# Schone waterlopen door O3G

## KWALITATIEVER OPPERVLAKTEWATER DANKZIJ EEN INNOVATIEVE TECHNIEK

Micropollutant removal from WWTP effluent

**Learn how Flanders and the Netherlands are tackling this!**

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Gefinancierd door de Europese Unie
Schone Waterlopen door O3G

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CAPTURE

# Combined treatment (ozonisation + GAK) for the removal of micropolutans

## PROBLEM DEFINITION / background


11-3-2025

Ruud Schemen

# Content

- The Waterauthorities
- Our tasks
- Environmental characteristics
- Clean(er) effluent / Legal frame work
- Other aspects
- Solutions ?

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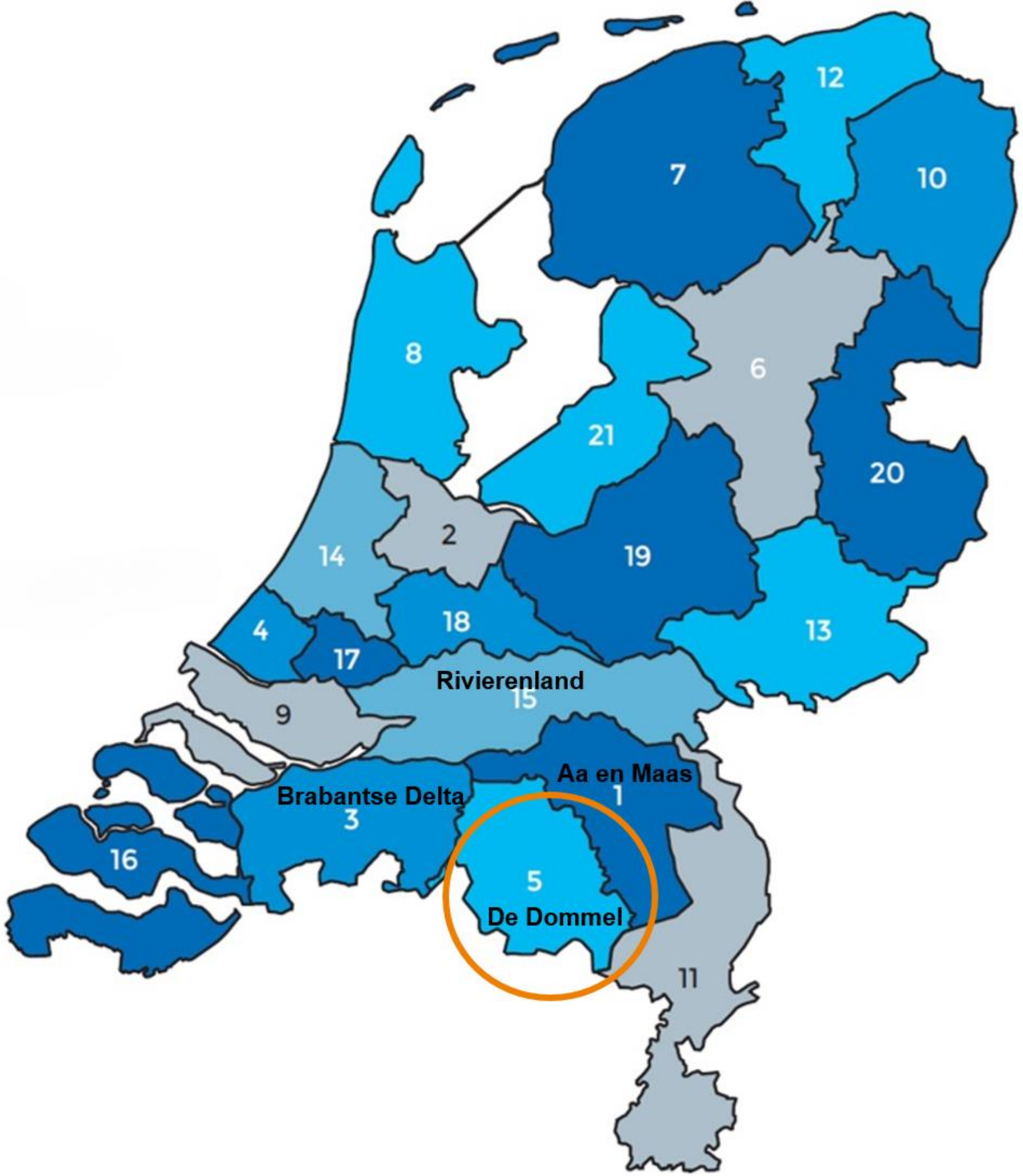
1. Waterschap Aa en Maas
2. Waterschap Amstel, Gooi en Vecht
3. Waterschap Brabantse Delta
4. Hoogheemraadschap van Delfland
5. **Waterschap De Dommel**
6. Waterschap Drents Overijsselse Delta
7. Wetterskip Fryslân
8. Hoogheemraadschap Hollands Noorderkwartier
9. Waterschap Hollandse Delta
10. Waterschap Hunze en Aa's
11. Waterschap Limburg
12. Waterschap Noorderzijlvest
13. Waterschap Rijn en IJssel
14. Hoogheemraadschap van Rijnland
15. Waterschap Rivierenland
16. Waterschap Scheldenstromen
17. Hoogheemraadschap van Schieland en de Krimpenerwaard
18. Hoogheemraadschap De Stichtse Rijnlanden
19. Waterschap Vallei en Veluwe
20. Waterschap Vechtstromen
21. Waterschap Zuiderzeeland



# Waterauthorities are responsible for

- Water quality

- Water quantity

- 

  Water safety (dry feet)

# Environmental characteristics (1)

- Dommel
- Beerze
- Reusel en Essche Stroom
- Zandleij
- Kleine Dommel

# Environmental caracteristics (2)

- Source of surface water

  - ground water

  - rainwater

  - effluent of WWTP


# Cleaner effluent
# Legal framework

- Clean Meuse water chain
- (revised) Urban WasteWaterTreatmentDirective (UWWTD)
- The Water Framework directive

