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# NuReDrain Webinar III:

# Filter technologies for N removal from agricultural waters

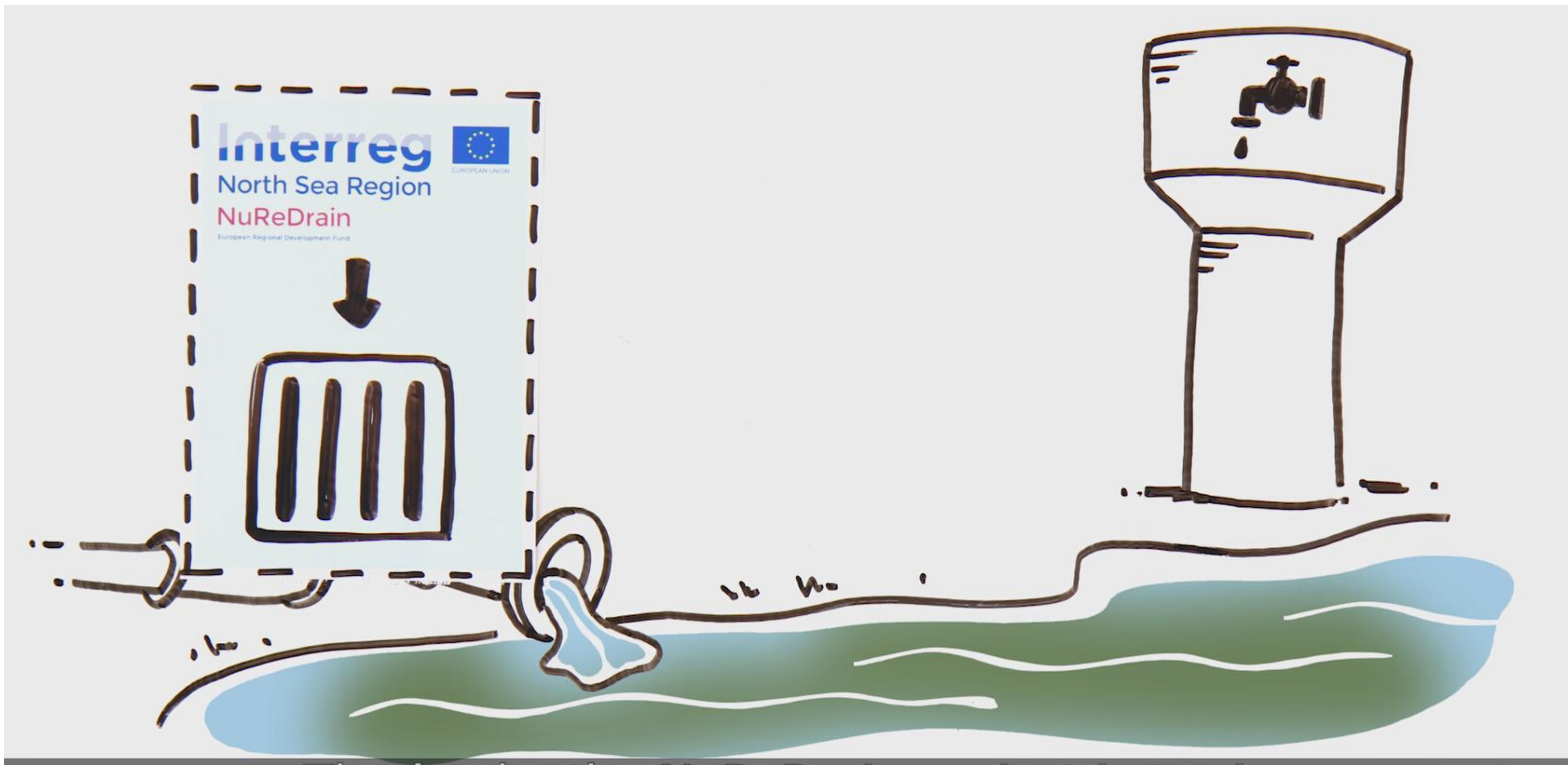
# Practical issues



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

- Nutrient Removal and Recovery from Drainage water
- 1/3/2017 – 30/9/2021
- Interreg North Sea Region
- Project cost: € 2 674 405 - Fund: € 1 337 203
- 11 partners in 3 countries

# Project goal



# Project goals

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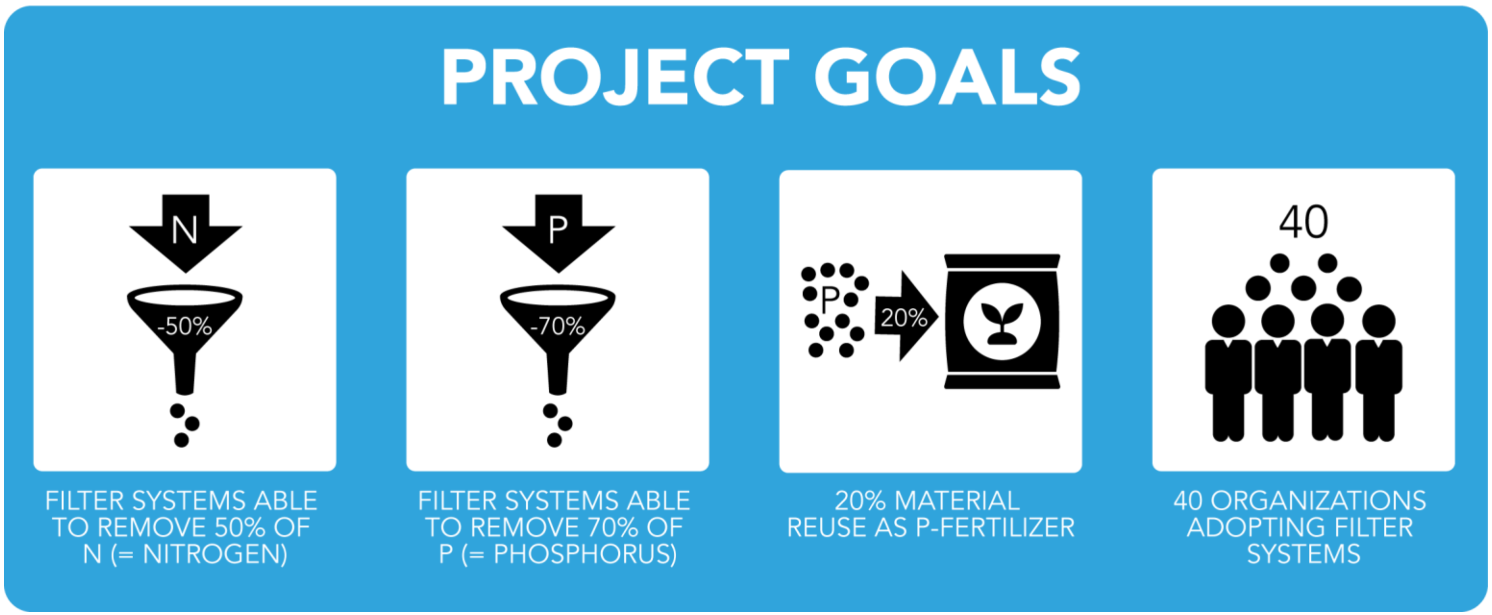

# Agricultural waters

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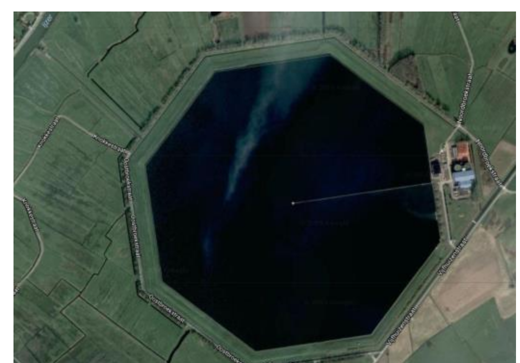
drainage water

greenhouse effluent

**NuReDrain**

surface water

water reservoir for drinking water production



# 6 field cases

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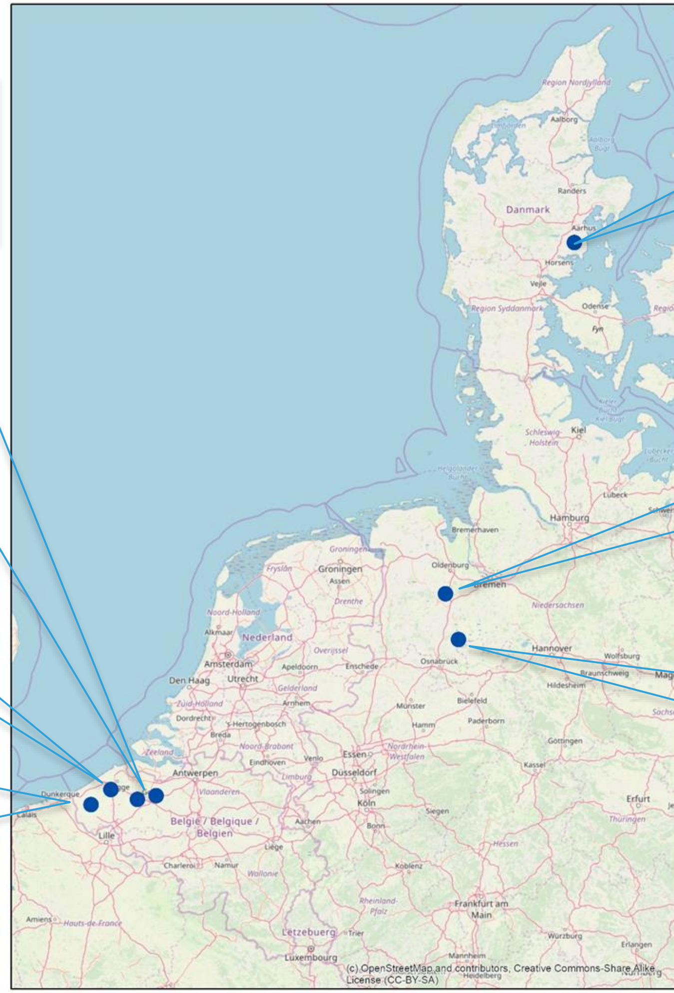
Greenhouse effluent
N + P removal

