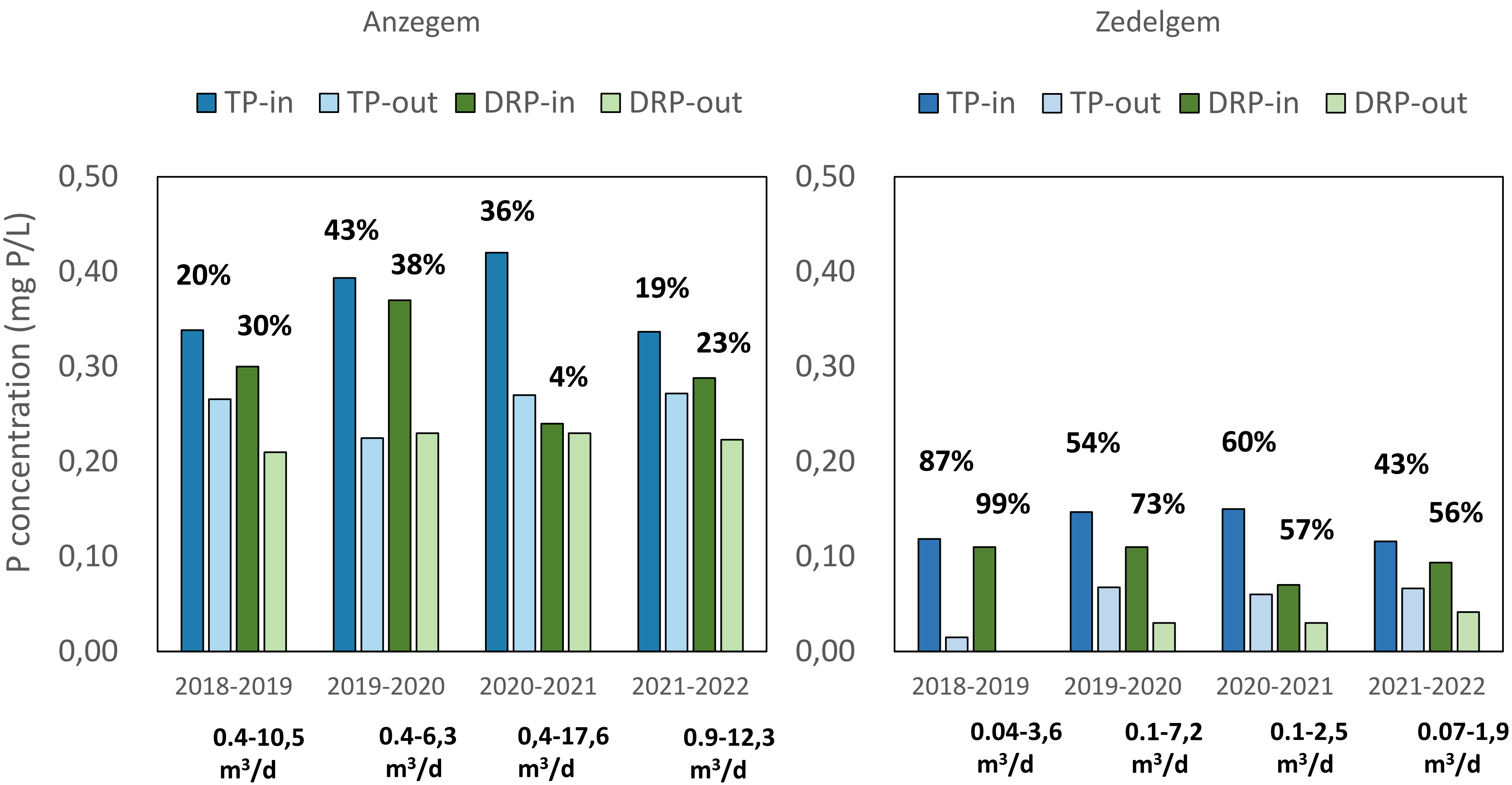
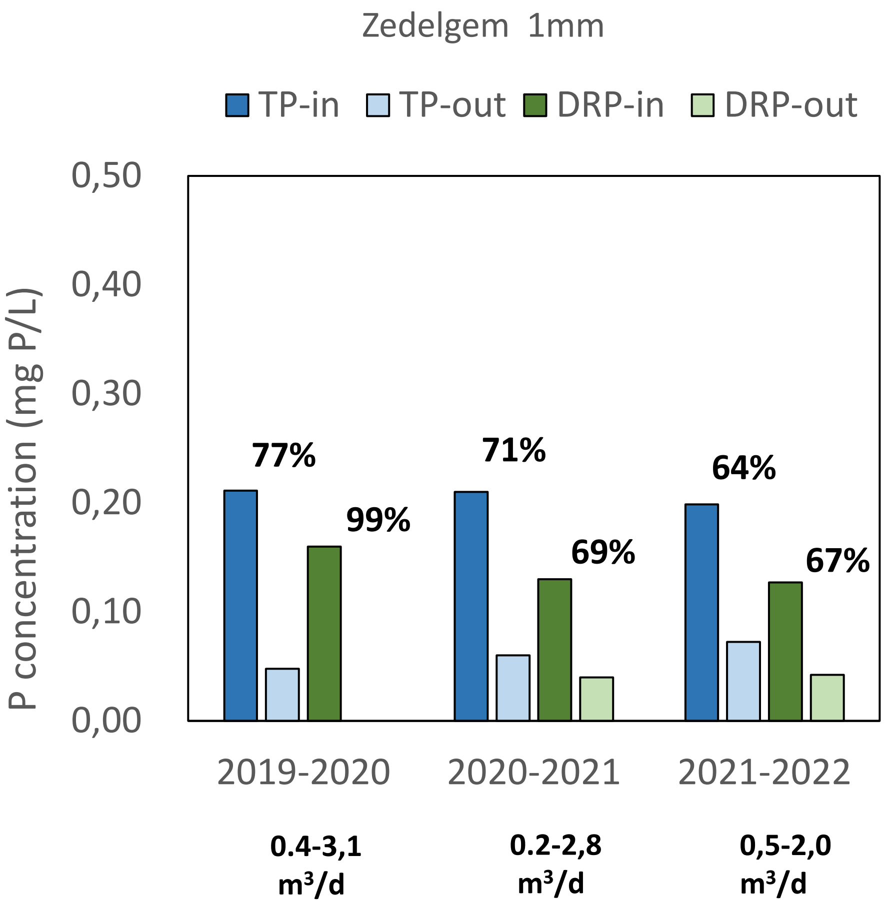
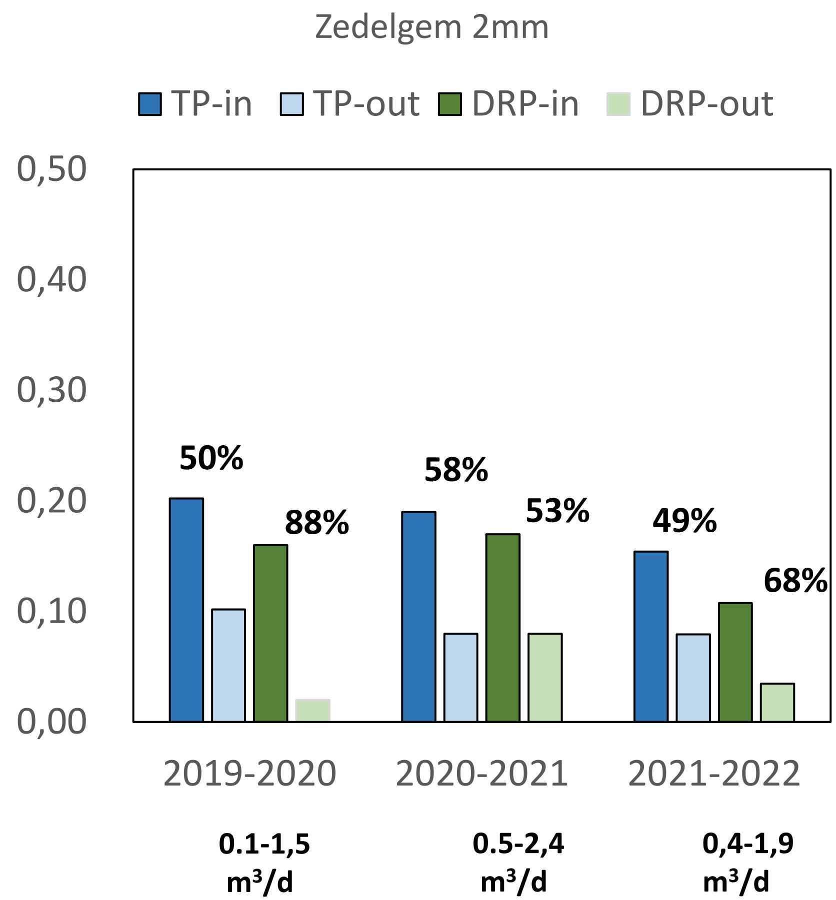
P removal efficiency



Long term performance

P removal efficiency





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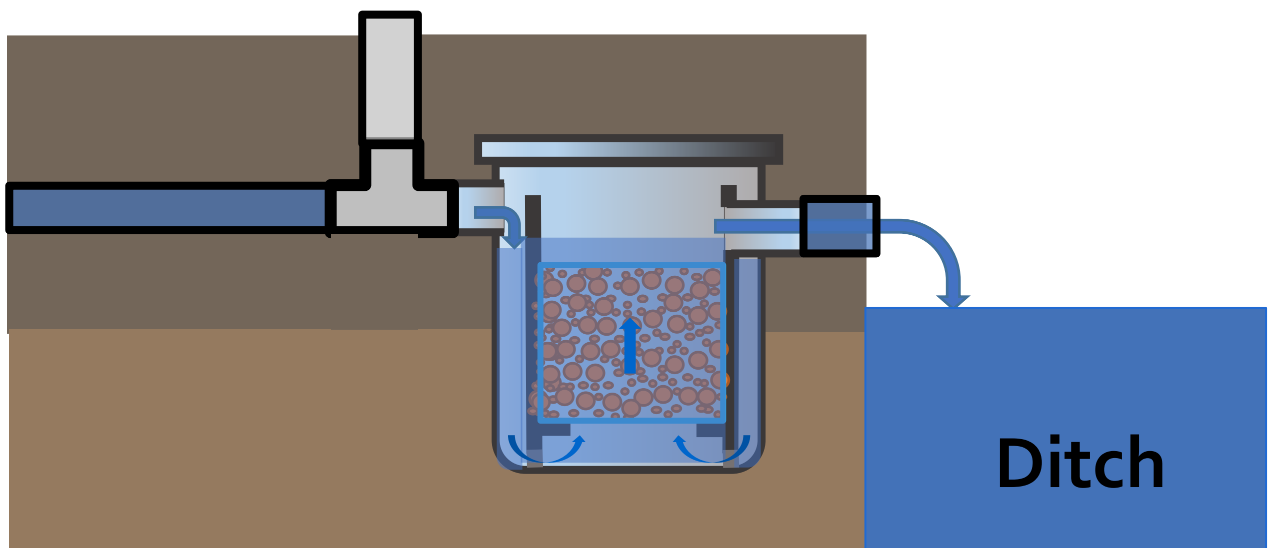
Dig-in filterbox

The P filterbox is currently placed in the ditch but ideally the ditch is not to be obstructed.



Dig-in filter box

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Staden dig-in (1)



Staden dig-in (2)



The installation was proven to be feasible

Dig-in filterbox

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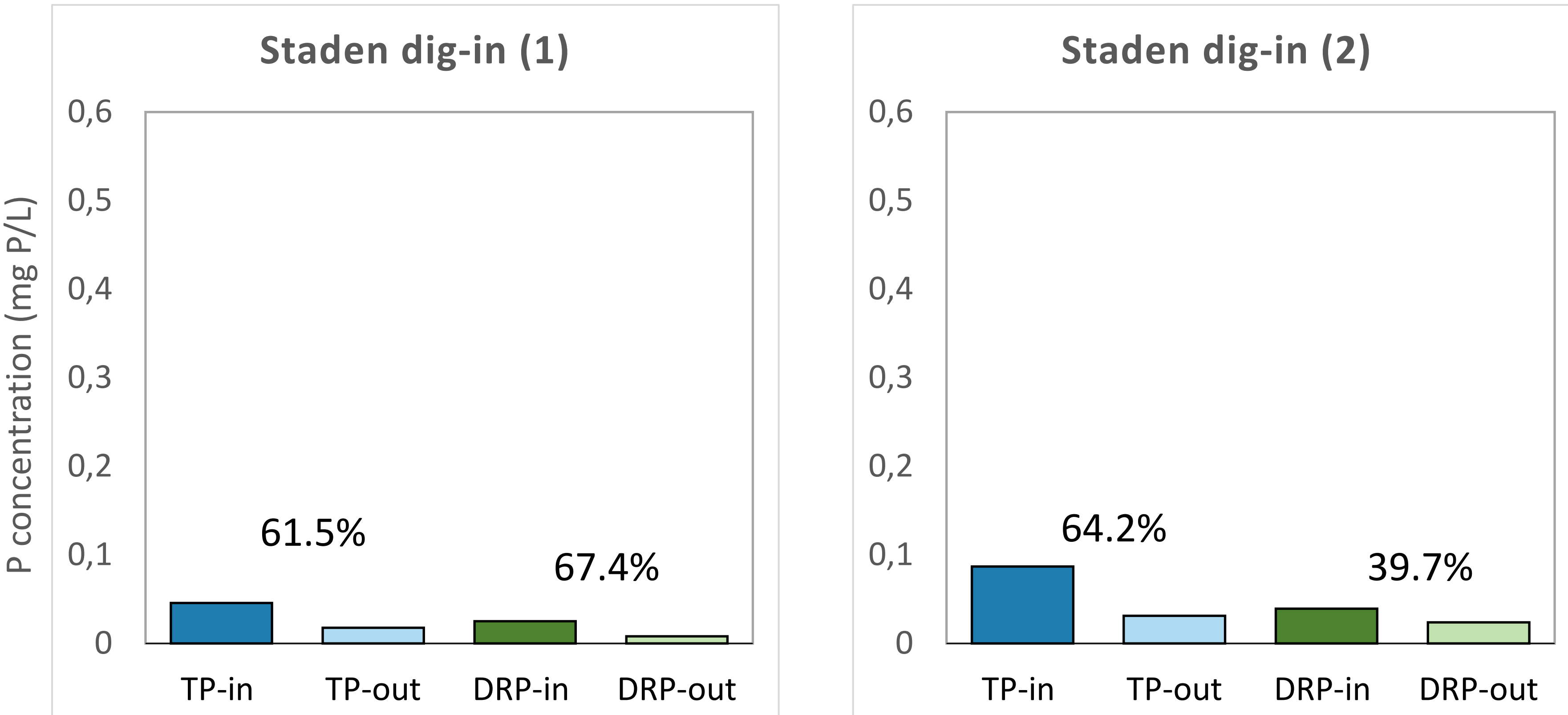
P removal efficiency