# Other aspects

**Higher (investment) costs**

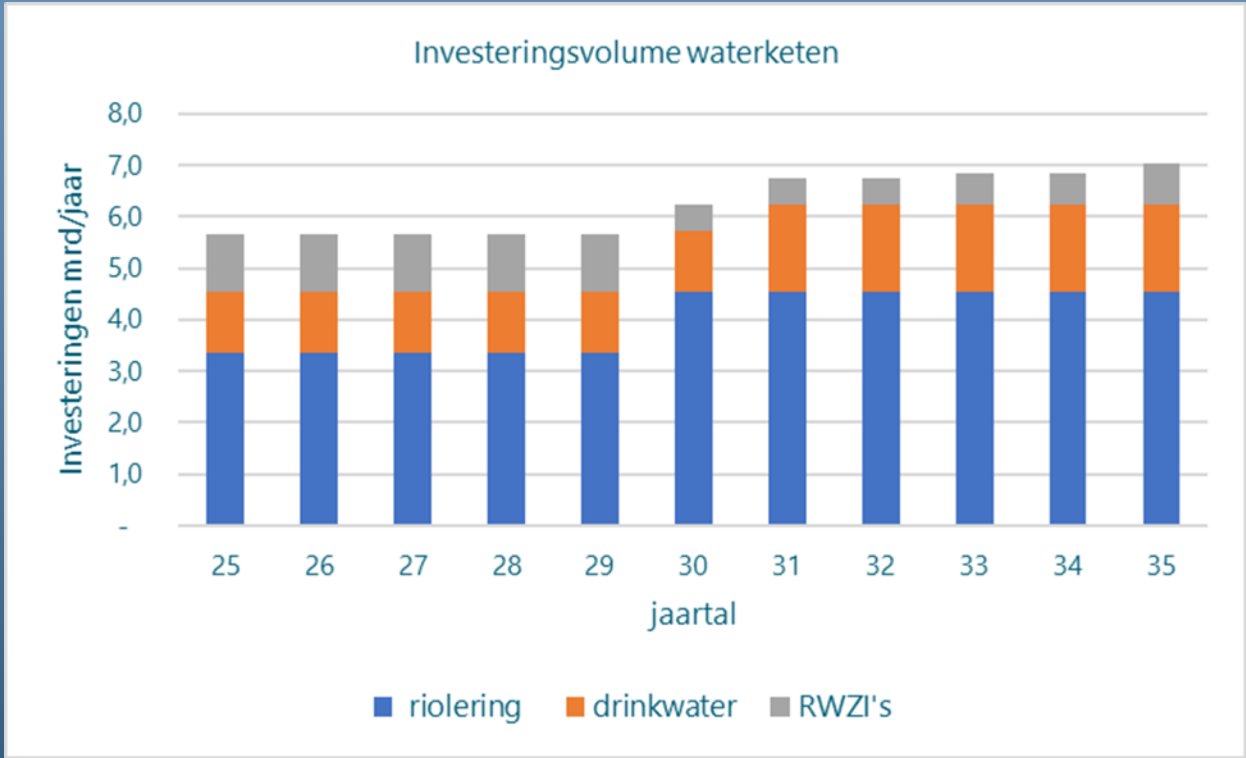
- Maintenance costs
- New investments for new regullation

**Climate goals / sustainability**

- Sustainable energy
- Low carbon footprint

**Lack of space for further treatment**

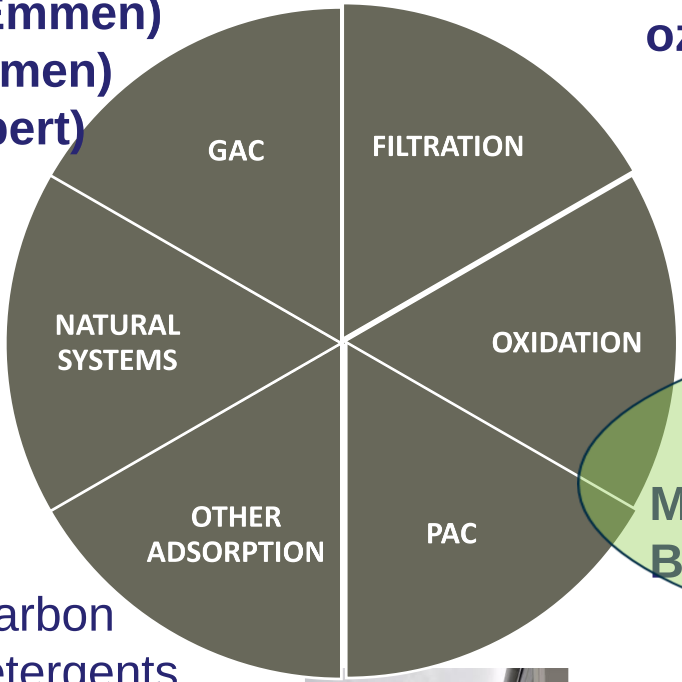
**Bromate standard 1 ug/l**



# INNOVATION PROGRAM

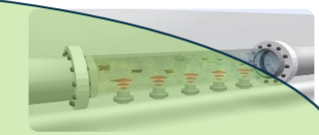
ARVIA
**O3-STEP (Horstermeer)**
**BODAC-O2 (Emmen)**
**Continuous Bio-GAC + air (Emmen)**
**Continuous Upflow µGAC (Hapert)**

**pretreatment – nano filtration (Waterfactory Wilp)**
**nano filtration effluent (Asten)**
**ozone with ceramic micro filtration (Wervershoof)**
Pharem - enzymes




Quick scan
natural systems

**Ultrasound and ozon (Winterswijk)**
**PACO3 (Leiden-Noord)**
**UV (Aarle Rixtel)**
**Ozone (Aarle Rixtel)**
**Microforce O3 and biofilm reactor (Walcheren)**
**B-O3 biological pretreatment, ozone (Horstermeer)**