Drainage water
P removal

Water reservoir
P removal




Drainage water
N + P removal

Surface water
N removal

Drainage water
P removal

# 6 field cases

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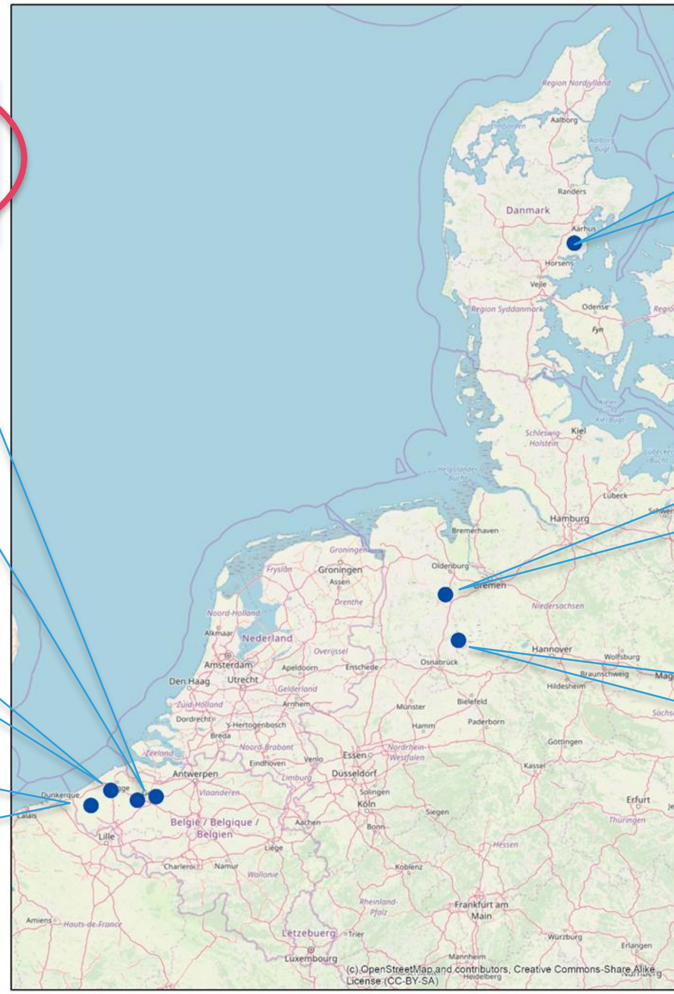
Greenhouse effluent
N + P removal

Drainage water
P removal

Water reservoir
P removal




Drainage water
N + P removal

Surface water
N removal

Drainage water
P removal

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# 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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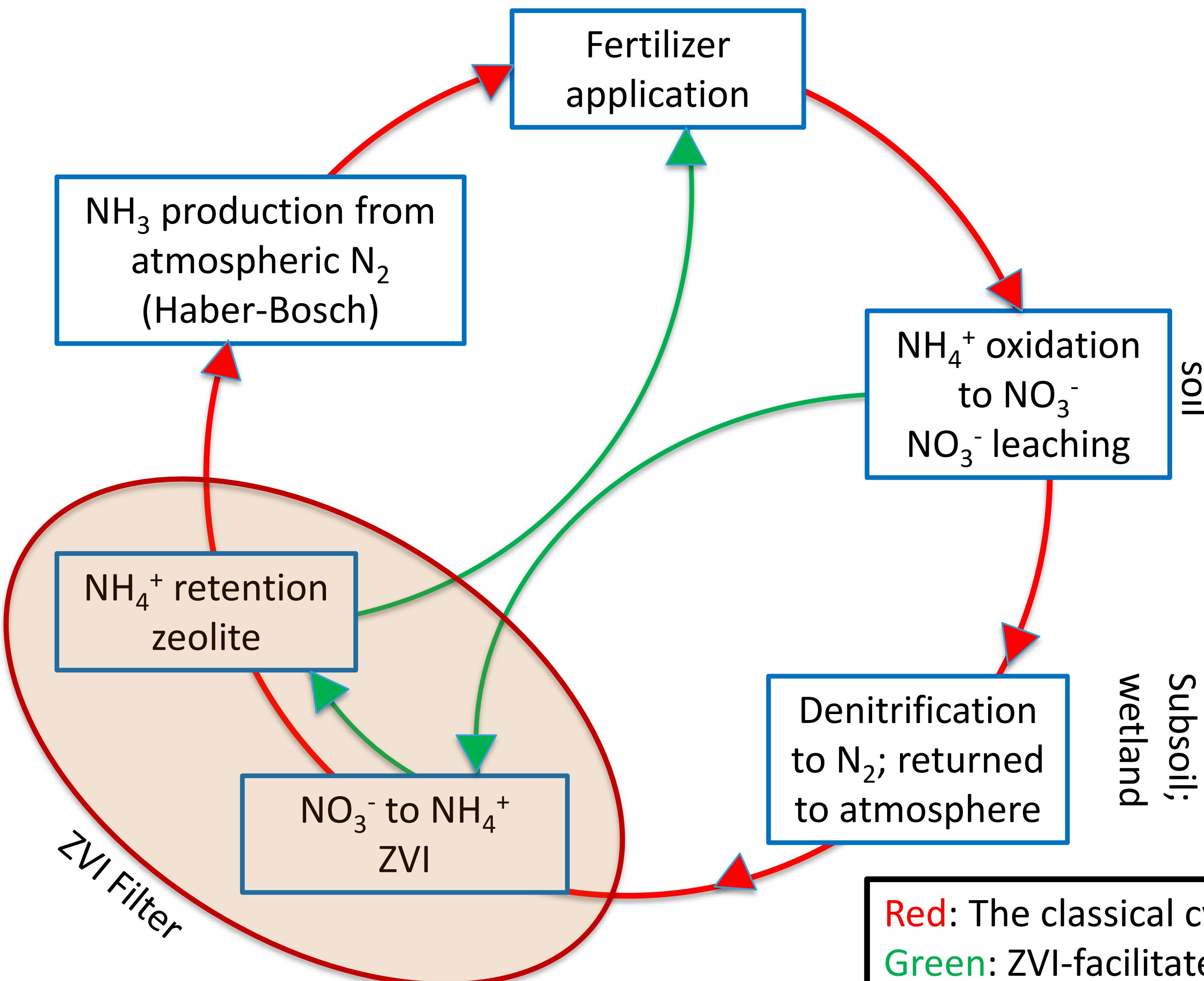
# The Nitrogen wheel




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 construct 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