Flow: 1.4-4.2 m3/d

Flow: 3.4-8.3 m3/d

Given the P concentration is low, the dig-in P filter boxes are functioning

Upscaled P filterbox

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- To treat bigger volume of drainage water

Collector drain

Open pond

Upscaled P filterbox

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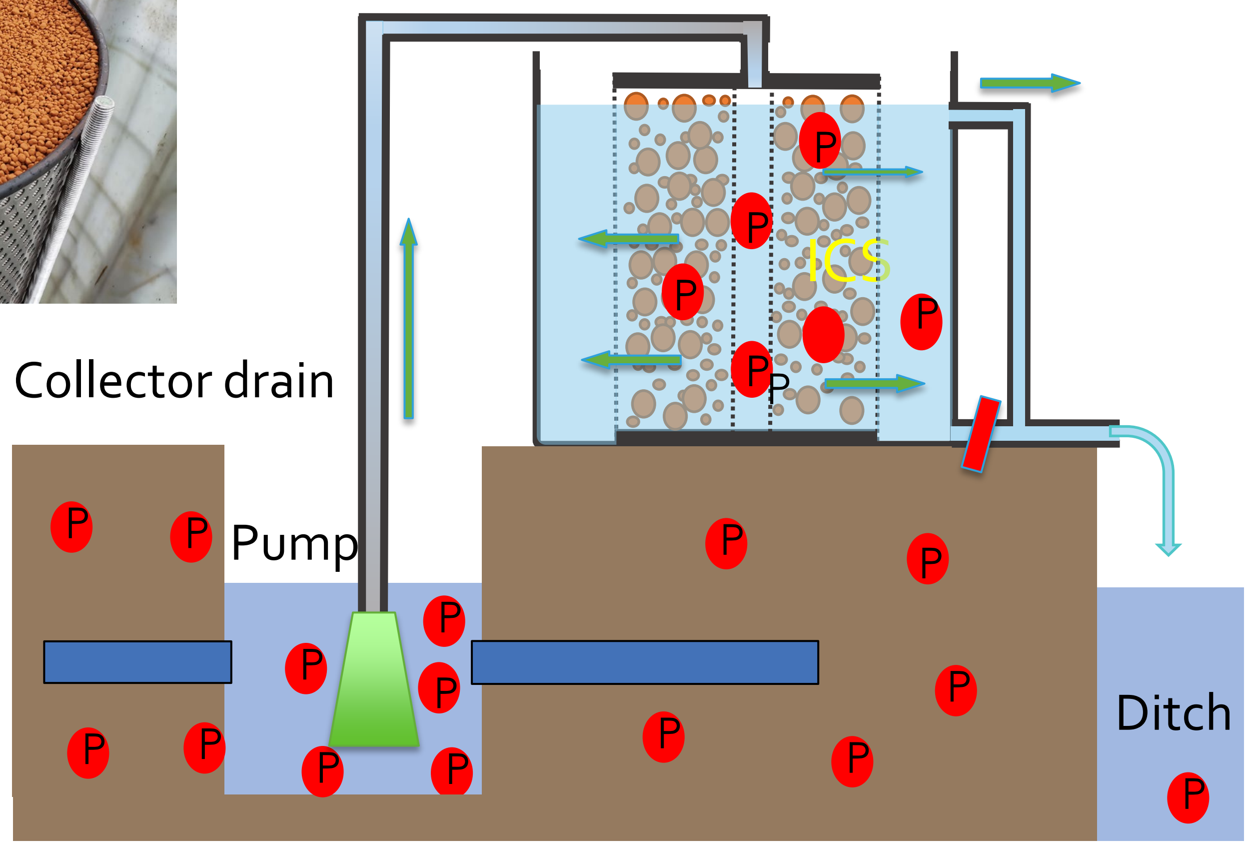
- Capable of treating bigger volume of drainage water
- 140 L iron coated sand



Upscaled P filterbox

Godelieve fields of Inagro

Middelkerke (Belgian coast)

Upscaled P filterbox

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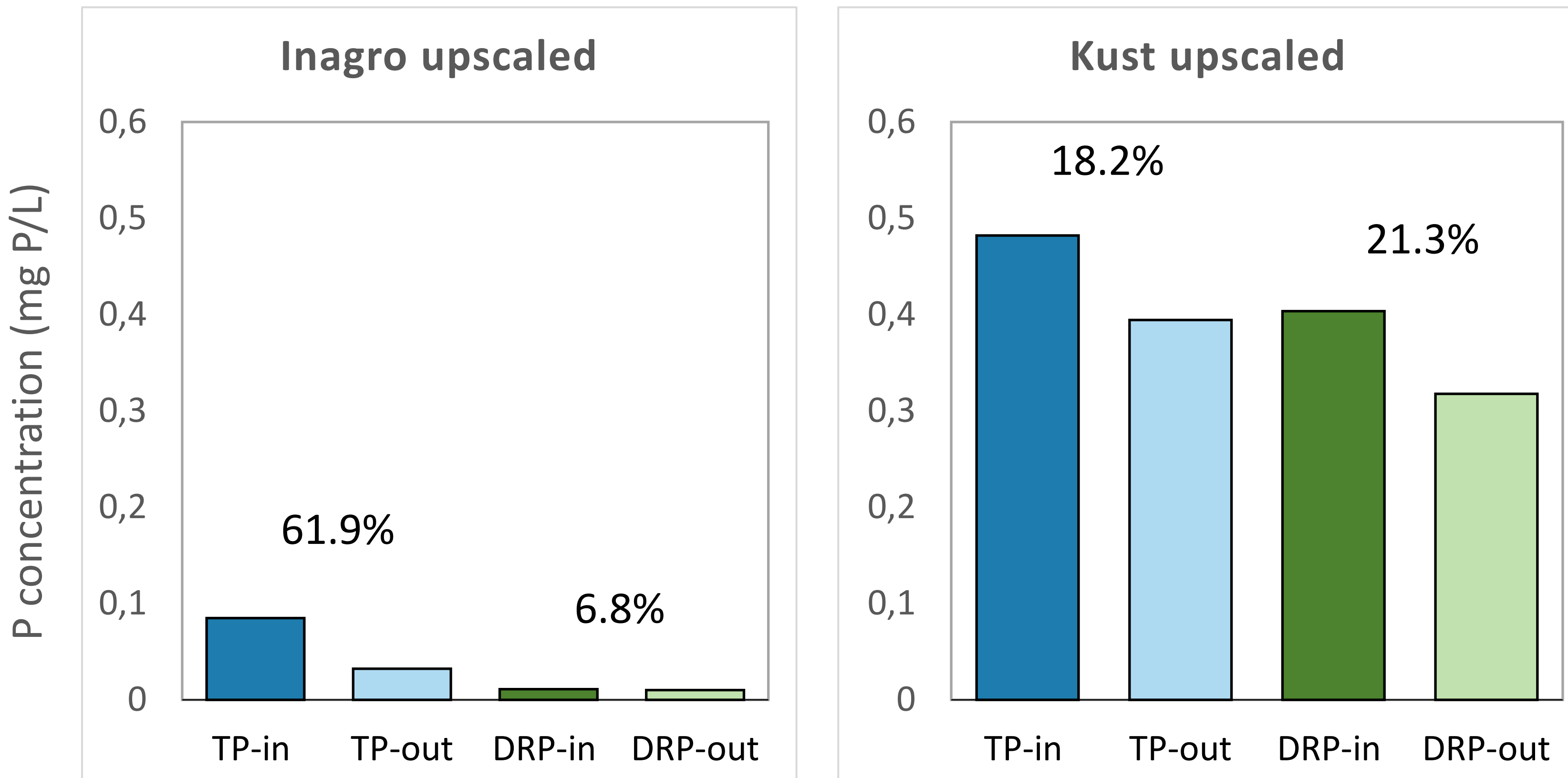
P removal efficiency



Flow: 7.2-16.9 m3/d

Flow: 17.0-36.2 m3/d

The next

- Effectiveness vs flow
- Clogging of water from open pond
- Electricity supply

Thanks!

Q & A

Programme

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Desorption of ICS grains

Jef Bergmans – VITO

Goal

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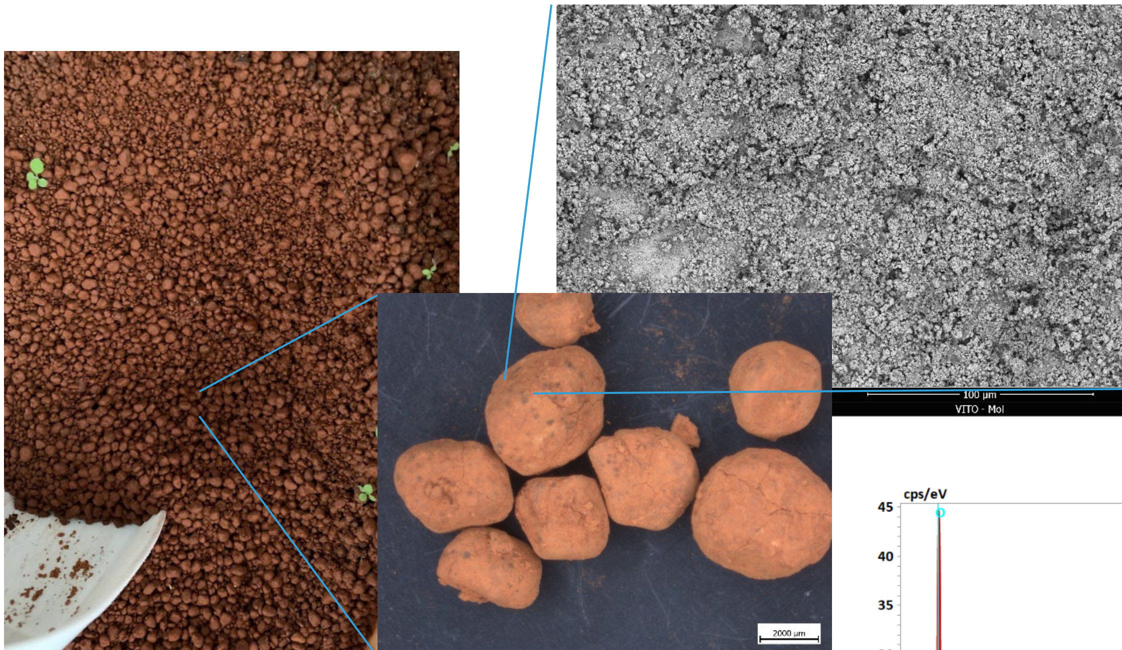
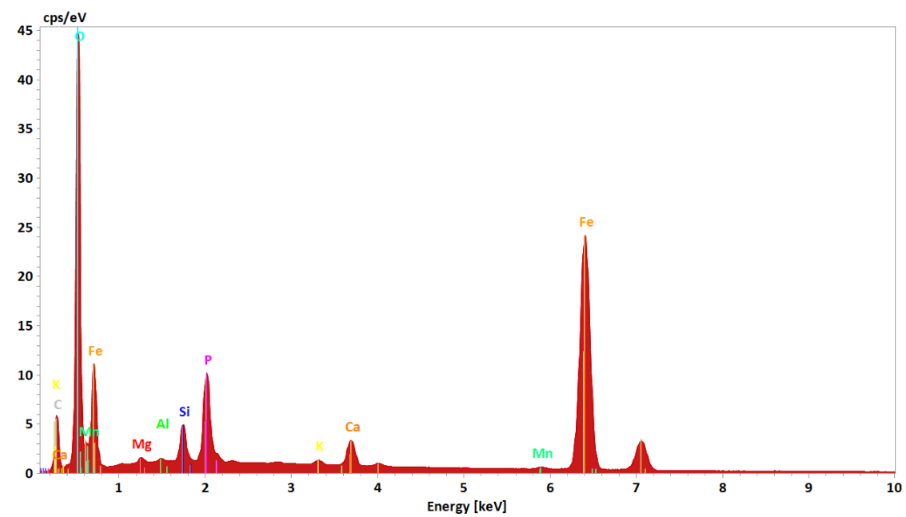
The opportunity to regenerate filter material enables that high-cost materials can be reused several times decreasing the total cost of operation.