Fossil free carbon
Zeolites in detergents
Fossil free adsorbents in sand filtration
**AdOx, zeolites filtration (Leiden)**
**Dexsorb, cyclodextrines (Lelystad)**

PACAS + Fe
**PACAS Nereda (Simpelveld)**
**PAC+cloth filtration (Vinkel)**

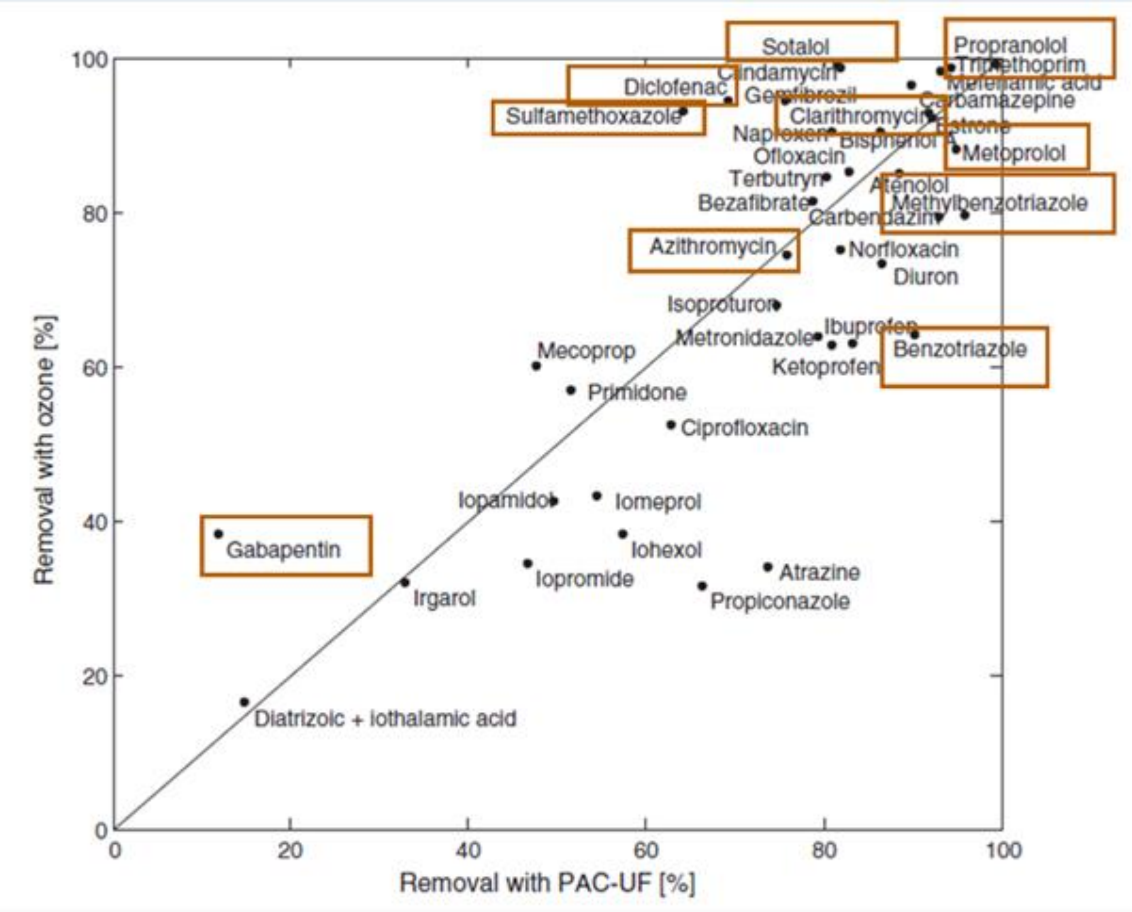
# Best of both Worlds

## Ozone

## - actual dose

## GAC

## - buffer




*Science of the Total Environment 461-462 (2013) 480-498; Margot et al.*

# Thank you for your attention !

- Hier moet nog het Interreg logo komen!

# COMBINING $O_3$ AND GAC FOR MICROPOLLUTANT REMOVAL FROM SECONDARY EFFLUENT: FUNDAMENTAL INSIGHTS

Prof. Dr. ir. Stijn Van Hulle (stijn.vanhulle@ugent.be)

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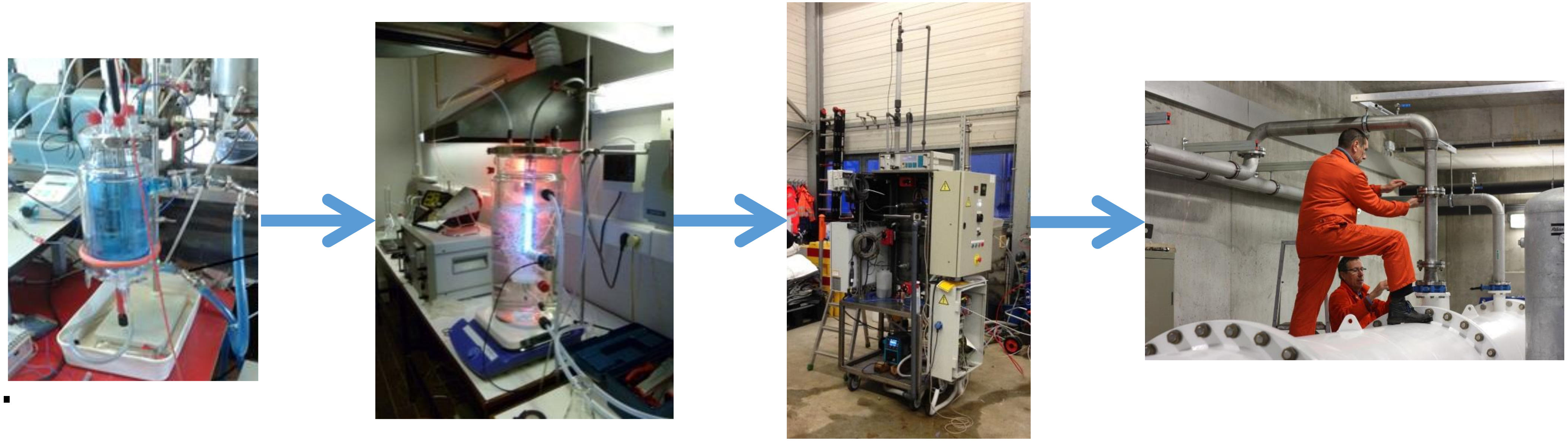
# LIWET@CAMPUS KORTRIJK