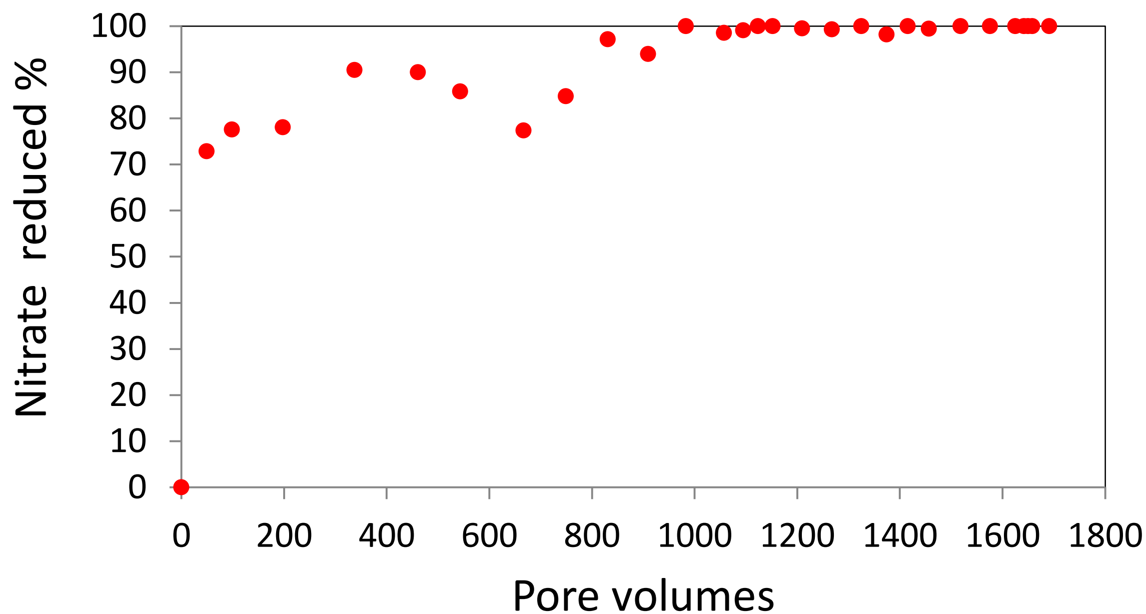


ZVI


Zeolite

# Results - 1

## Nitrate removal

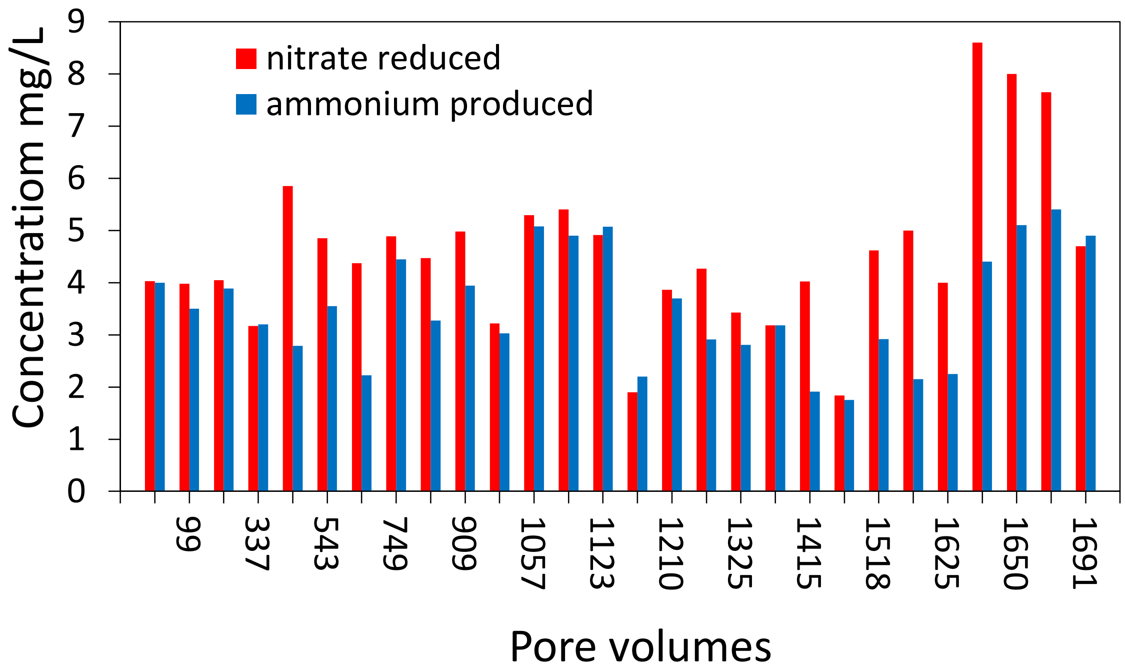



$NO_3^-$ measured at end of column 1


- 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

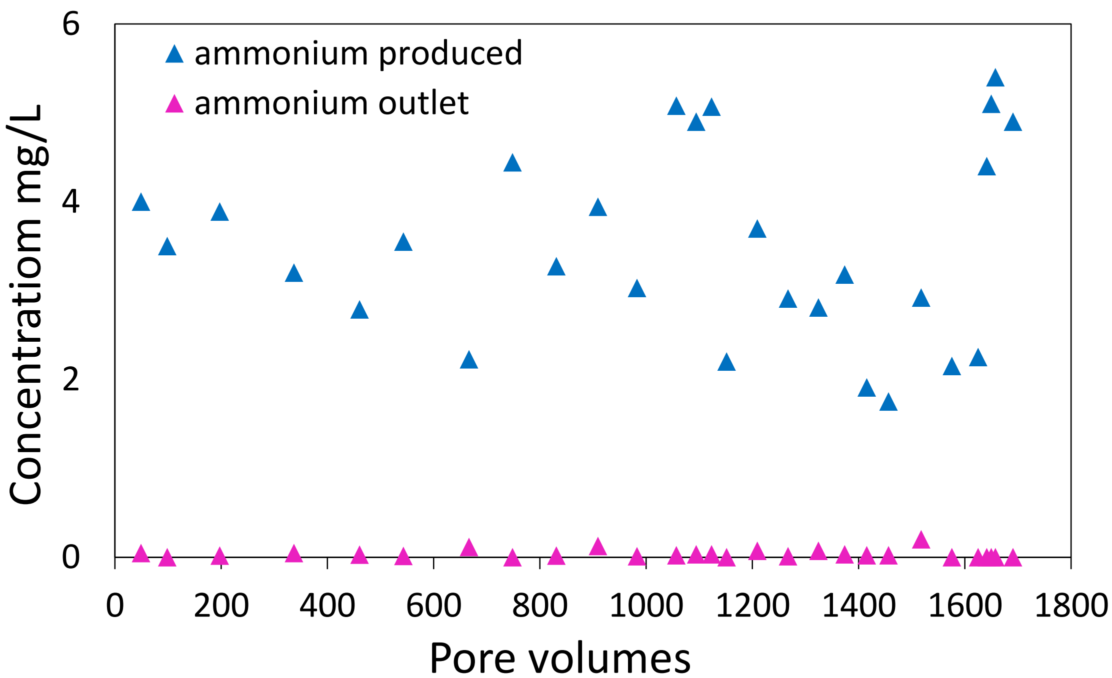



$NO_3^-$ and $NH_4^+$ measured at end of column 1

- $NO_3^-$ is converted to $NH_4^+$. 100 % at start and then at about 70 % at end of the period
- Similar results as in laboratory experiment
- 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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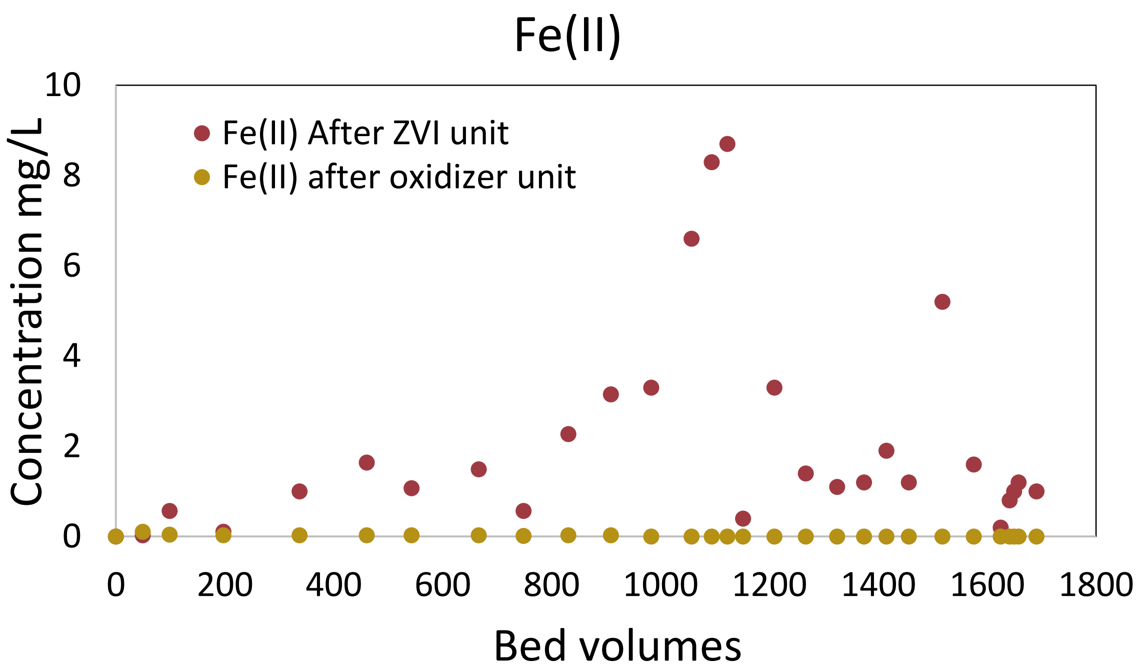
## Removal of iron(II)




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)