- protocol for the regeneration P saturated filter material
- scale-up of the process

Characterisation of saturated ICS grains



Mostly Fe, Si and P
Also C, Mg and Ca found



Literature

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Different strategies are available in literature

- Acidic route → focus on P recovery
- Alkaline route → focus on **filter material recovery**

The alkaline route regenerates the hydroxyl groups

$$\text{Fe-OH} + \text{H}_2(\text{PO}_4)^- \rightarrow \text{Fe-O-H}_2(\text{PO}_3) + \text{OH}^-$$

A significant amount of OH- ions are needed to reverse the equilibrium and the excess OH^- ions are slowly release afterwards changing the pH of the eluate

Several studies available in literature providing valuable information, However:

- Static small scale desorption experiments
- Test performed on artificially loaded sorbents

Optimisation of regeneration protocol

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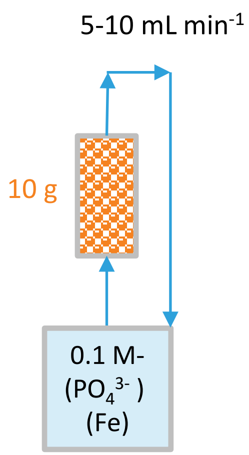

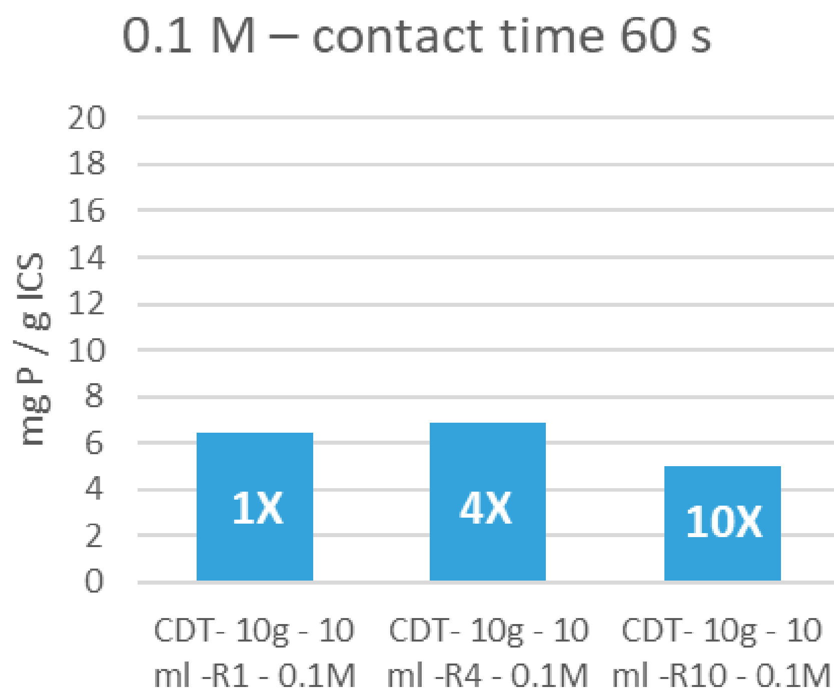

Re-use of the stripping solution also gives similar results for lower base concentration
Improved P desorption by changing contact time needs further investigation

Scale-up

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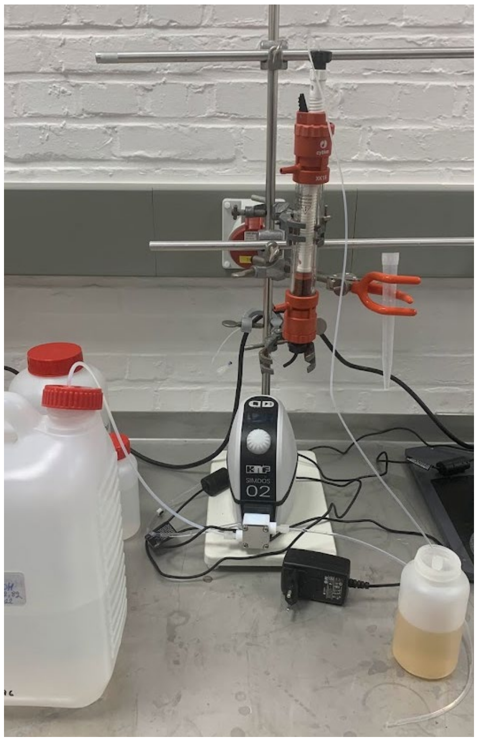
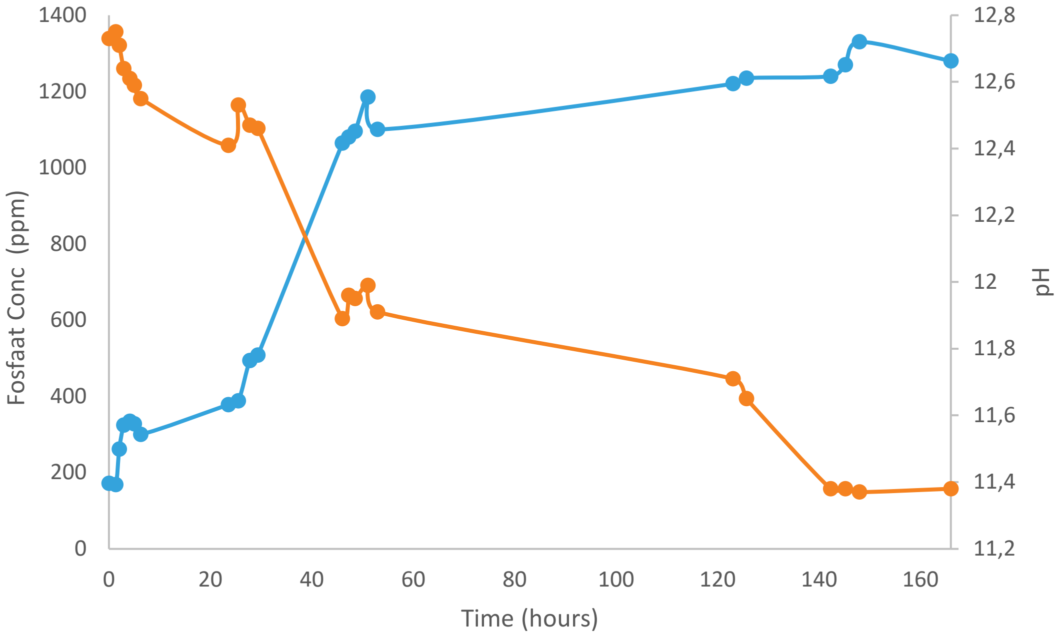


Optimisation at small scale
(10 g)

Larger scale
(1000 g)

Scale-up

Recirculation with 0.1 M NaOH
Liquid/Solid (L/S) ratio = 10
Flow 60 ml/min



5.2 mg P desorbed per g ICS
Equilibrium after 18 recirculations
< 1 ppm Fe in the solution

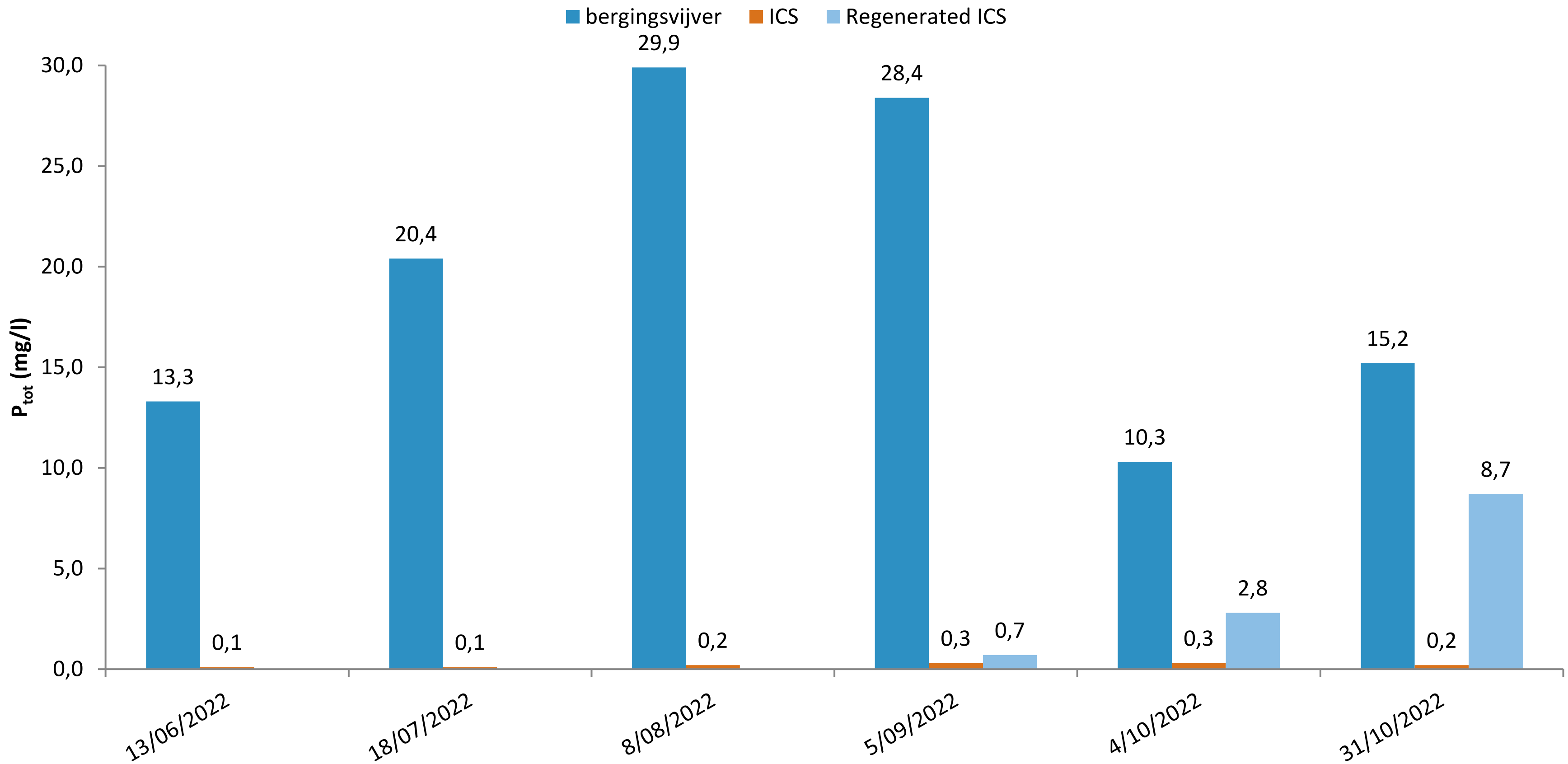
Scale-up

Larger scale
(12 kg)

- Keeping pH at pH 12.5
- 25 liter for 12 kg

- Desorption of ±6.0 g P /kg sorbent
- Desorbed sorbents sent to PCS after washing step (water) and pH decrease

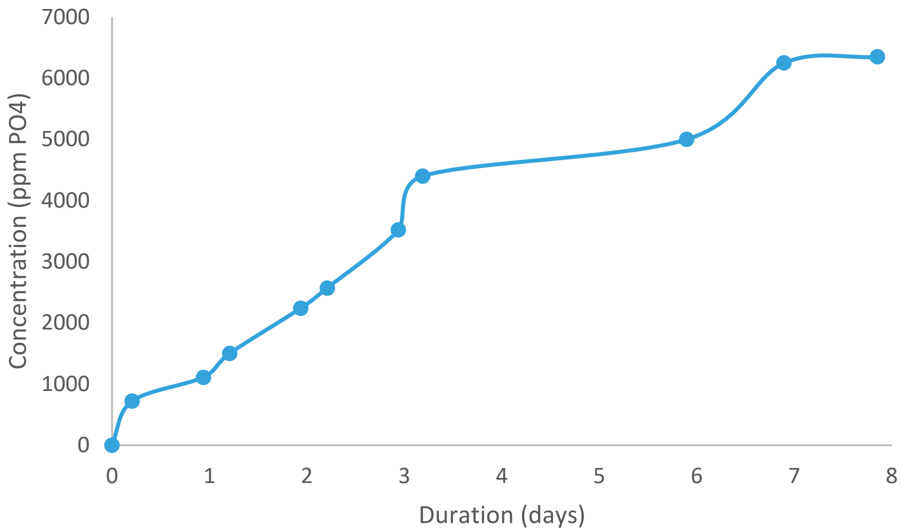
NuReDrain: results 2022



Sorption at pH = 12.5

- **L/S = 5**
- **Desorption of 10.7 g P /kg sorbent**

- **Higher pH: damaging ICS grain integrity**



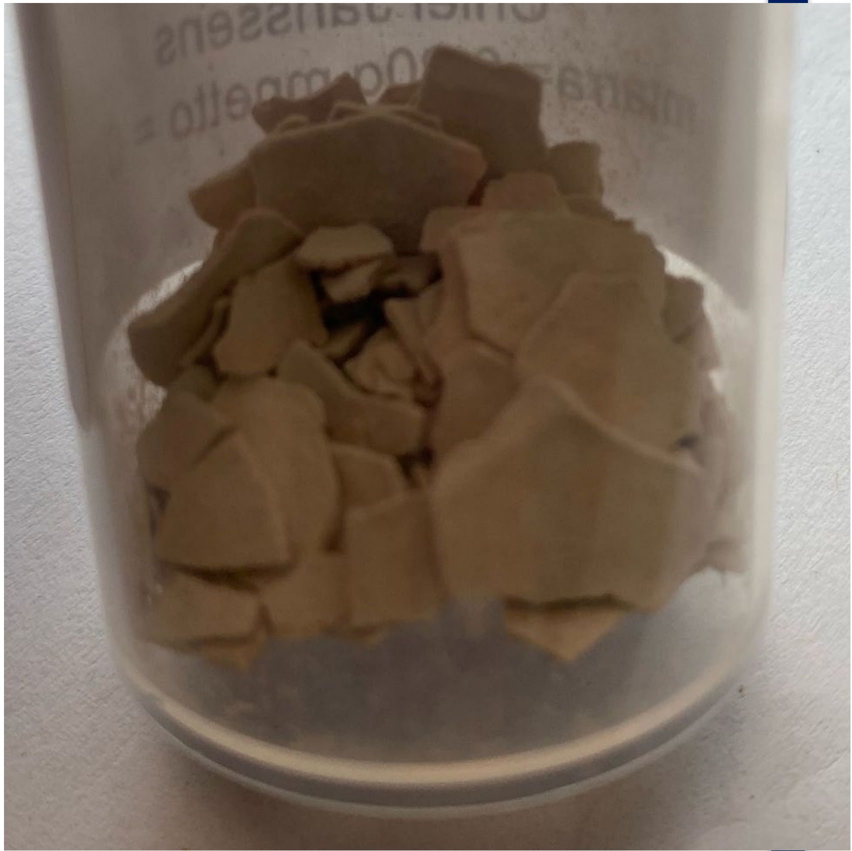
Scale-up: precipitation

Precipitation of phosphate
With 1 g $Ca(OH)_2$ per liter

⇒ Precipitation product over filtration: 0.96 g

First analysis results:

- Mainly calcium phosphate carbonates $[Ca_5(PO_4)_3(CO_3)_{0.5}]$: ±75%
- About 25% $CaCO_3/Ca(OH)_2$
- Trace levels of Fe, Si, Zn



Is precipitation necessary?