- Industrial water treatment and re-use
- Upscaling philosophy



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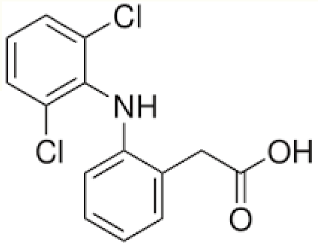
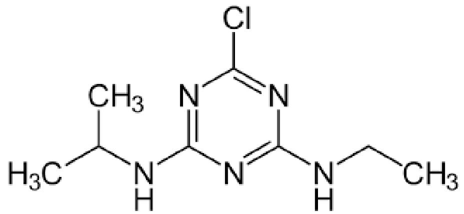
Focus on application: optimising and combining existing technologies

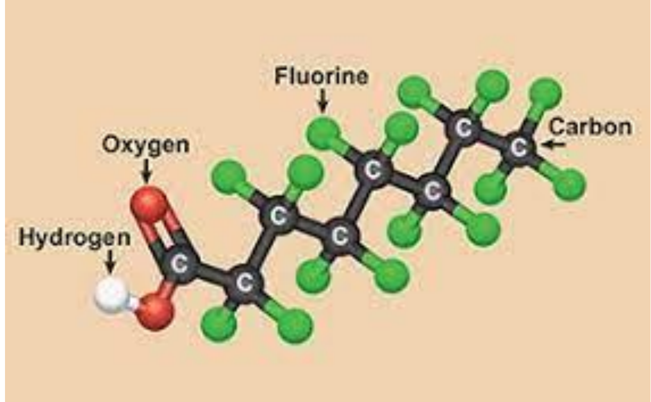
# SITUATING THE PROBLEM

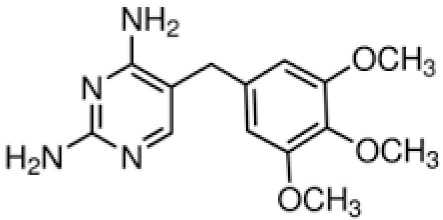
Diclofenac
(Pain relief)

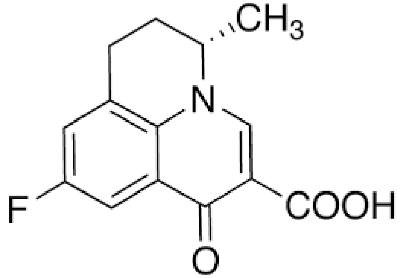










(antibiotic)

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# Eels are getting high on cocaine in Britain's drug-polluted rivers