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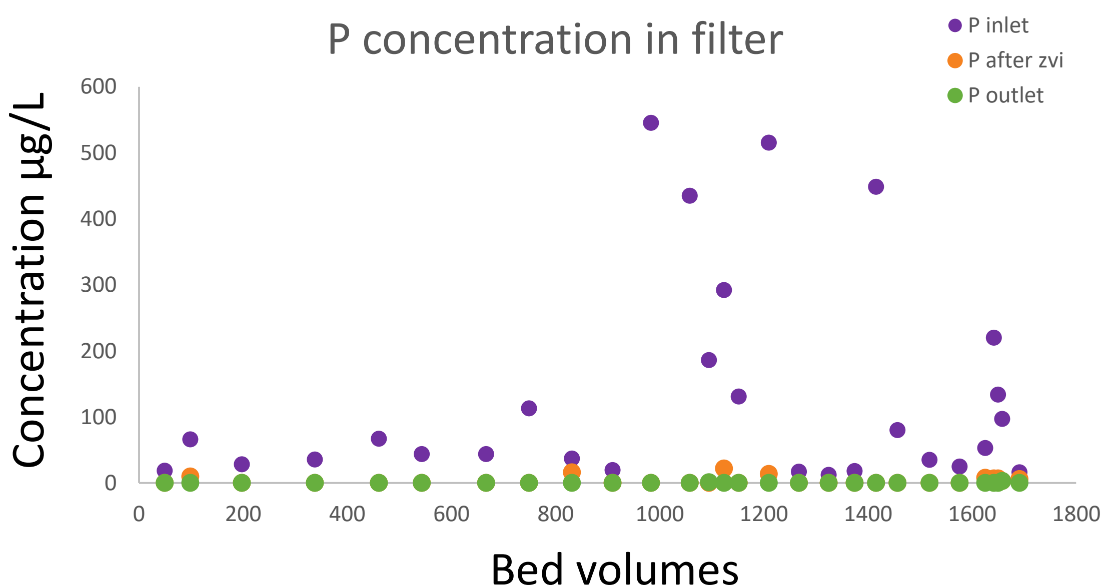
# Phosphate is 100 % retained





$HPO_4^{2-}$

- 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

# Results - 6

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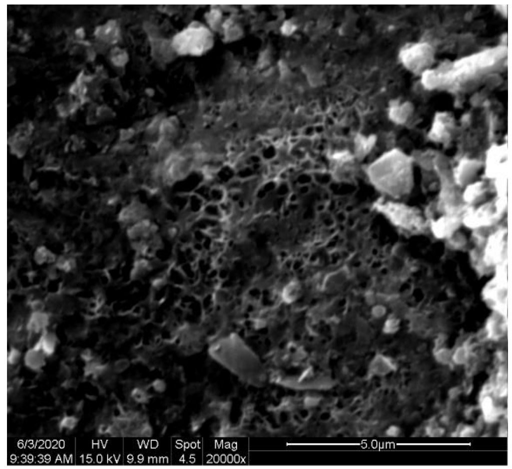
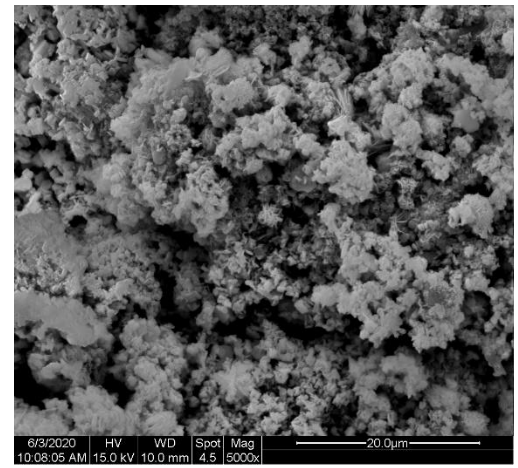
## Green rust formation in ZVI unit




- Green rust (GR) is an unstable corrosion product typically produced in a low-oxygen environment and contain iron(II) and iron(III), the hydroxide ($HO^-$), and another anion such as carbonate($CO^{2-}{}_{3}$), chloride($Cl^-$) or sulphate ($SO^{2-}{}_{4}$).
- GR have good potential in applications such as water-purification processes and can reduce nitrate to ammonium.
- In ZVI field filter system - GR with carbonate as the interlayer anions

# 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

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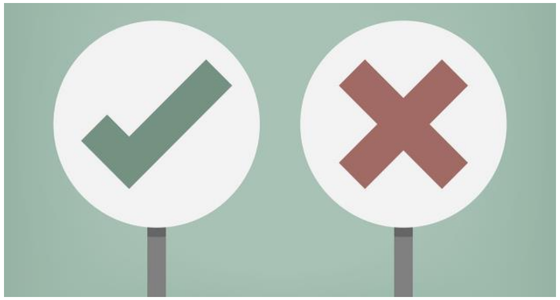
**Pros**

- 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 ✓
- Iron(II) formed during ZVI corrosion can be oxidized and removed ✓
- The unit is advantageous for concentrated effluents such as from 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 in column) ✗
- Maintenance: requires aeration (pump) ✗
- High iron consumption ✗



**Improvements**

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

# Q & A

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# Mobile constructed wetland at the Lethe river in Germany

Presented by Sascha Kochendörfer

OOWV

# Table of Content

- Problem Description
- Filter Description
- Preliminary Results
- Future Work

# Problem Description

# Study Area

- North-Western Germany
- River length: 36.5 km
- Catchment area: 180 km²
- Sum fish pond area: 120 ha
- Area nature reserve: 465 ha
- Status of nature reserve is threatened
  - red listed shore-weeds less competitive at high Nitrate concentrations