- High pH solution: ±12.5 or lower (mixing with washing and/or acidic solution)
  - Phosphate: 25 g/l
  - Calcium: 0.7 g/l
  - Iron: 0.3 mg/l
  - Trace levels of Si, Zn

  - Sodium?
  - Desorption is also possible with KOH

Summary and perspectives

- Desorption of P is possible for the saturated ICS
  - Type of base has neglible influence (KOH vs NaOH)
  - Recirculation of solution is possible
  - Automated addition of extra alkaline solution

- Higher alkalinity gives better P removal but
  - A balance will have to be found between ICS integrity and P recovered capacity

Q & A

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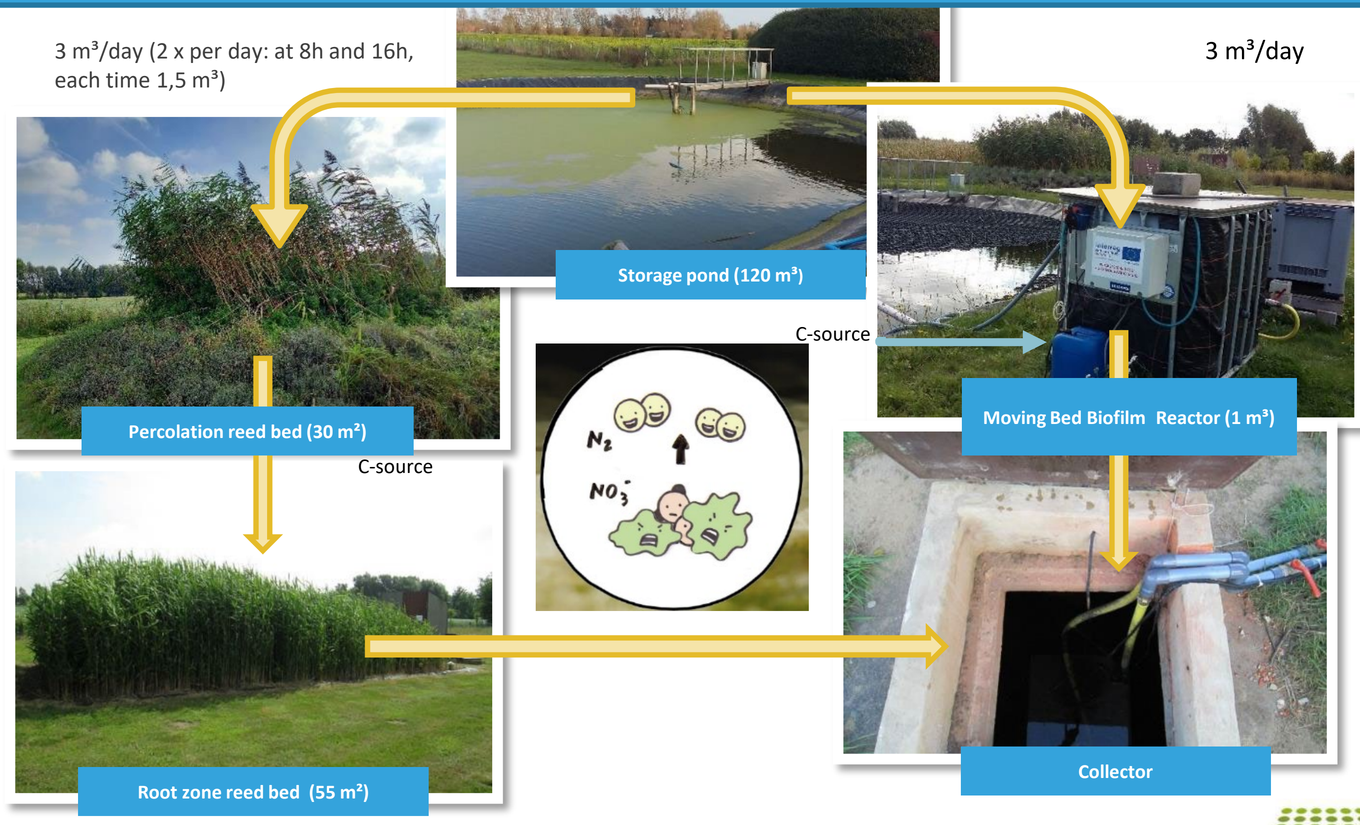
NuReDrain 2.0 Webinar:

Combining filter systems for N and P removal from greenhouse wastewater

Els Pauwels (PCS Ornamental Plant Research)