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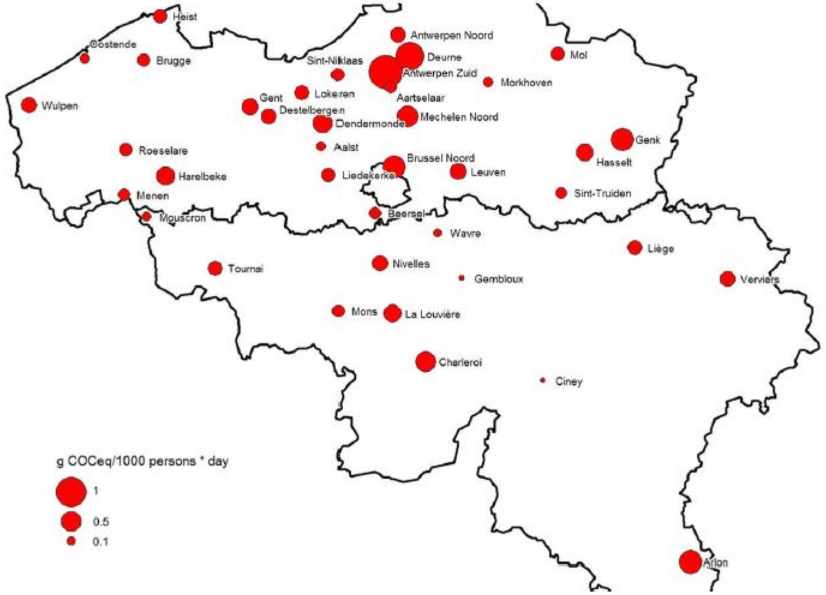
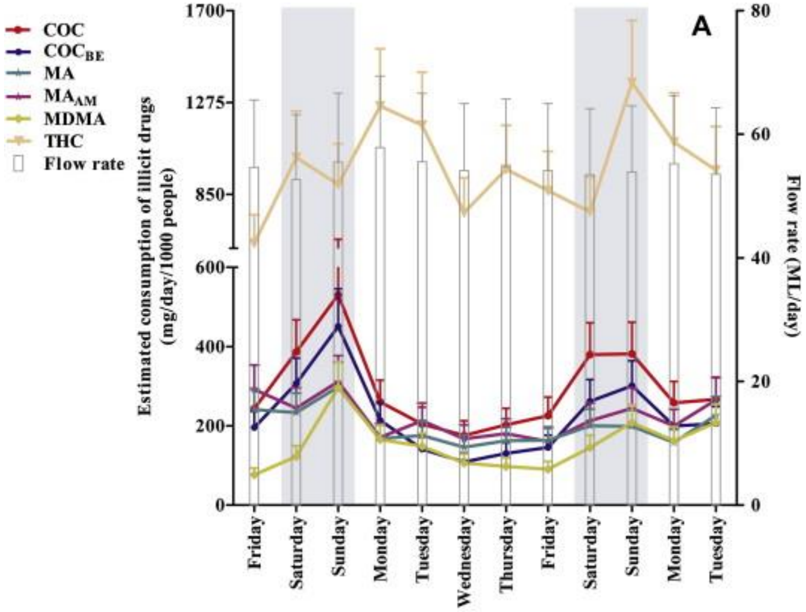
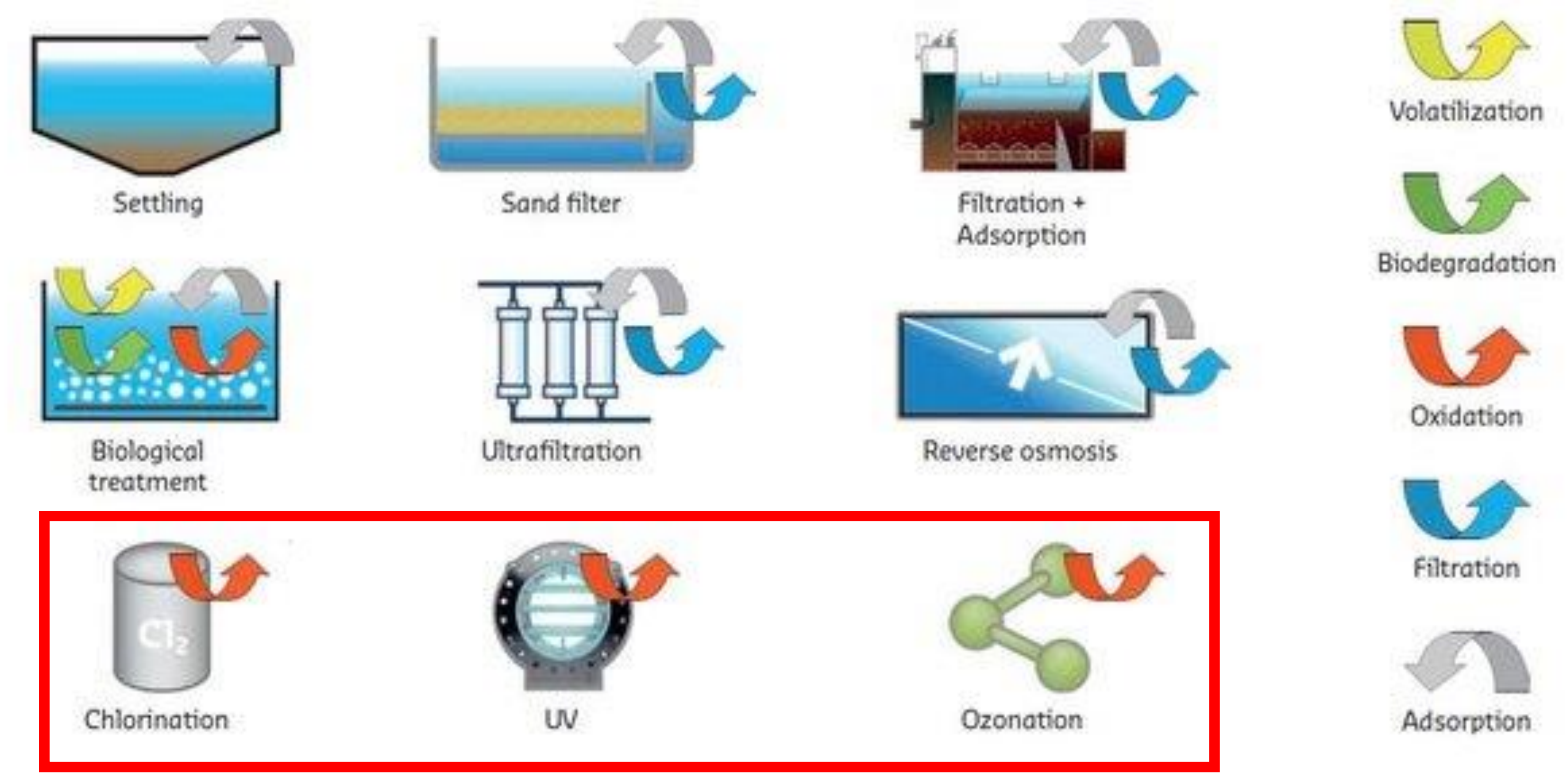



Fig. 1. Locations and results (in COC equivalents in g/day per 1000 inhabitants) of WWTP water samples collected during weekend.