**(External load: 38.5 t $NO_3$–N/a)**

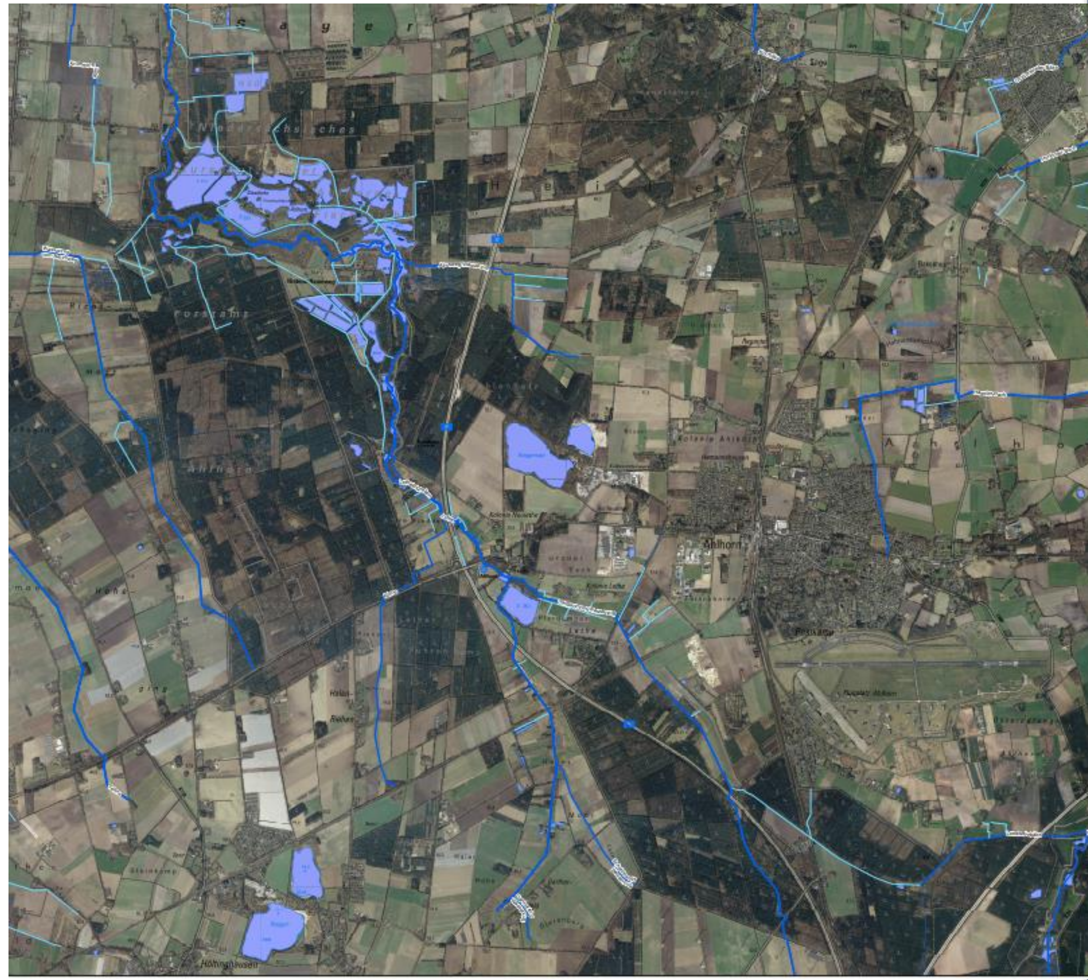

*Fig. 1: Satellite image of fish ponds (a) and Lethe spring area (b)*

# Measurement Sites

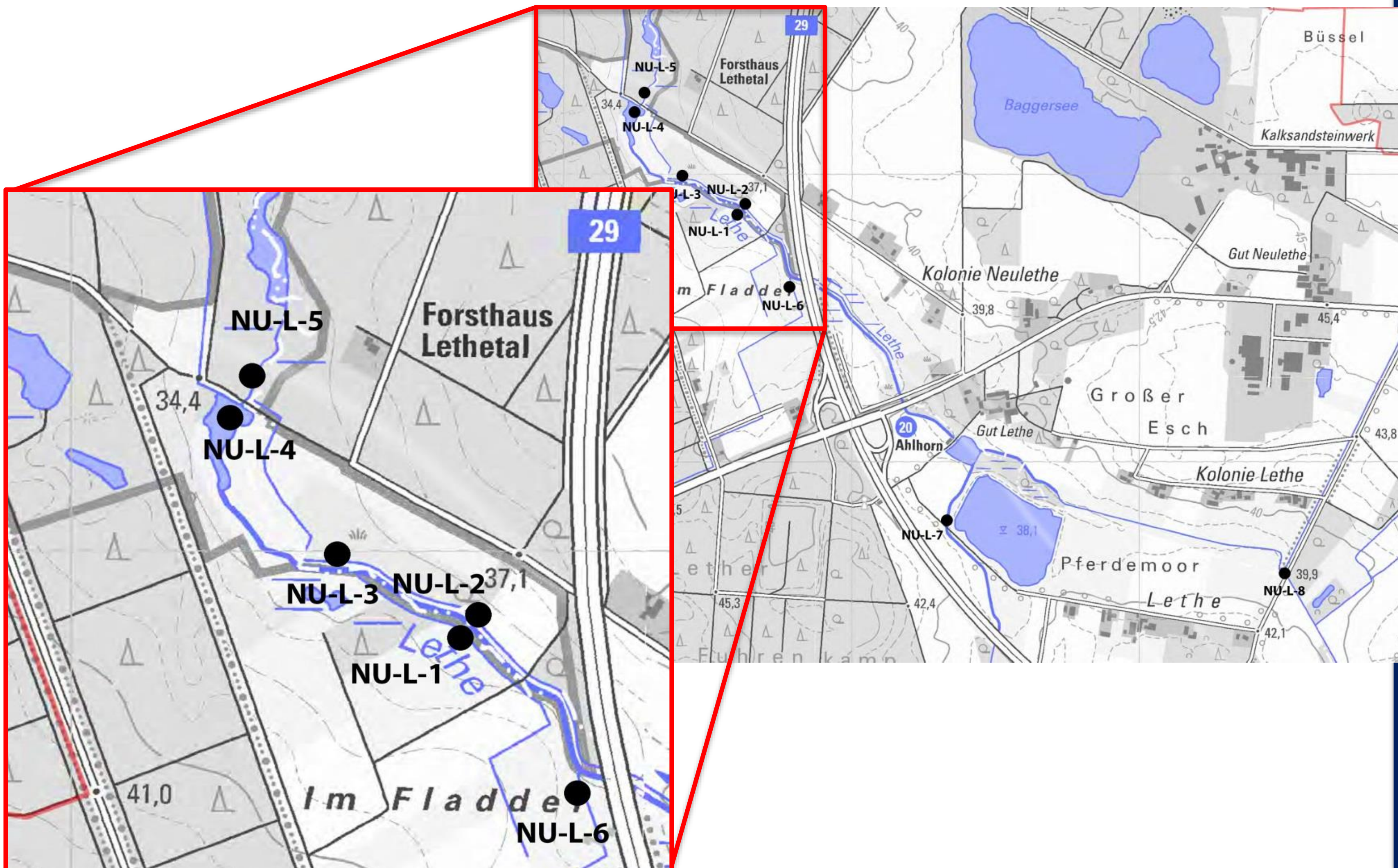


*Fig. 2: Position measurement sites NU-L-1 – NU-L-8*

# Monitoring-Results: Lethe and Lethe-ditch

- Both water courses show similar changes in nitrate concentrations
- Elevated values in winter
- Greatest relative increase of nitrate concentrations from summer to winter in the ditch (NU-L-2)
- Highest concentrations in the spring area (NU-L-7)

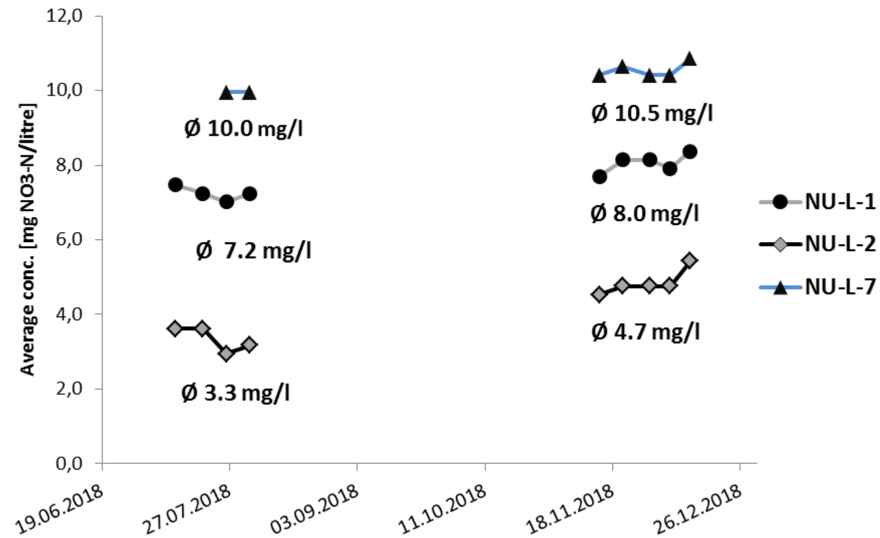


*Fig. 3: $NO_3$-N concentrations in Lethe river (NU-L-1, NU-L-7) and in Lethe-ditch (NU-L-2)*

# First Construction Site

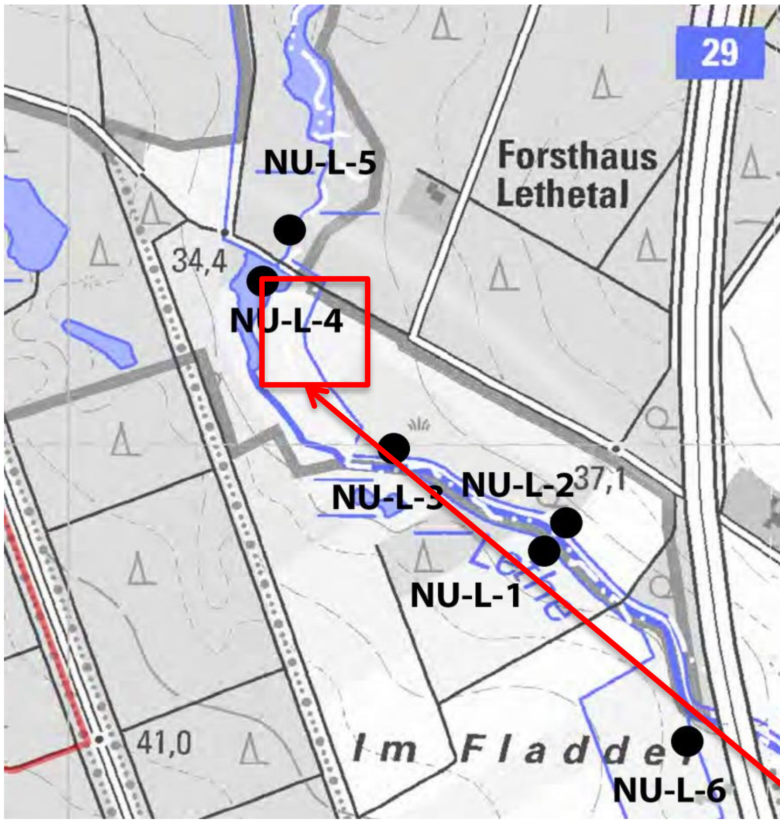


*Fig. 4: First construction site*

- First site was chosen, to test backwater caused by the wetlands and its suitability for ditches
- If backwater would be small we would have been permitted to move the wetland upstream, where concentrations are higher and discharge much lower

Wetland location

# Obstacles for field trial

*Fig. 5: Issues with the soil substrate during construction*

- First site wasn´t suitable due to high flows, high groundwater table and fine-sandy substrate
- Permits for building in natural protection area necessary but very difficult to obtain

-> suitable sites had to be dismissed

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# Filter Description

# Second Construction Site

- The plant was built on a field, above ground, that is owned by the OOWV
- Water is pumped from the Lethe river
- To solemnly test denitrification efficiency

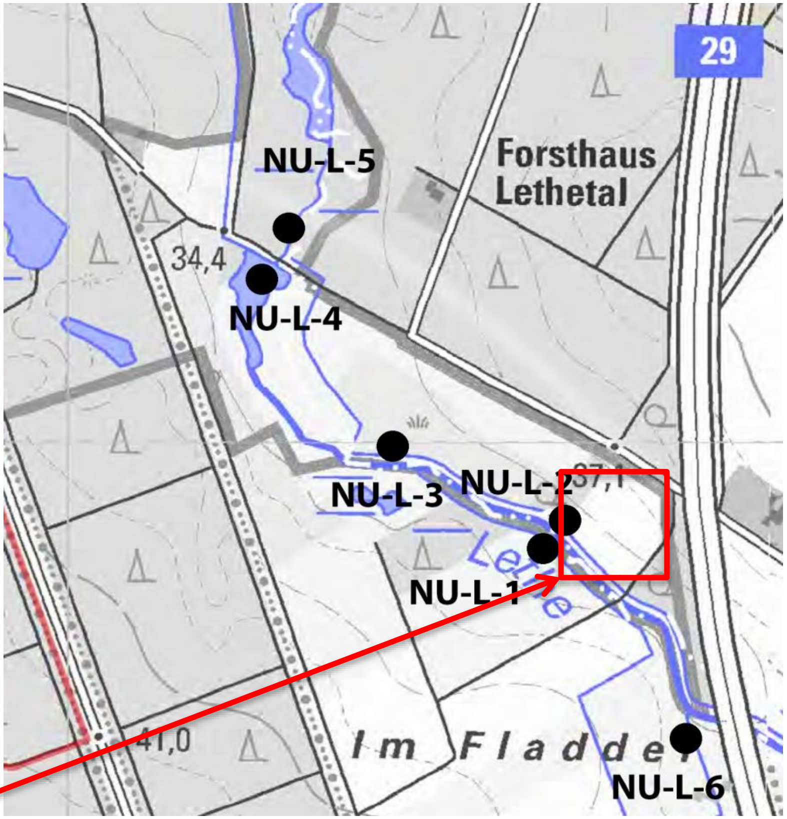


*Fig. 6: Second construction site*

Wetland location

# Filter Description

- Transportable wetland
- Combination of:
  - Plants for aeration and nutrient uptake
  - Plastic carriers and burnt clay for microbial growth
- Plant bearing pots divided into two parts:
  - Upper part: Burnt clay, flowers
  - Lower part: Root system, carriers
- Six denitrification pots are installed
- A 50W pond pump is installed in the Lethe river for water supply (around 70 ml/s)