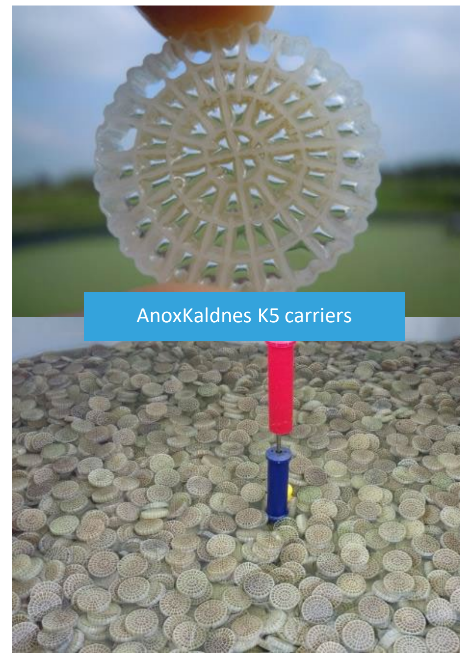
N-removal: constructed wetlands + MBBR



MBBR: Biological denitrification on bio-carriers

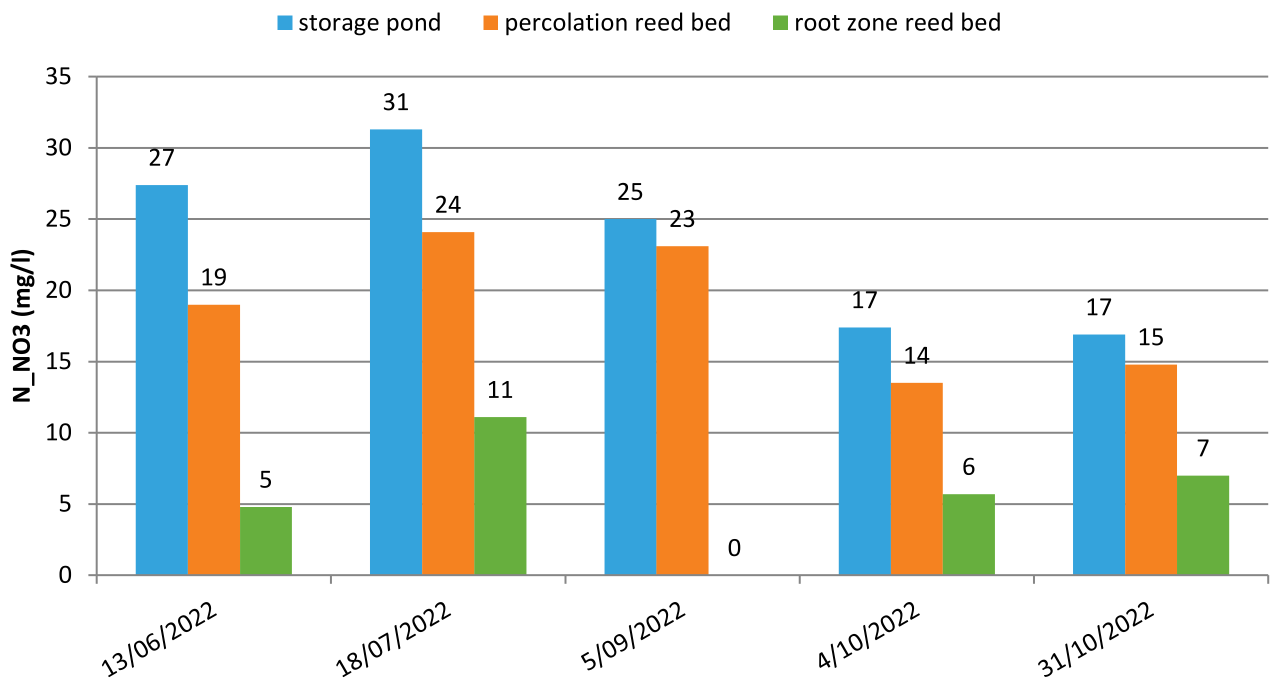
- Carbon-source
- Aeration pump

Carbon-source



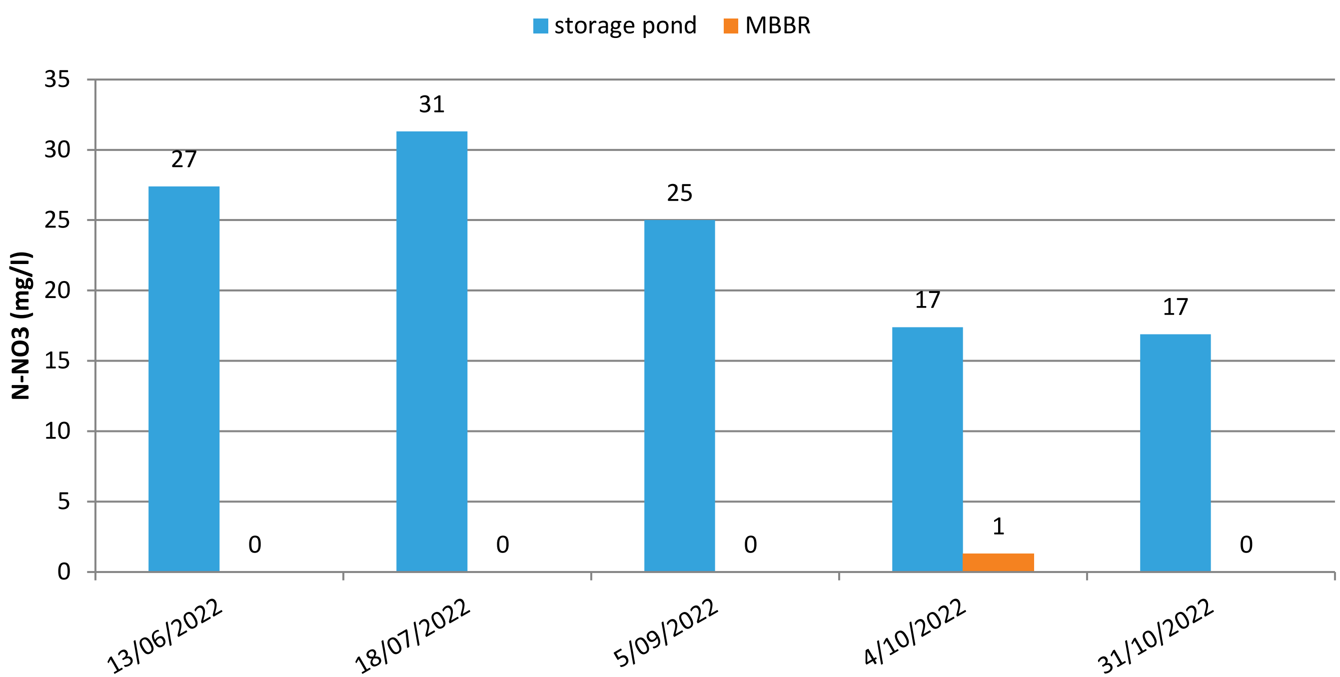
NuReDrain: results 2022

- **PCS: constructed wetlands**



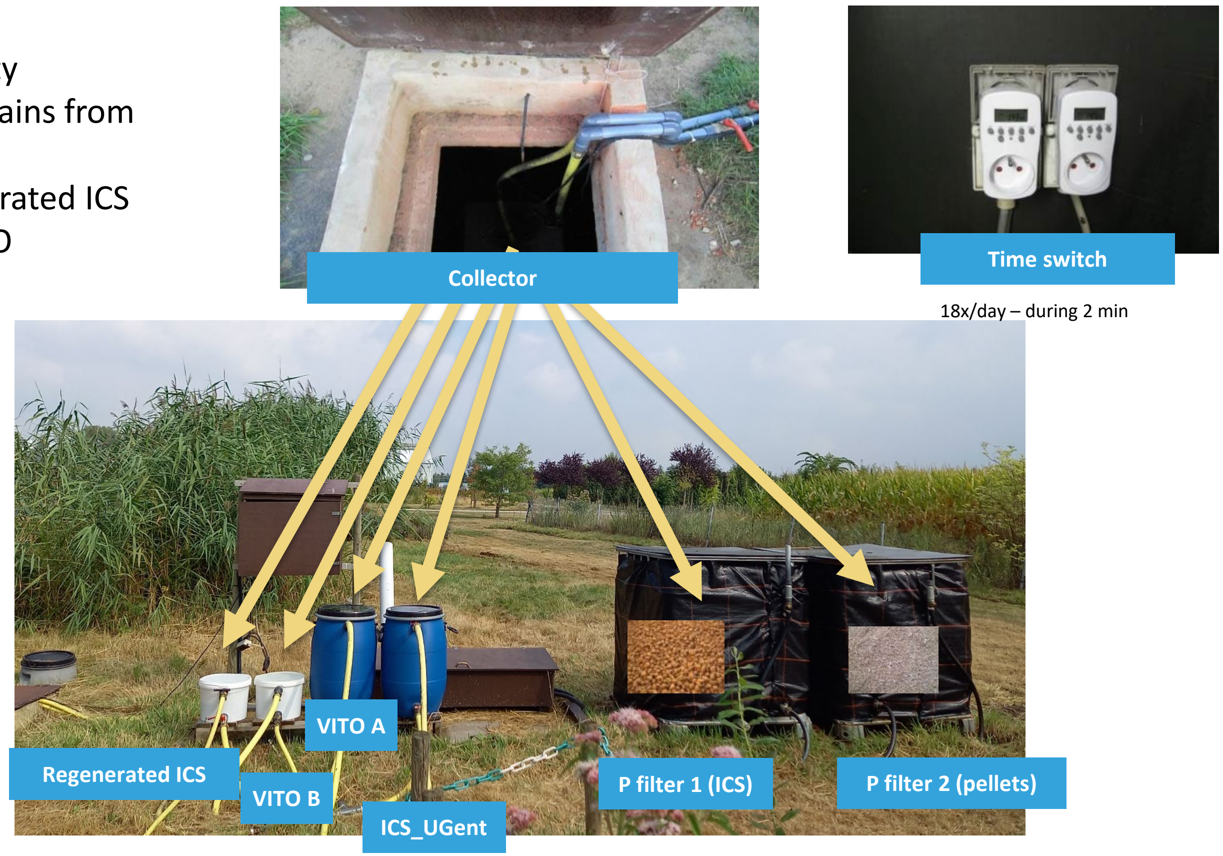
NuReDrain: results 2022

- **PCS: MBBR**



P-Removal P-filters

- Testing capacity saturated ICS grains from UGent
- Testing regenerated ICS grains from VITO



Filter-material P-filters


Iron Coated Sand korrels (ICS)


Pellets


Regenerated ICS


Regenerated ICS

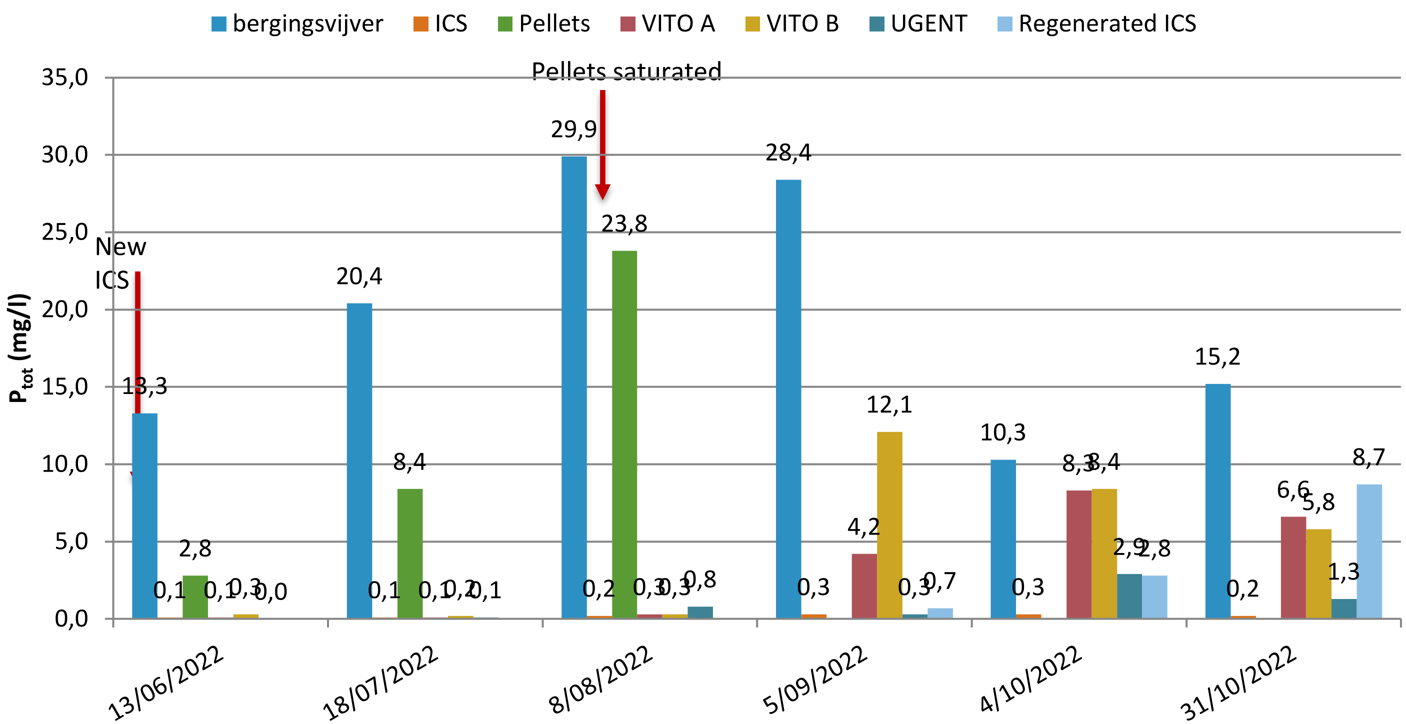

VITO A


VITO B


ICS

NuReDrain: results 2022

- **PCS: P-Filters**

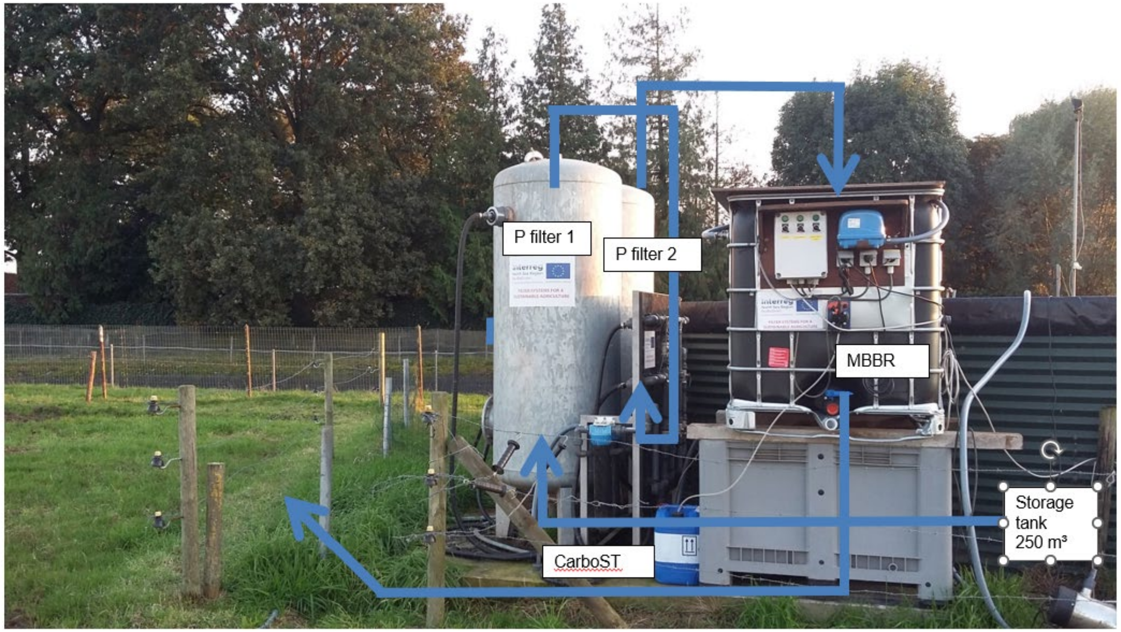


Grower potted plants (Meuninck) - P-filter + MBBR

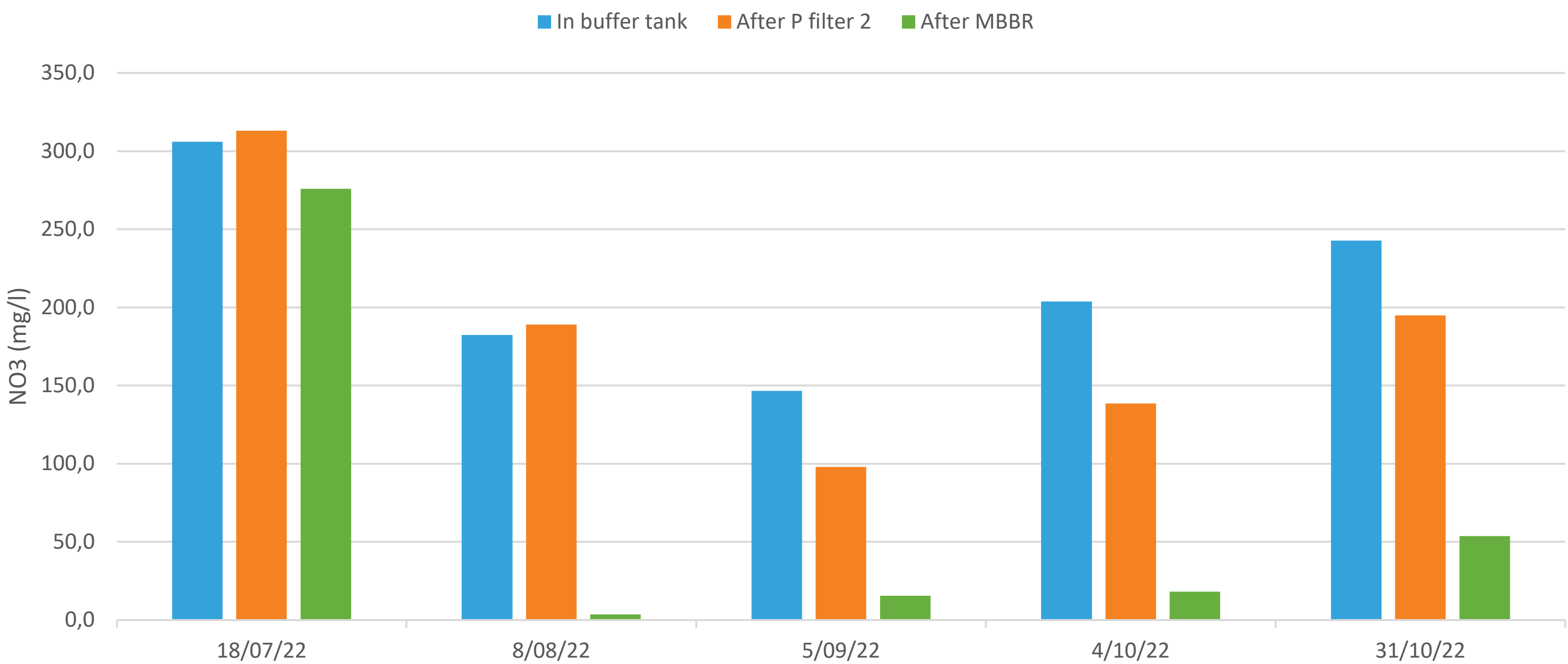
Waterflow in 2022

In 2020-2021:
MBBR + P-filter - adaptations were needed

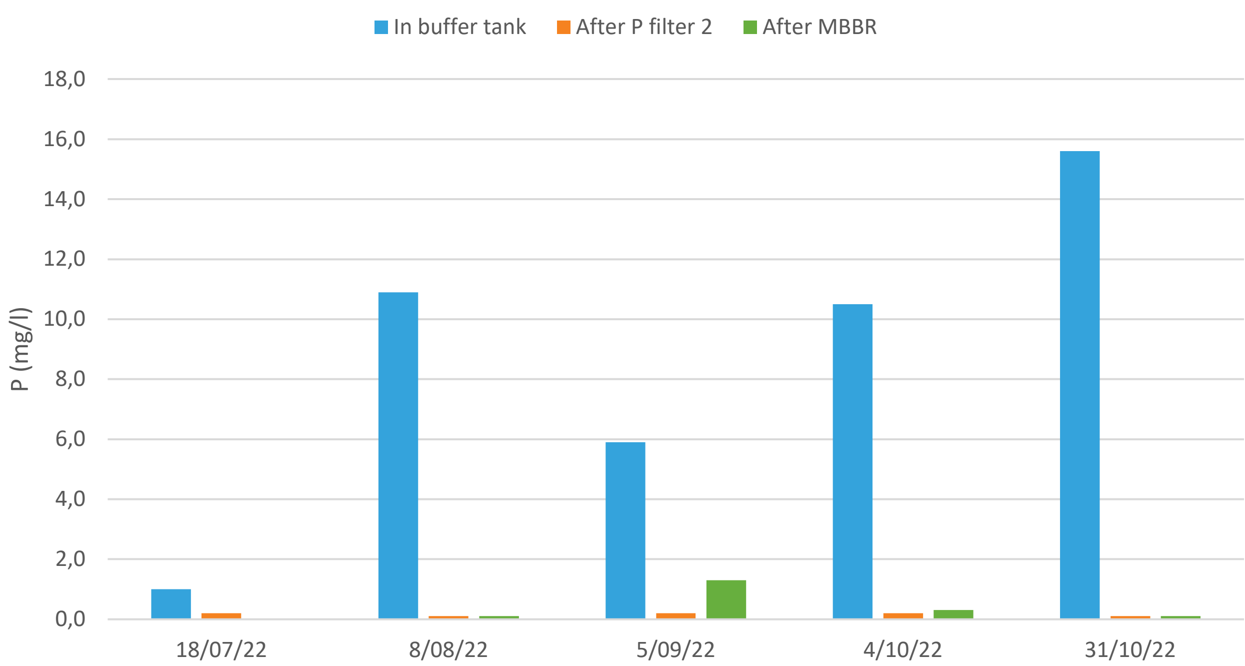
In 2022:
first P-filter and then N-filter
ICS were replaced