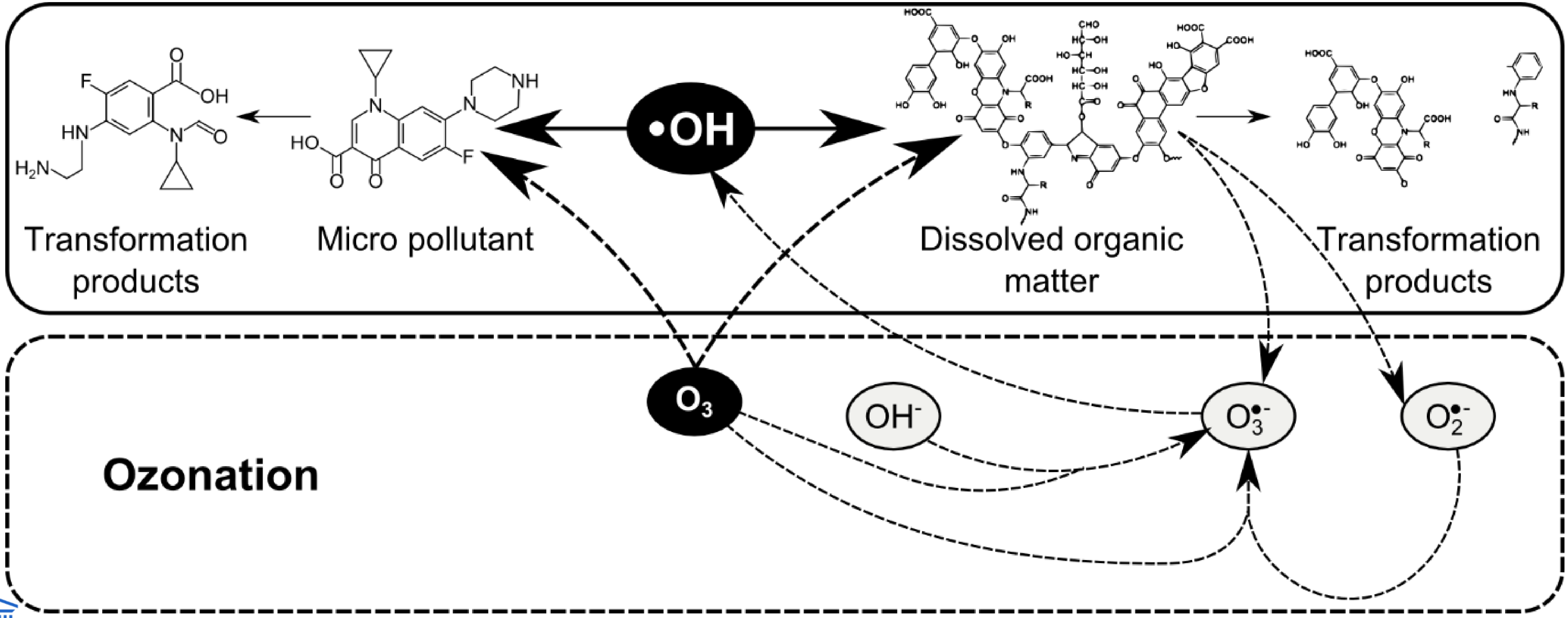
# THE SOLUTION?

– Limited biodegradation
– "Law of conservation of misery"