*Fig. 7: Images of the mobile wetland*

# Filter Description

- Each pot holds around 750l
  - The plastic carriers are filled with clay pebbles
  - The system holds around 1.5m³ of water
- Green nets help to avoid material to move inside the pots
- Inflow is diverted to the bottom of the pots to avoid bypass of the plastic carriers
- Costs for 6 pots around 6000 €

*Fig. 8: Plastic carriers and burnt clay inside one wetland pot*

# Monitoring Equipment

- Monitoring equipment in the inlet and outlet pipes
- TriOS – Opus multi-parameter sensors are used
- Nitrate concentrations, TSS, water temperature, CODeq and O2 concentrations are monitored continuously


*Fig. 9: Multiparameter sensor in the inflow pipe*

# Power Supply

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- Power supply via solar modules and an electric cell as a buffer to fill the battery during the night and cloudy weather
- This setup is necessary in remote areas without access to the power grid
- High fuel consumption during cloudy weather and during night


*Fig. 10: Solar panel and electric cell for power supply*

# Preliminary Results

- Because of earlier pumping tests and heavy rainfalls, the pots were already filled. This explains the rising values in the output after regular pumping started
- Due to low values of Nitrate in the water before the loading phase, the biofilm might need time to grow
- During the ongoing growth phase, around 6-9% (7.4 mg/l input, 7.0 mg/l output) of input Nitrate is taken up
- Nutrient uptake is, however, expected to diminish during winter

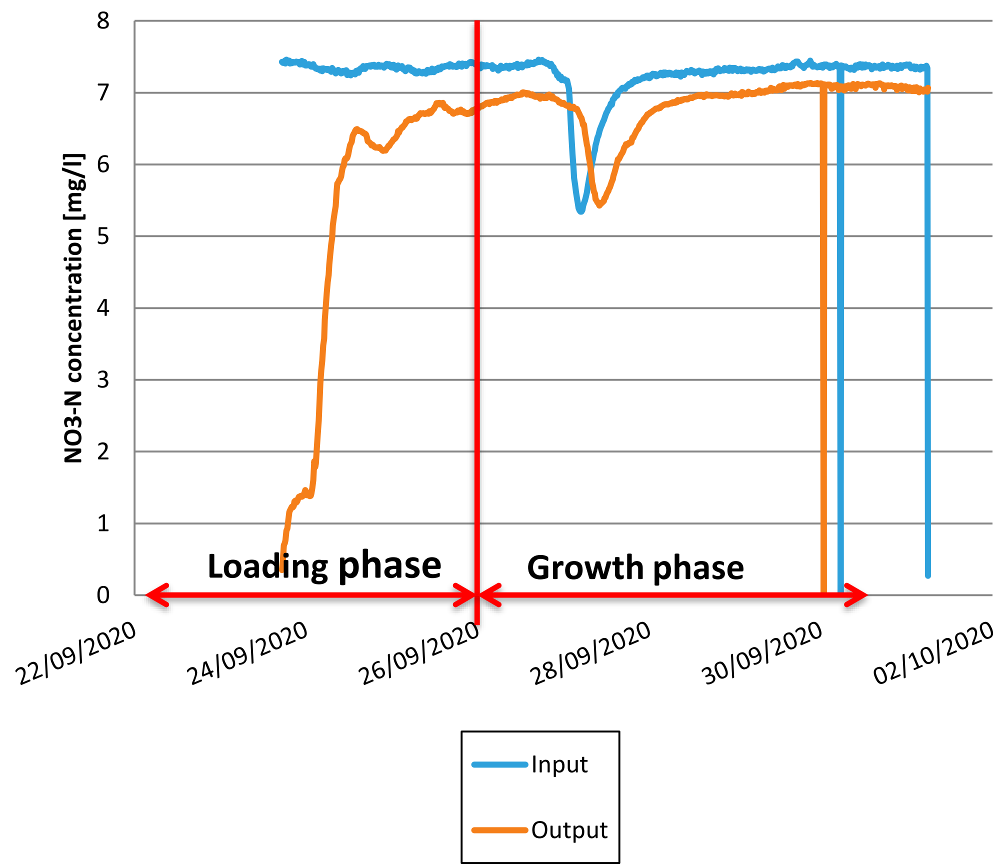



*Fig. 11: Preliminary results of Nitrate-N concentrations in inflow and outflow*

# Future Work

# Future Work

- During the next weeks the power supply will be adapted to the weather conditions
  - Both solar modules will be used for the pump
  - A second electric cell will power the monitoring equipment
- Depending on the development of the denitrification efficiency of the wetland, a decrease of the water volume flow needs to be considered

# Thank you
# for your attention!

# Q & A

# Moving Bed BioReactor treating greenhouse effluent and drainage water in Belgium

Prof. Raf Dewil
Nico Lambert
Pieter Van Aken

# Nutrient filter: Moving Bed Bioreactor

- Biological denitrification in anoxic conditions

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

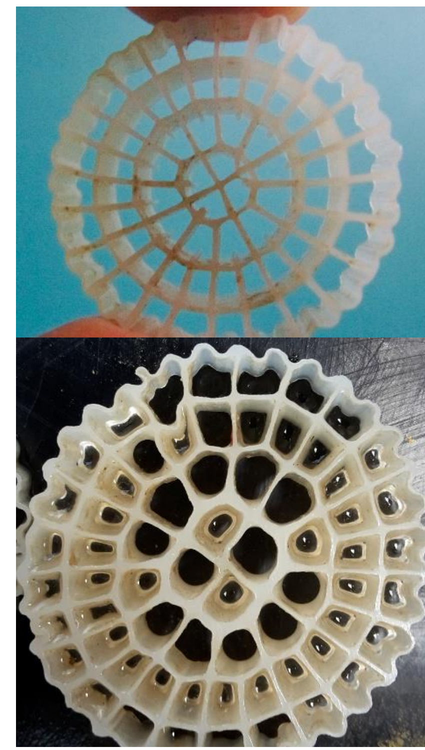
$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

$5C_3H_8O_3$: *Carbon source (glycerol-based)*

$14H^+$: *pH increase*

$7N_2$: *No recovery possible*

- Moving-bed Bioreactor technology
  - Biofilm growth on AnoxKaldnes® plastic carriers (K5)
  - Benefits: Limited growth of biomass, high active biomass concentration & no sludge settling problems
  - 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**