Results 2022 (Meuninck) - P-filter + MBBR



Results 2022 (Meuninck) - P-filter + MBBR

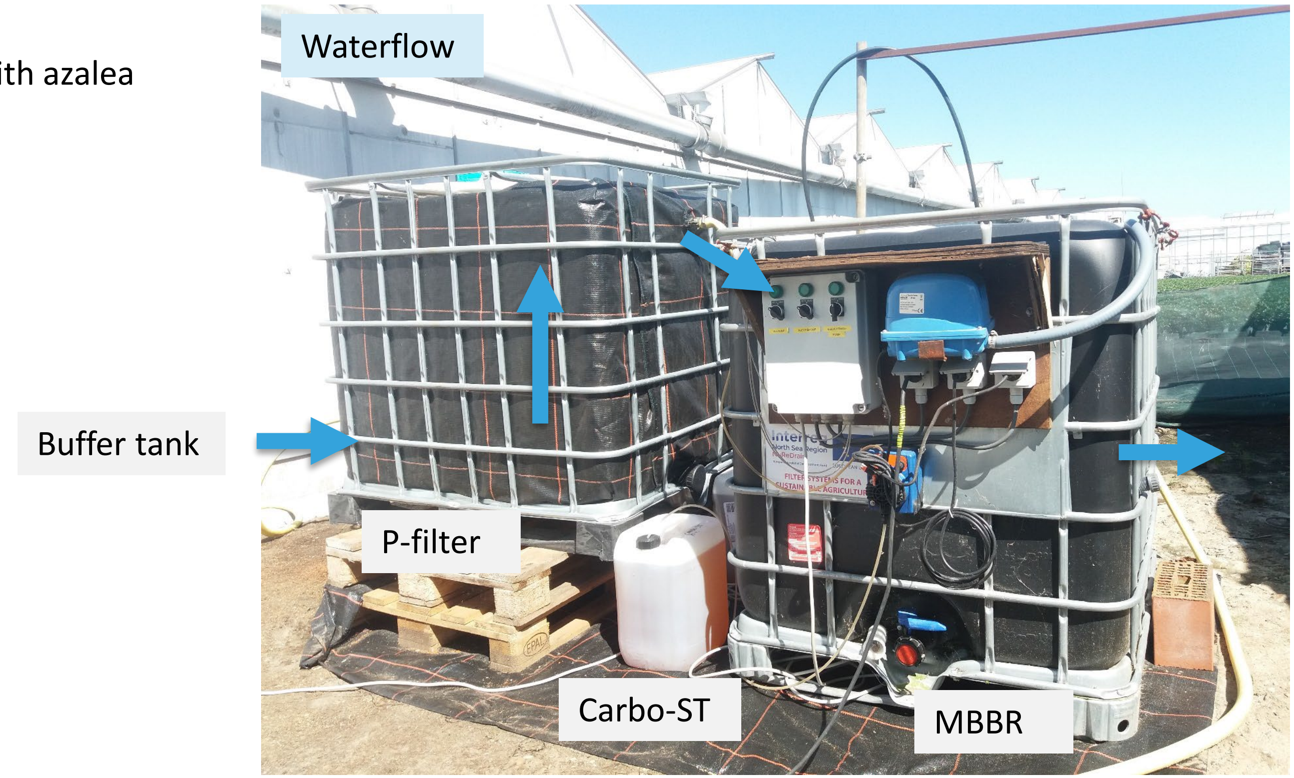


New ICS grains in both filters!!

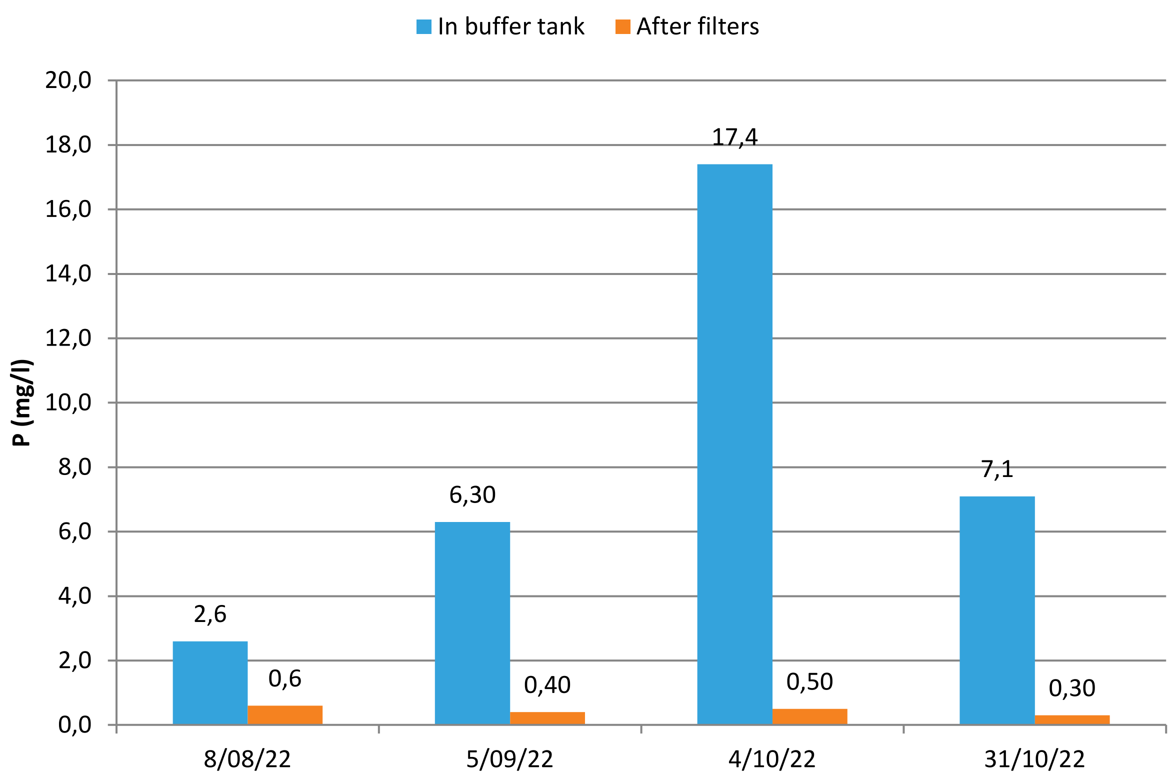
Grower azalea (VDS Plant) - P-filter + MBBR

Drainwater from greenhouse with azalea

- Buffer tank 5 m³
- P filter
- MBBR
- Daily volume: 1,5 m³



Results 2022 (VDS Plant) - P-filter + MBBR



Results 2022 (VDS Plant) - P-filter + MBBR

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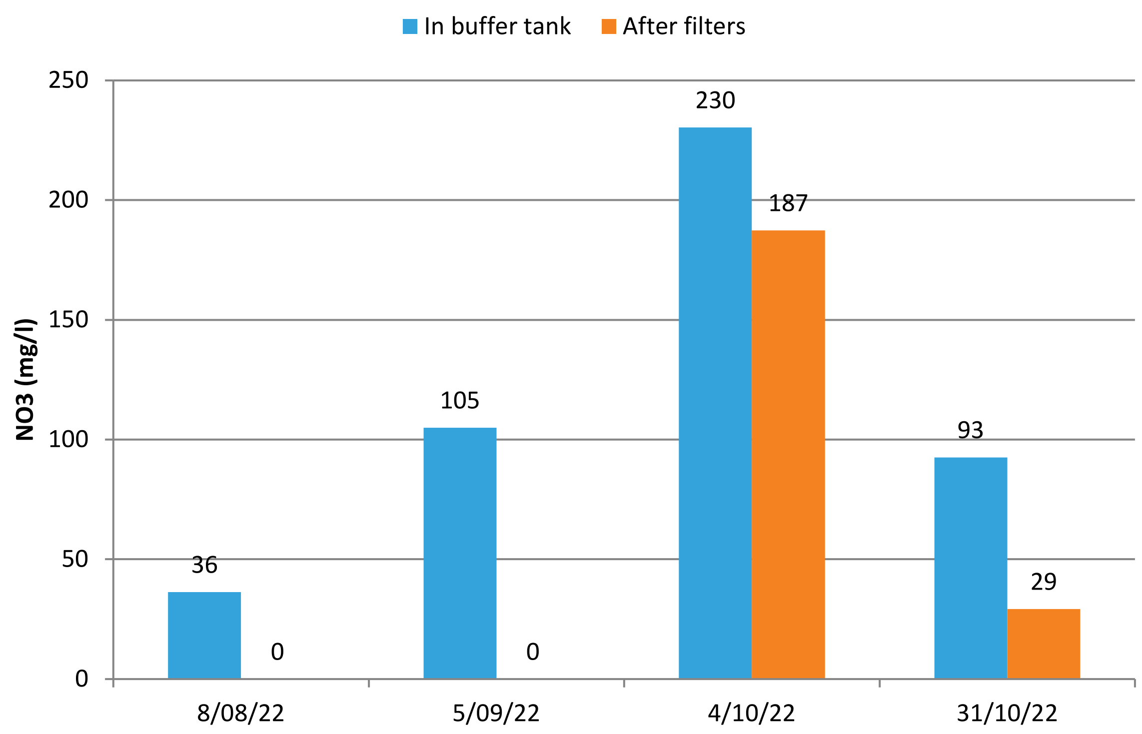

Microflor - Orchid

MBBR: Biological denitrification on bio-carriers

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.
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Manual available: Dutch and English

- ✓ Simple and compact
- ✓ Processes 3 m³/day
- ✓ Robust
- ✓ Cheap
- ✓ No recovery

- ✓ Add C-source (5-8%)
- ✓ Difficult operation in winter

Questions?

Thanks to:
Marijke Dierickx
Bruno Jacobson Da Silva

E: Els.Pauwels@pcsierteelt.be
T: +32 9 353 94 88

Q & A

Programme

1. **Long term evaluation and upscaling of iron coated sand filters for P removal from agricultural drainage water**
Junwei Hu (Ghent University)

2. **Can filter materials be regenerated and reused?**
Jef Bergmans (VITO)

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Cost effectiveness of nutrient removal filters at a catchment scale

Andreas Bauwe, Bernd Lennartz – University of Rostock

NUREDRAIN 2.0 WEBINAR
November 24 2022

Universität Rostock
Traditio et Innovatio

Filter types

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a) NuReDrain applications

Moving Bed Bioreactor (MBBR) **N**

Phosphorus filter **P**

b) other applications

Woodchip filter **N** + P

Constructed Wetland **N** + P

The main study questions were:

1. What is the **nitrate removal potential** using filters at catchment scale and
2. what are the **annual costs**?

Cost calculations

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Necessary data

- Mean annual waterflow of the drainage pipe Q (m^3/yr)
- Mean annual NO_3^--N concentration in the drainage water **C** (mg/L)
- Removal efficiency of the filter (%)
- Costs (€/ kg N reduction)