# THE SOLUTION?

– Post-ozonisation

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# CHALLENGES

- Post-ozonisation
  - Removal function of $k_{O3}$

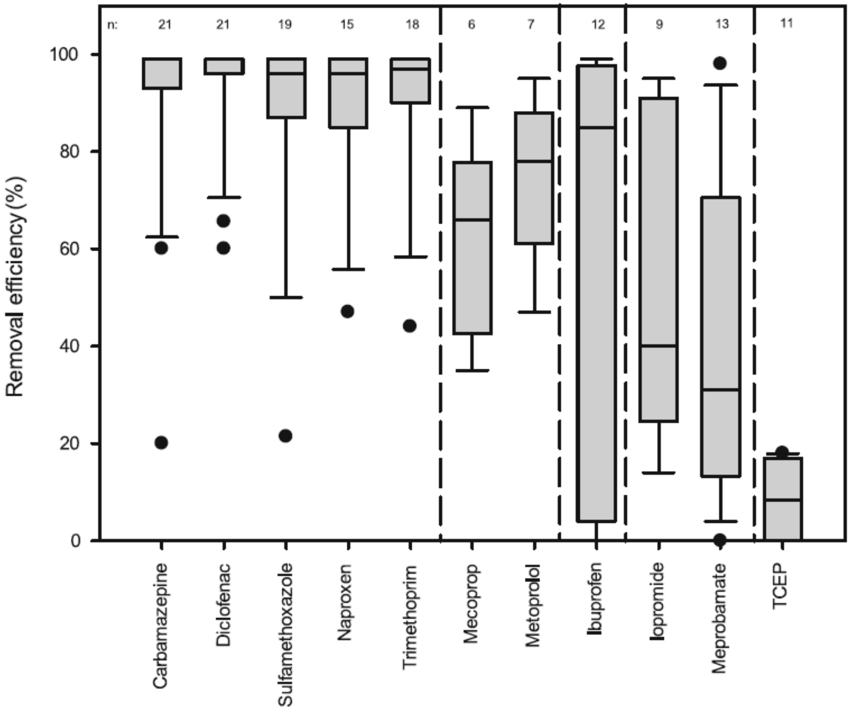


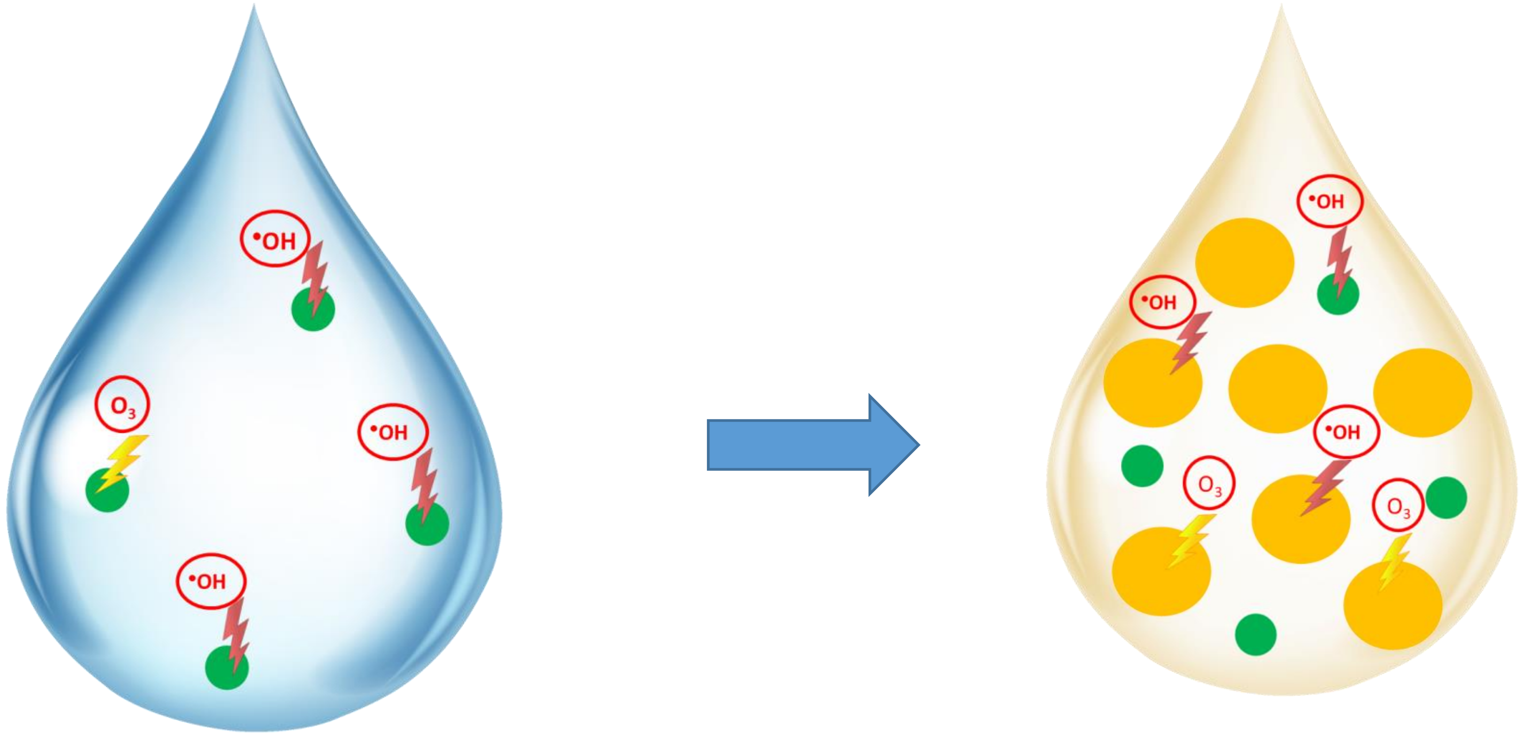

**Fig. 2** Summary of removal efficiencies of TrOCs that can be classified as group I (carbamazepine, diclofenac, sulfamethoxazole, naproxen and trimethoprim), group II (mecoprop and metoprolol), group III (ibuprofen), group IV (iopromide and meprobamate) and group V (TCEP) compounds. Data is extracted from Blackbeard et al. (2016); Gerrity et al. (2012); Hollender et al. (2009); Leikam and Huber (2015); Park et al. (2017); Pisarenko et al. (2012); Singh et al. (2015); Snyder et al. (2006); Wert et al. (2009)

**Table 1** Different groups of TrOCs defined by their specific second order reaction rate constants for both direct ($k_{O3,TrOC,pH7}$) and indirect ($k_{OH,TrOC,pH7}$) ozonation reactions (Gerrity et al. 2012; Lee et al. 2013)

| Group | Description | $k_{O3,TrOC,pH7}$($M^{-1}$ $s^{-1}$) | $k_{OH,TrOC,pH7}$($10^9$ $M^{-1}$ $s^{-1}$) |
|---|---|---|---|
| I | High reactivity with both ozone and ·OH | $\geq 10^5$ | $\geq 5$ |
| II | Moderate reactivity with ozone and high reactivity with ·OH | $< 10^5$ and $\geq 10$ | $\geq 5$ |
| III | Low reactivity with ozone and high reactivity with ·OH | $< 10$ | $\geq 5$ |
| IV | Low reactivity with ozone and moderate reactivity with ·OH | $< 10$ | $< 5$ and $\geq 1$ |
| V | Low reactivity with both ozone and ·OH | $< 10$ | $< 1$ |

# CHALLENGES

- E.g. post-ozonation
  - Reactions with NOM and scavengers




$O_3 + {}^{-}OH \rightarrow \dots \rightarrow {}^{\bullet}OH$

$O_3 + NOM \rightarrow \dots \rightarrow {}^{\bullet}OH$

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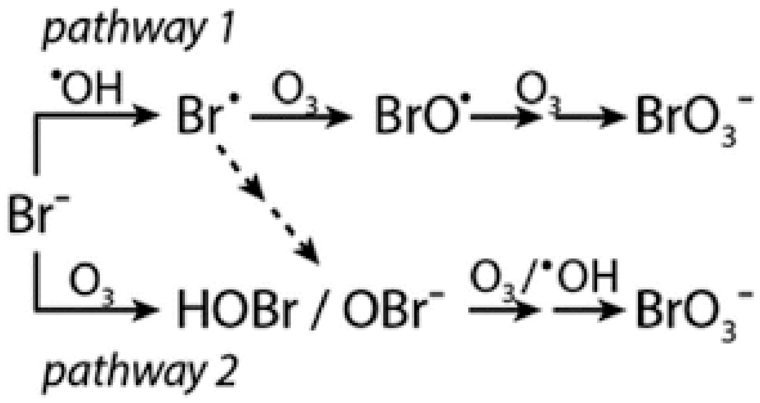
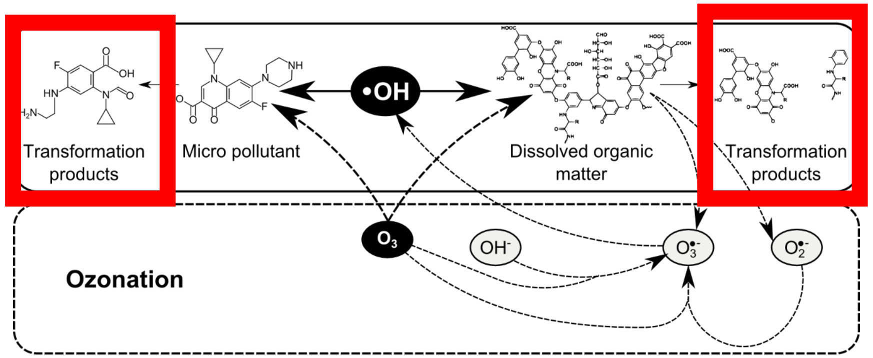
# CHALLENGES