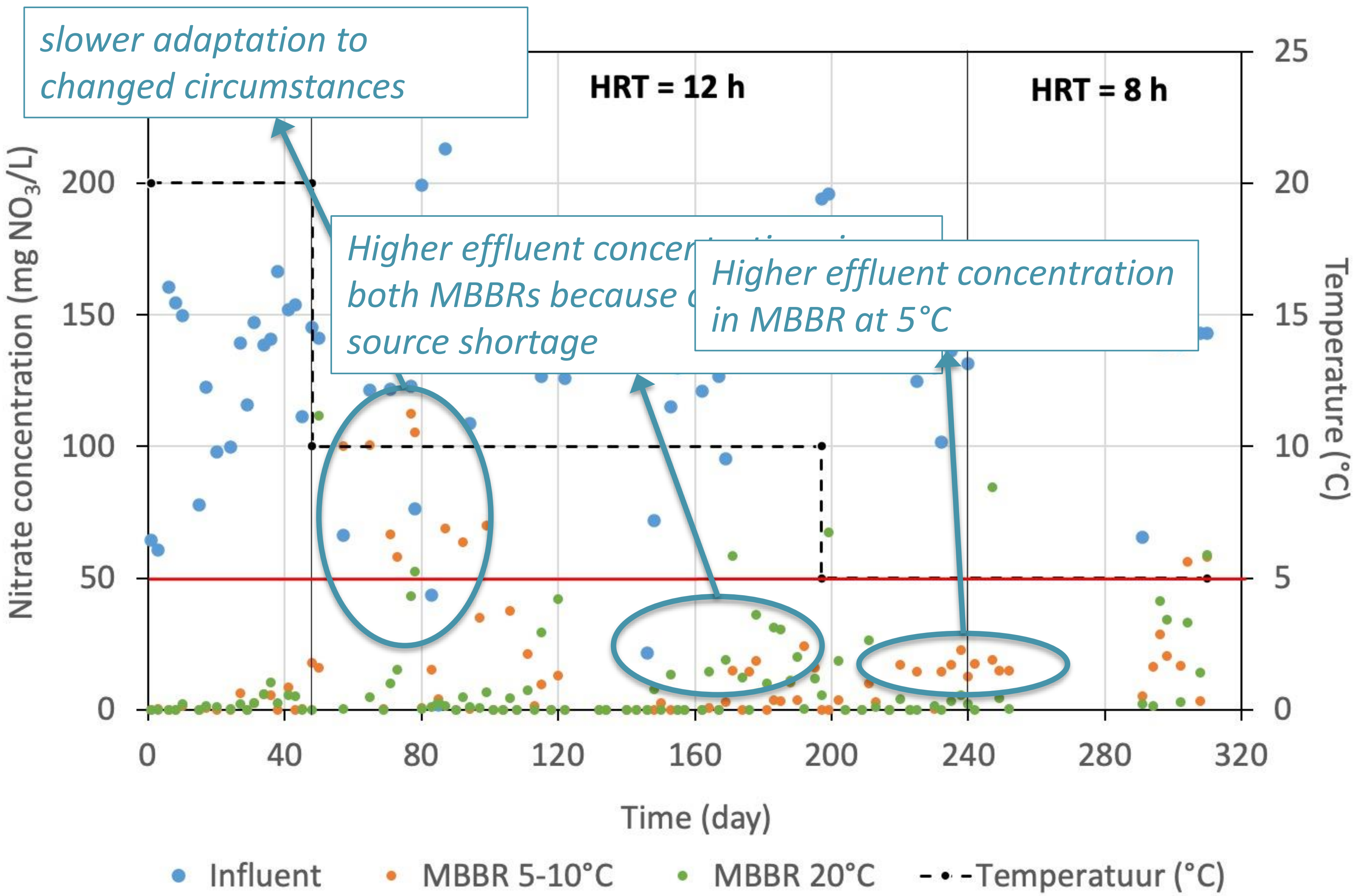
→ Simple and robust system
→ Low water temperatures (between 5 – 15 °C)
→ Variable flow rates and nitrate concentrations
→ Remote locations
→ Low budget solution

# Feasibility study at pilot scale

## Long term experiment: 320 days

- Volume: 13 L
- Continuously stirred
- Carrier fill: 30%
- $C_0$ = 150 mg $NO_3$/L
- C/N = 8 – 10
- Carbon source: Carbo ST *(glycerol-based)*
- P source: $H_3PO_4$
- pH = 6 - 7.5
- Temperature controlled

# Feasibility study at pilot scale



# MBBR concept to treat agricultural waters

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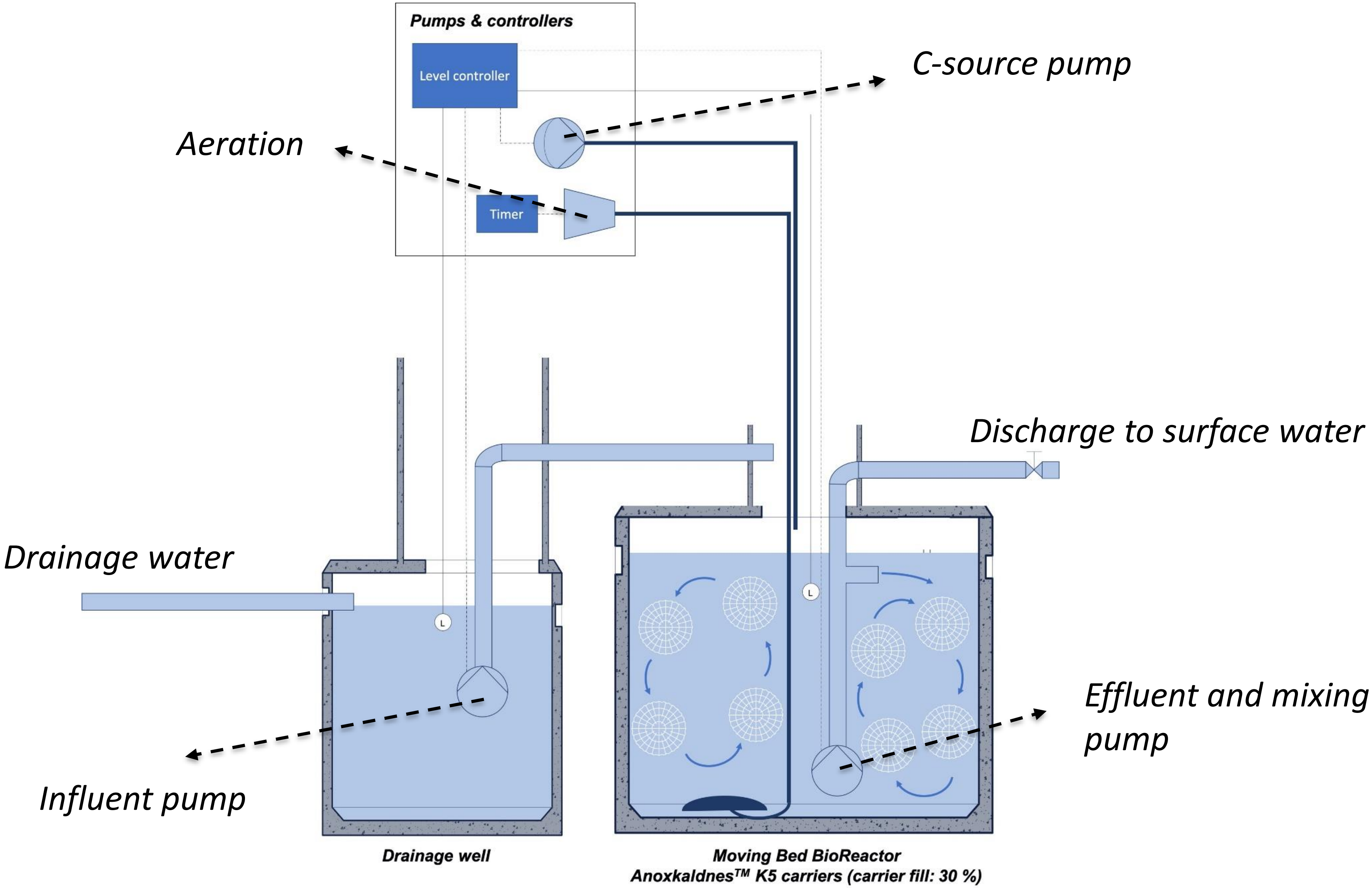