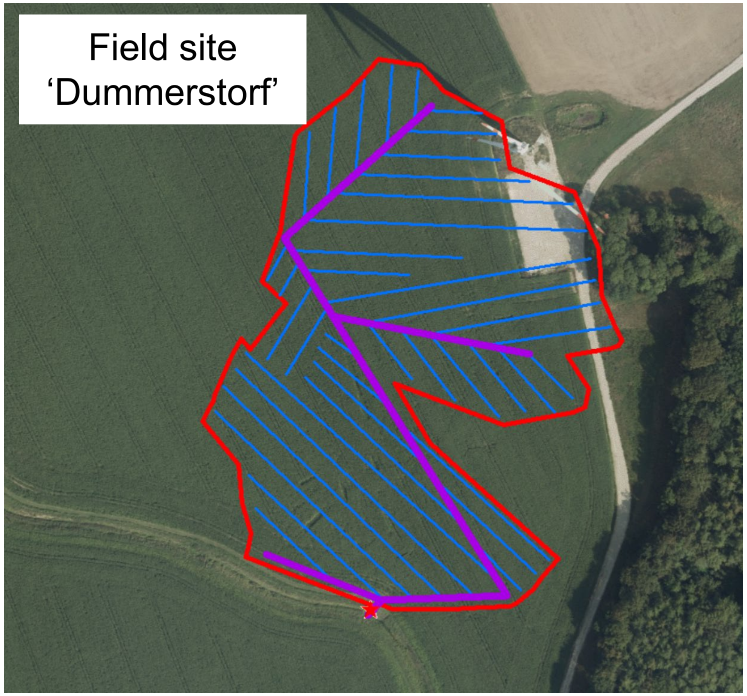
Calculations

$$F_{actual}\left(\frac{kg}{yr}\right) = Q\left(\frac{m^3}{yr}\right) * c\left(\frac{kg}{m^3}\right)$$

$$F_{filter}\left(\frac{kg}{yr}\right) = F_{actual}\left(\frac{kg}{yr}\right) * \left(1 - \frac{Removal\ efficiency\ (\%)}{100\ (\%)}\right)$$

$$Costs\left(\frac{€}{yr}\right) = \left(F_{actual}\left(\frac{kg}{yr}\right) - F_{filter}\left(\frac{kg}{yr}\right)\right) * Costs\left(\frac{€}{kg}\right)$$

Example 1: Drainage plot



Drain plot characteristics

Size: 4.2 ha

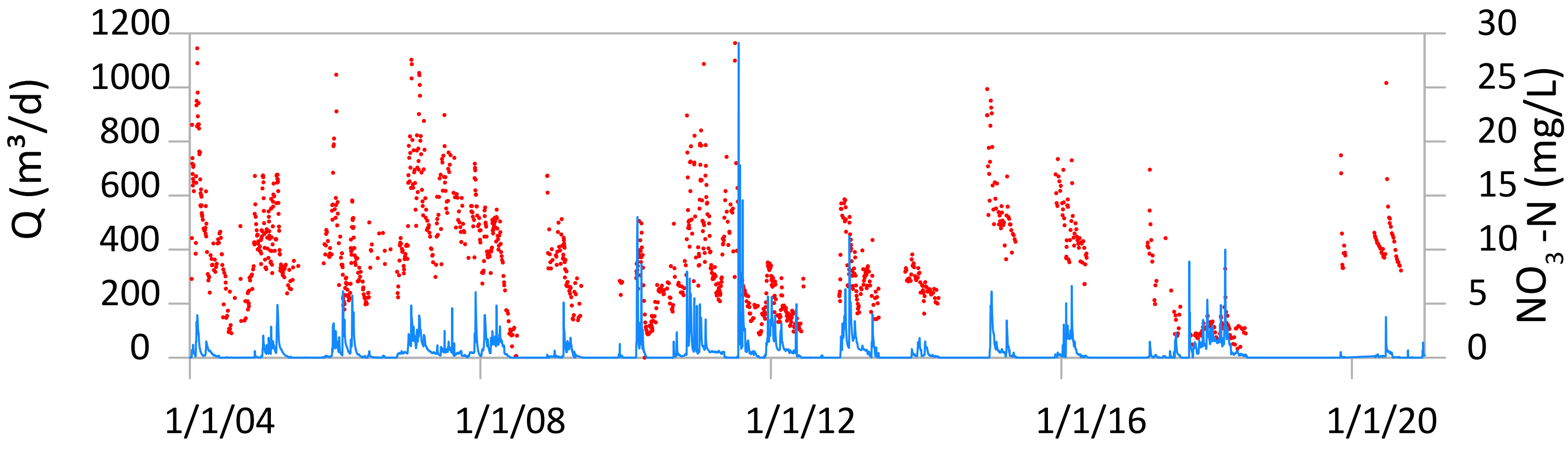
Q = 39 m³/d or 7056 m³/yr

c = 9.6 mg NO_3^--N/L

Assumptions

Removal efficiency: 30 – 90%

Costs: MBBR: 50 – 500 €/kg reduction
WF: 2 – 20 €/kg reduction
SFW: 5 – 95 €/kg reduction



Example 1: Drainage plot

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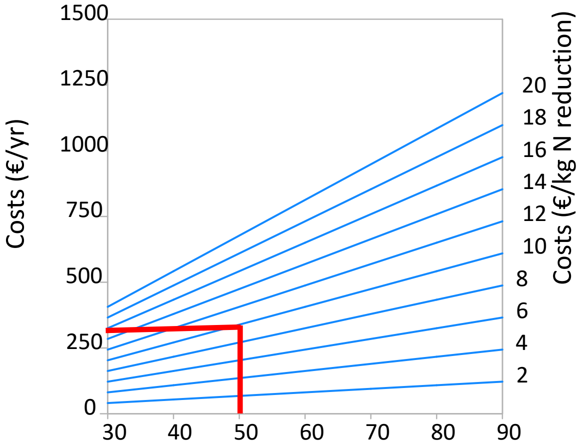
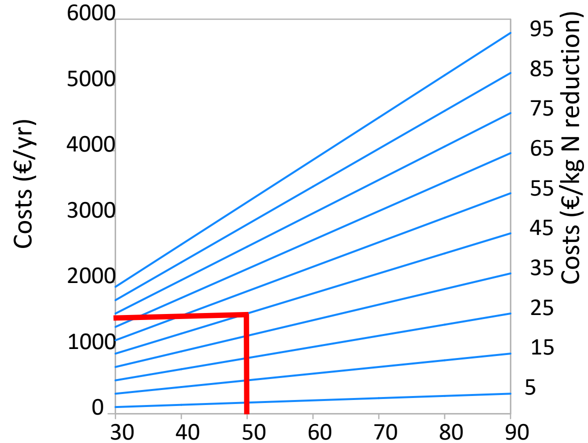
Nomograms to calculate annual costs based on varying removal efficiencies and installation/maintenance costs

Woodchip filter



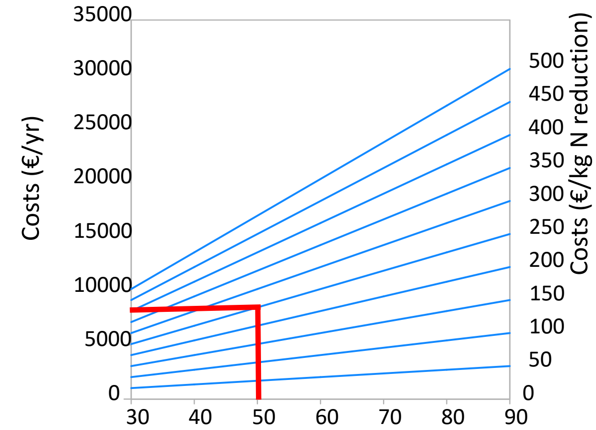
Removal efficiency (%)

Constructed Wetland



Removal efficiency (%)

MBBR



Removal efficiency (%)

Reading example

removal efficiency: 50%
Costs: 10 €/kg N red.
Total Costs: 339 €/year

removal efficiency: 50%
Costs: 45 €/kg N red.
Total Costs: 1524 €/year

removal efficiency: 50%
Costs: 250 €/kg N red.
Total Costs: 8467 €/year

Example 2: Catchment

Example 2: Catchment

Assumptions

Annual discharge: 80 - 150 mm/yr

NO_3^--N concentrations: 3 - 15 mg/L

Implementation of filter technologies: NO_3^--N concentrations >10 mg/L

- MBBR: small-sized drainage plots (<2 ha) at costs of 50 - 500 €/kg N reduction
- Woodchip filters: medium-sized drainage plots (2-10 ha) at costs of 2 - 20 €/kg N reduction
- Surface-flow constructed wetlands: large-sized drainage plots (>10 ha) at costs of 5 - 95 €/kg N reduction

Removal efficiencies: 30 - 90%

Calculations

All values will be randomly selected within the given ranges

100 runs were conducted

Example 2: Catchment

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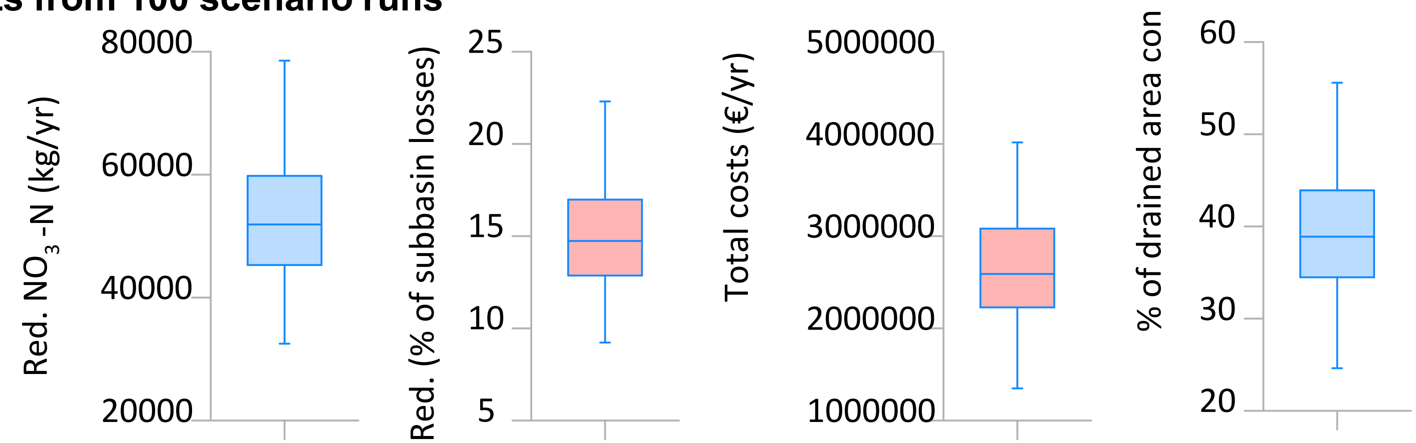
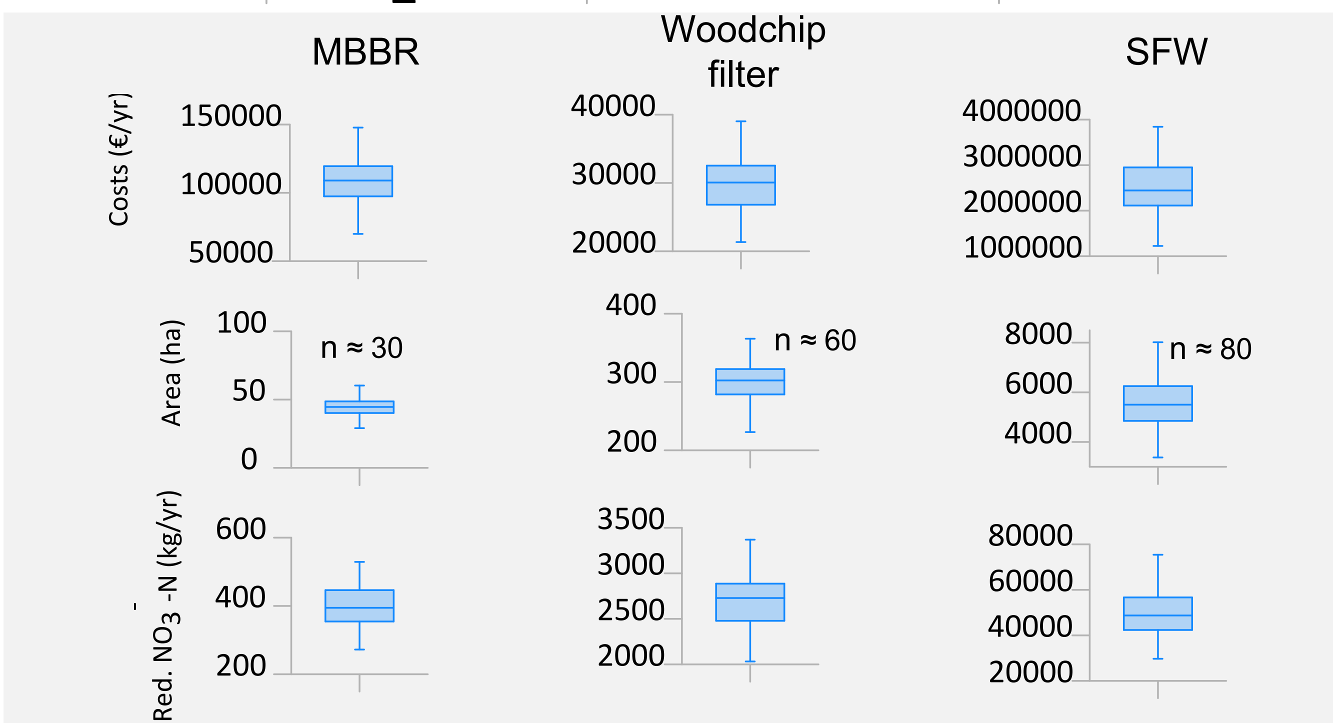
Results from 100 scenario runs





Conclusion

- Due to many hardly predictable costs and necessary simplifications, **single calculations** are mostly to be understood as rough estimates.
- Therefore, scenario analyses using **multiple calculations** can provide a realistic range of expected costs and nutrient reductions that policymakers and stakeholders can work with at the watershed level.
- The results suggest that filter systems, if installed widely, can help to reduce nutrient pollution in surface waters significantly.
- The installation and maintenance of filter systems can be very costly.
- Filter systems will always be side-measures and will not replace the necessity of sustainable agricultural systems.

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Q & A

Programme

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Nutrient filter systems in practice: construction manuals, fact sheets and cost assessment

Charlotte Boeckaert, Vlakwa

Nuredrain information

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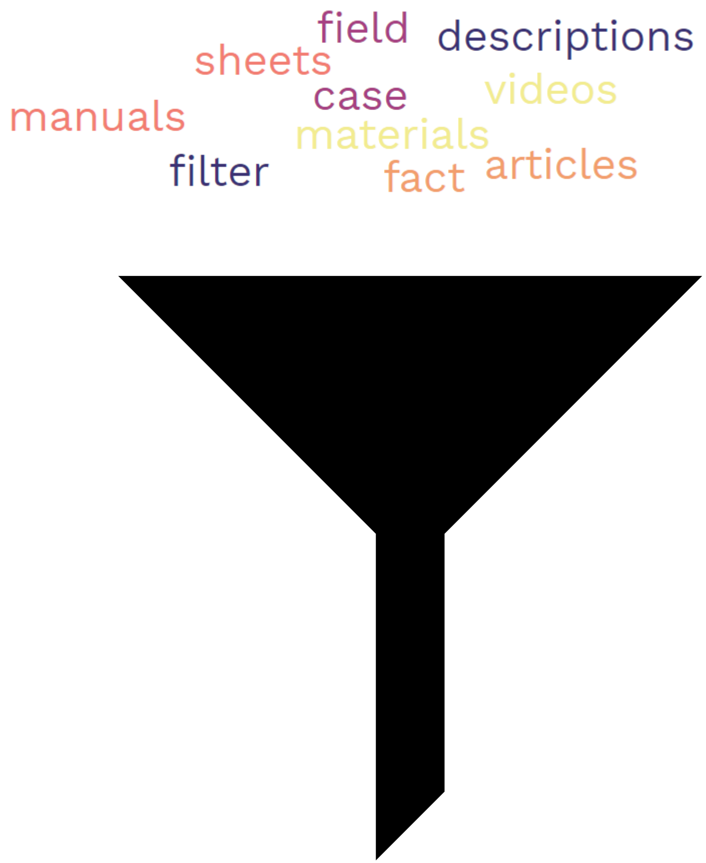

[NuReDrain, Interreg VB North Sea Region Programme](#)

Project videos

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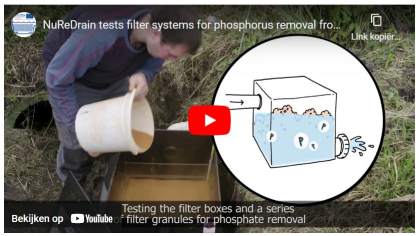
Phosphorus filter box for drainage water in agricultural fields

Tests on filter systems for phosphorus removal from drainage water in agricultural fields by Ghent University and Inagro



Nitrogen and phosphorus removal in horticulture

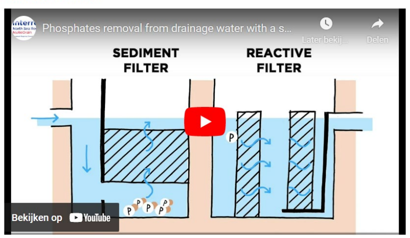
Filter systems for Nitrogen and Phosphorus removal in horticulture by PCS and KU Leuven

Phosphorus filter system for a water production centre

Video about tests on a phosphorus filter system in a water production centre by De Watergroep and VITO

Phosphorus filtering with a sediment and reactive filter in Denmark

Video about the phosphor removal filter system of Aarhus University and Copenhagen University in Fensholt



Mobile constructed wetland for nitrate removal

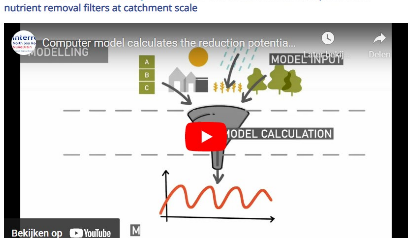
Video about the field test of a denitrication filter system by OOWV at Lethe river in Lower Saxony

Inline phosphorus filter system for drainage water

Video about the field test of a phosphorus filter system by LWK Niedersachsen for drainage water at Venner Bruchkanal in Lower Saxony

Modelling the reduction potential of filters at catchment scale

Video about Rostock University's model that estimates the reduction potential of nutrient removal filters at catchment scale



A zero valent iron filter for drainage water

Copenhagen University is testing an experimental Zero Valent Iron filter for the removal of phosphorus and nitrogen from drainage water.

Relive the NuReDrain webinars

NuReDrain Webinars

In September and October 2020 NuReDrain organised a series of webinars about the research results.

Webinar I : phosphorus filter systems for drainage water

Fact sheets

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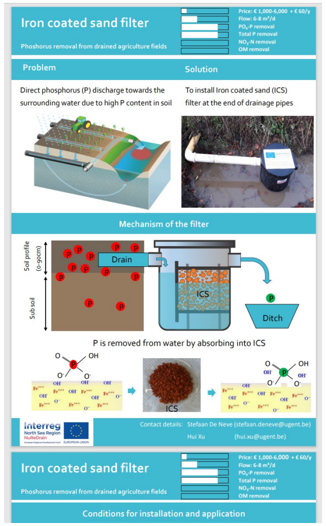

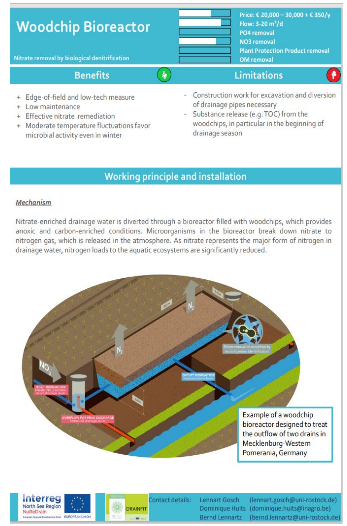

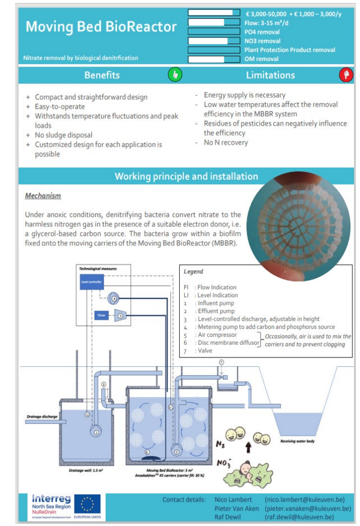

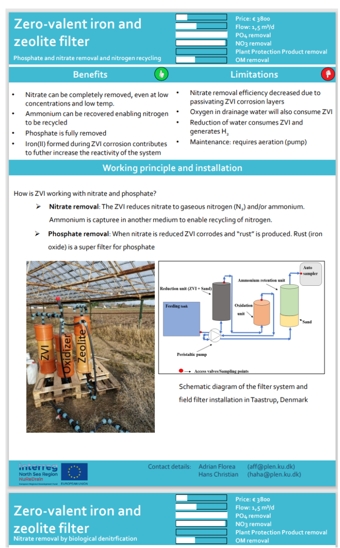

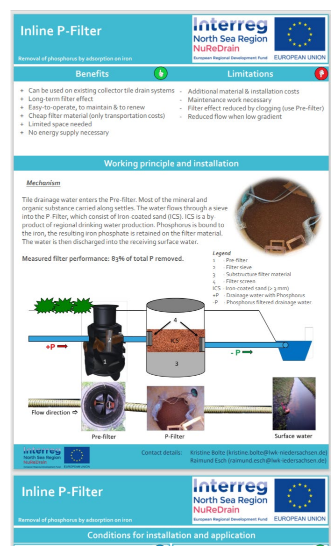

Filter construction manual

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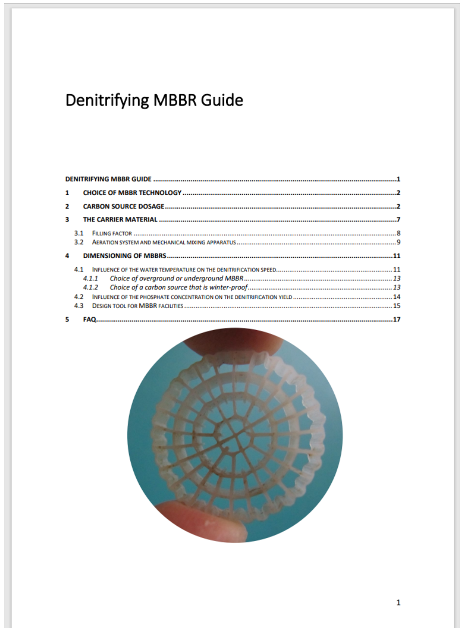
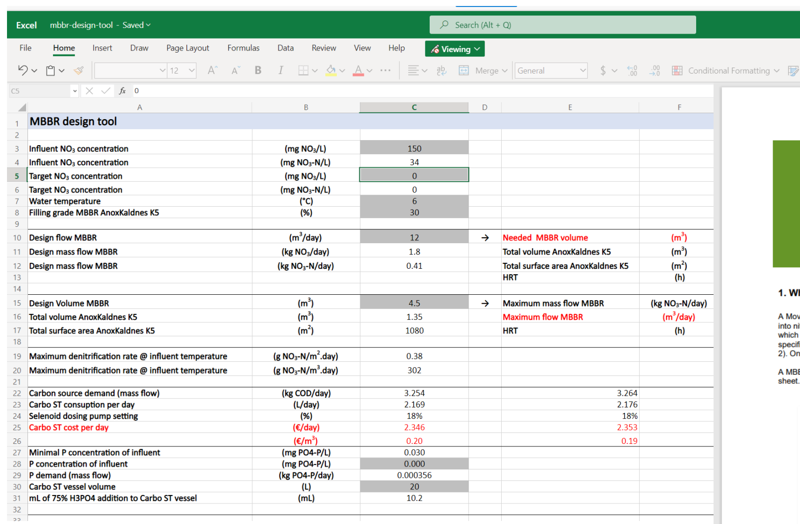

Denitrifying MBBR Guide

1

1. Working principles


Excel mbbr-design-tool - Saved

MBBR design tool

	A	B	C	D	E	F
1	MBBR design tool					
2						
3	Influent NO_3 concentration	(mg NO_3/L)	150			
4	Influent NO_3 concentration	(mg NO_3-N/L)	34			
5	Target NO_3 concentration	(mg NO_3/L)	0			
6	Target NO_3 concentration	(mg NO_3-N/L)	0			
7	Water temperature	(°C)	6			
8	Filling grade MBBR AnoxKaldnes K5	(%)	30			
9						
10	Design flow MBBR	(m^3/day)	12	→	Needed MBBR volume	(m^3)
11	Design mass flow MBBR	(kg NO_3/day)	1.8		Total volume AnoxKaldnes K5	(m^3)
12	Design mass flow MBBR	(kg NO_3-N/day)	0.41		Total surface area AnoxKaldnes K5	(m^2)
13					HRT	(h)
14						
15	Design Volume MBBR	(m^3)	4.5	→	Maximum mass flow MBBR	(kg NO_3-N/day)
16	Total volume AnoxKaldnes K5	(m^3)	1.35		Maximum flow MBBR	(m^3/day)
17	Total surface area AnoxKaldnes K5	(m^2)	1080		HRT	(h)
18						
19	Maximum denitrification rate @ influent temperature	(g NO_3-N/m^2.day)	0.38			
20	Maximum denitrification rate @ influent temperature	(g NO_3-N/m^3.day)	302			
21						
22	Carbon source demand (mass flow)	(kg COD/day)	3.254		3.264	
23	Carbo ST consuption per day	(L/day)	2.169		2.176	
24	Selenoid dosing pump setting	(%)	18%		18%	
25	Carbo ST cost per day	(€/day)	2.346		2.353	
26		(€/m^3)	0.20		0.19	
27	Minimal P concentration of influent	(mg PO4-P/L)	0.030			
28	P concentration of influent	(mg PO4-P/L)	0.000			
29	P demand (mass flow)	(kg PO4-P/day)	0.000356			
30	Carbo ST vessel volume	(L)	20			
31	mL of 75% H3PO4 addition to Carbo ST vessel	(mL)	10.2			
32						

2. Dimensioning


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
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3. DIY building

Cost filterbox - 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	€ 8,62	€ 702	0,06	**1.304**
	Drainage water (0,46 mg P/l)				0,19	↓
	Drainage water (0,12 mg P/l)				0,02	↑
Greenhouse (15 mg P/l)	DIY	€ 690	€ 9,10	€ 291	1,94	**327**

Cost MBBR - N filter

	Application	CAPEX	OPEX	Yearly cost	Total N removal (kg P)	Cost effectiveness (€/kg N)
DIY	Greenhouse effluent	€ 3.000	€ 1.131	€ 1.400	12,44	113
Subsoil	Drainage	€ 30.000	€ 3.260	€ 6.000	52,84	114
Containerized	Drainage Off-grid	€ 50.000	€ 1.867	€ 6.034	44,44	136
	Drainage	€ 40.900	€ 2.967	€ 6.315	44,44	142

Approach

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European Regional Development Fund
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1. Source based measures
2. Identification of nutrient hot spots
3. Set reduction goals
4. Calculate costs
5. Prioritize locations
6. Install filter systems

Acknowledgements

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European Regional Development Fund
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VLAKWA
vito
OOWV
KU LEUVEN
inagro
Landwirtschaftskammer Niedersachsen
De Watergroep WATER. VANDAAG EN MORGEN.
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

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Thank you for your attention!