# MBBR concept to treat agricultural waters

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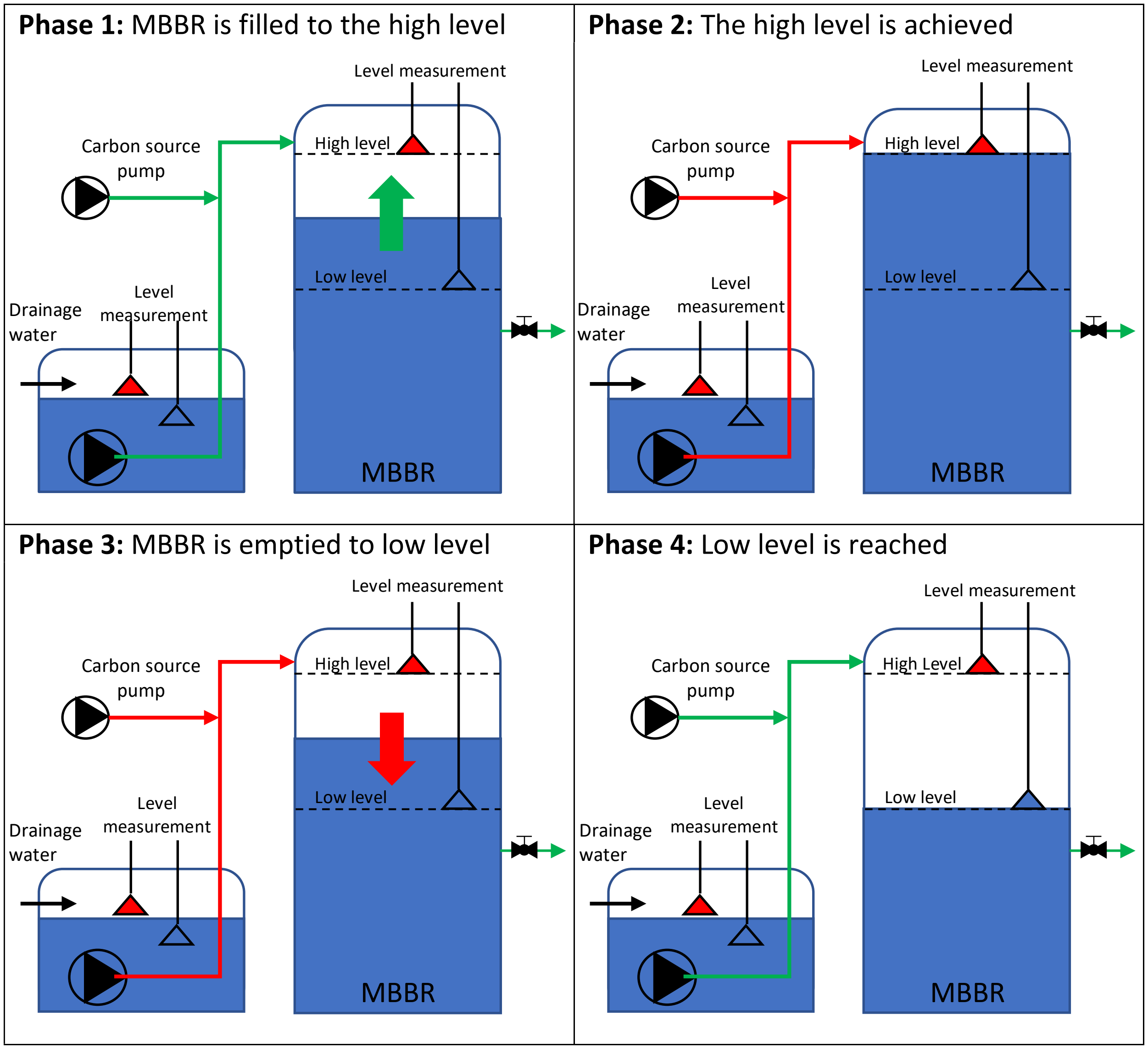
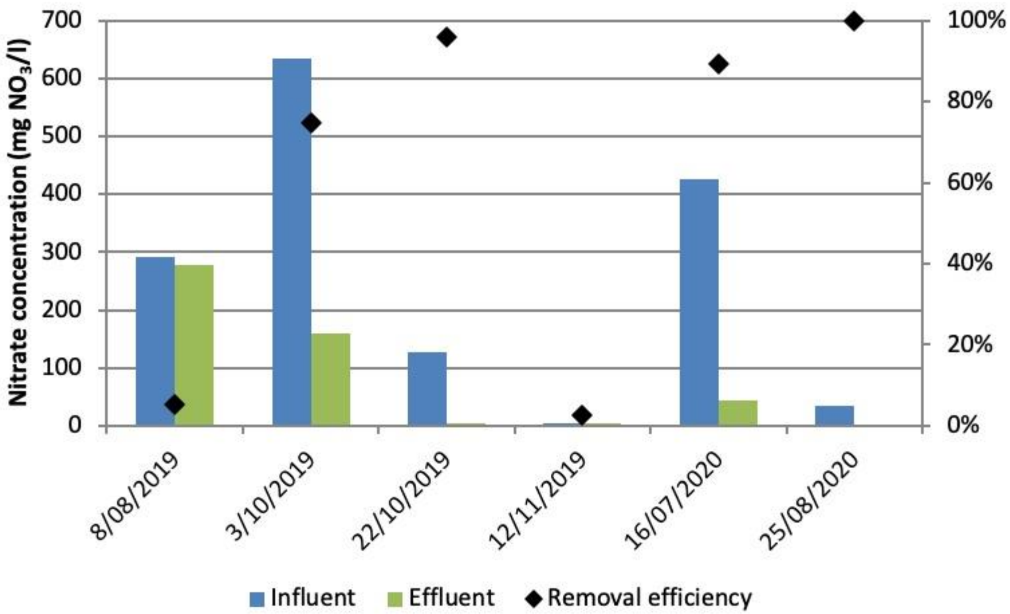


# Self-assembly concept: Greenhouse effluent

- Greenhouse effluent
- Concept based on an universal cubic container: Volume = 1 $m^3$
- Flow rate: 3 $m^3$/day
- Investment cost: 3 000 €
- Operational cost: 1 000 €/year
- Efficiency cost: 107 €/kg $NO_3$-N removed




# Container concept

inagro
ONDERZOEK & ADVIES IN LAND- & TUINBOUW

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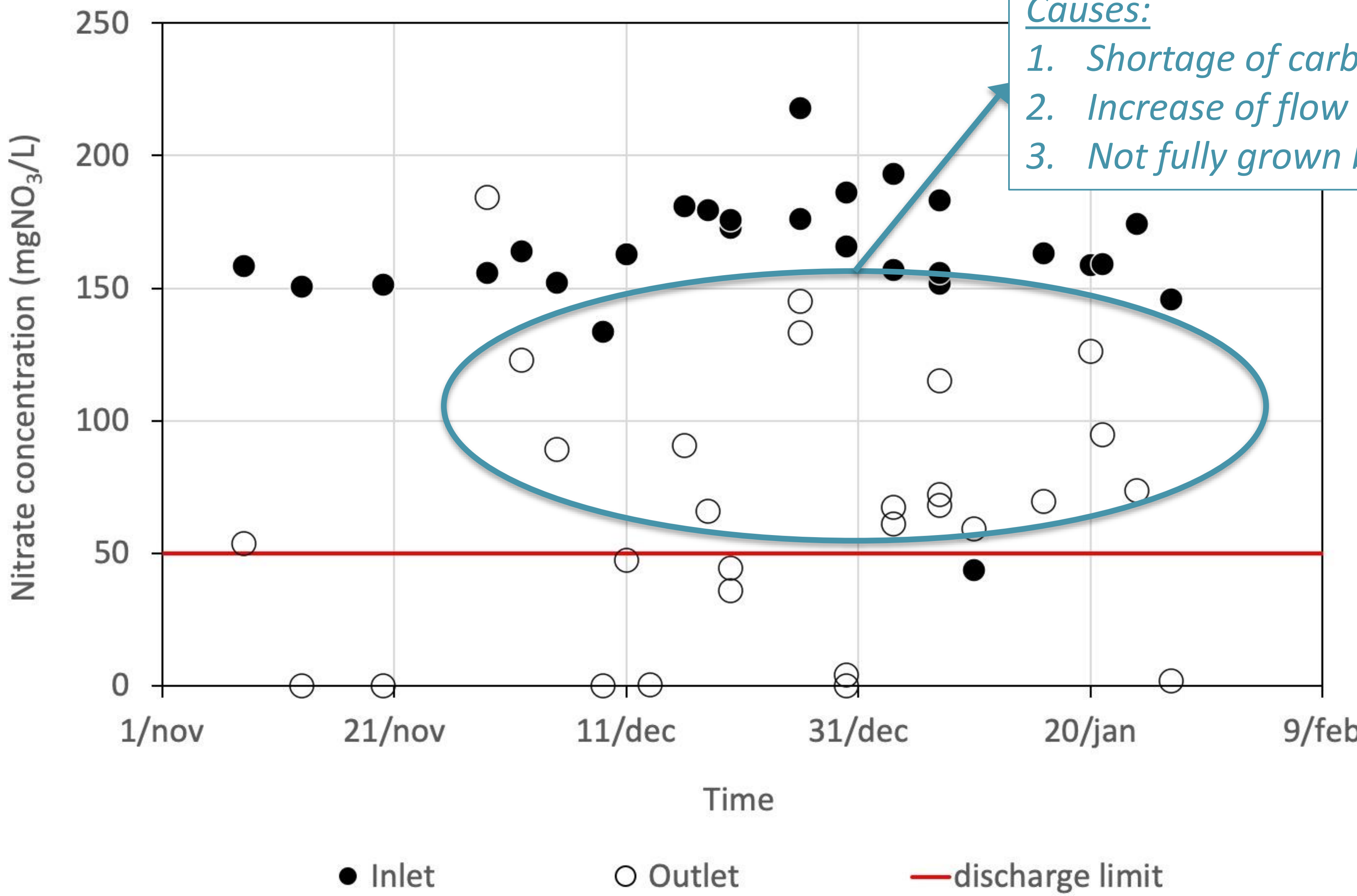
- Drainage water from tile-drained fields
- 10 ft-container: Volume MBBR = 8 $m^3$
- Flow rate: 15 $m^3$/day
- Investment cost: 37 000 € (excl. solar panels)
- Operational cost: 2 660 €/year
- Average removal efficiency: 77% ($C_0$ = 142 mg $NO_3$/L)
- Efficiency cost: 135 €/kg $NO_3$-N removed


# Underground concept

- Drainage water from tile-drained fields
- Concrete well: Volume MBBR = 15 $m^3$
- Flow rate: 15 $m^3$/day
- Investment cost: 30 000 €
- Operational cost: 2 830 €/year
- Efficiency cost: 105 €/kg $NO_3$-N removed

# Underground concept




*Causes:*

1. *Shortage of carbon source*
2. *Increase of flow rate*
3. *Not fully grown biofilm*

# Q & A

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# Acknowledgements


Vlakwa
VLAAMS KENNISCENTRUM WATER
FLANDERS KNOWLEDGE CENTER WATER
empowered by vito

vito

OOWV

KU LEUVEN

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Landwirtschaftskammer Niedersachsen

De Watergroep
WATER. VANDAAG EN MORGEN.

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Provincie Antwerpen

Provincie
Oost-Vlaanderen
Voor ieder van ons

west-vlaanderen
de gedreven provincie