- E.g. post-ozonation
  - Challenges: oxidation products
    - Bromate




    - Transformation products

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# O3G PROJECT

- Tackle some of these challenges
- Pilot and full-scale demonstration

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# O3G INITIATED BY CAPTURE

– Capture platform

## CAPTURE SUMMARY

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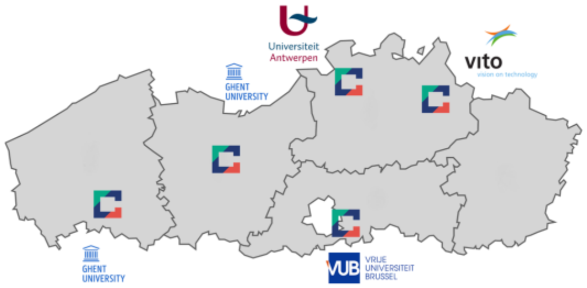


**3 Pipelines**

**14 Programs**

70 research group leaders

>45 research groups

>300 researchers involved

3 business platforms

>45 business platform members

>100 companies we work with

11 staff members

22 supporting members

6 business developers

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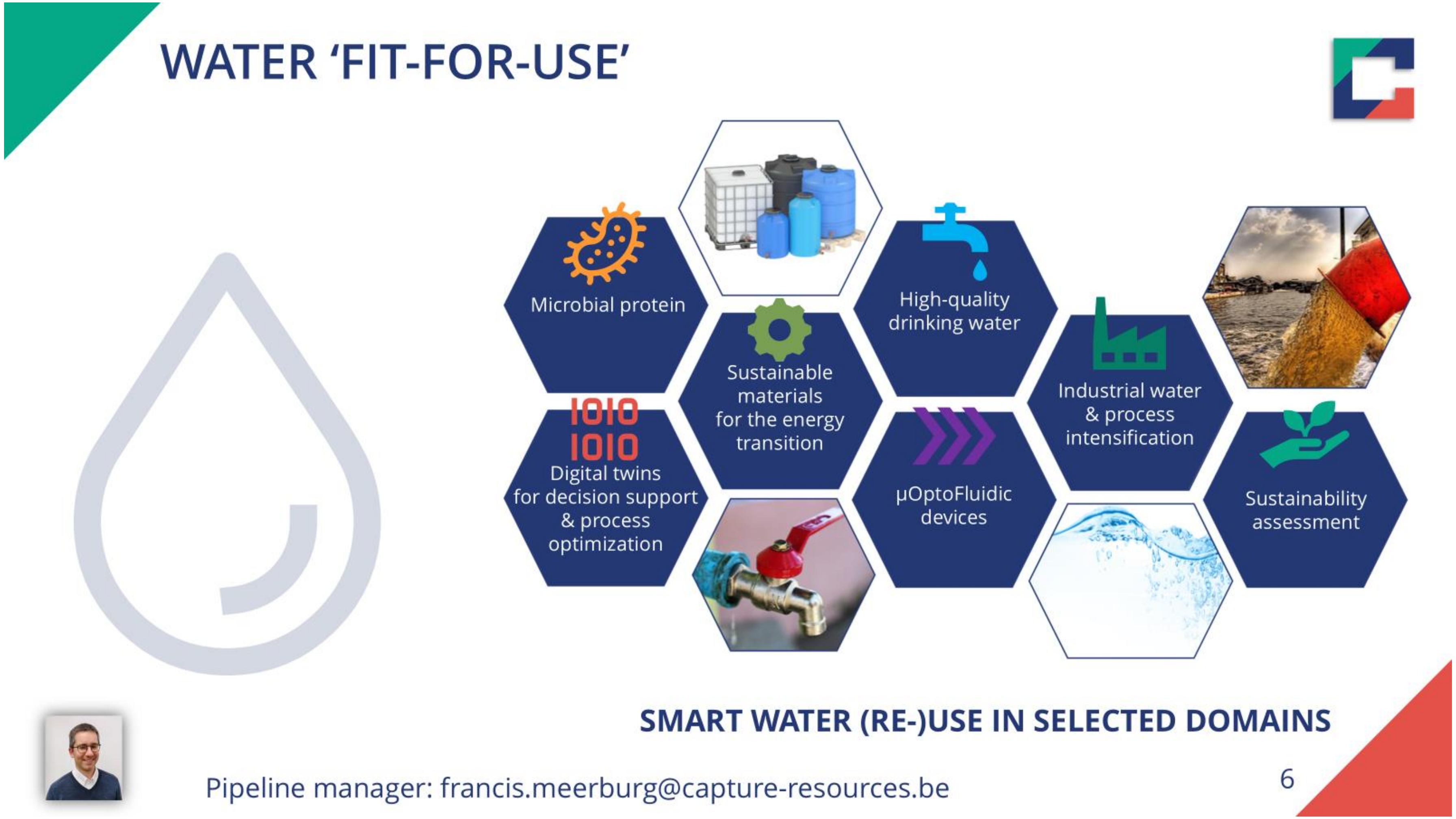
# O3G INITIATED BY CAPTURE

– Capture platform

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# CAPTURE team involved

Stijn Van Hulle
Professor
UGent

Kristof Demeestere
Professor
UGent

Jan Dries
Professor
University of Antwerp

## CAPTURE water platform

The water pipeline was originally conceived as the ´Resource Recovery Technology' business platform at UGent. With the growth of CAPTURE to include additional academic and research institutes, the Water pipeline has expanded it´s scope to include the expertise of all research group leaders that collaborate closely with the companies present in the business platform.

Cooperation is aimed at long term projects/trajectories to develop new, disruptive water technologies for the future. These high risk projects are funded through institutional, regional (Flemish, Belgian) or European funding programs. Next to that, several projects receive funding through bi-lateral funding from companies or sector organizations.

Air Liquide | Evides industriewater | Aquafin | AM TEAM | Witteveen+Bos | Colsen
pidpa | farys | Waterleau | Hydrohm | Ekopak | Waterschap De Dommel
umicore | Kytos

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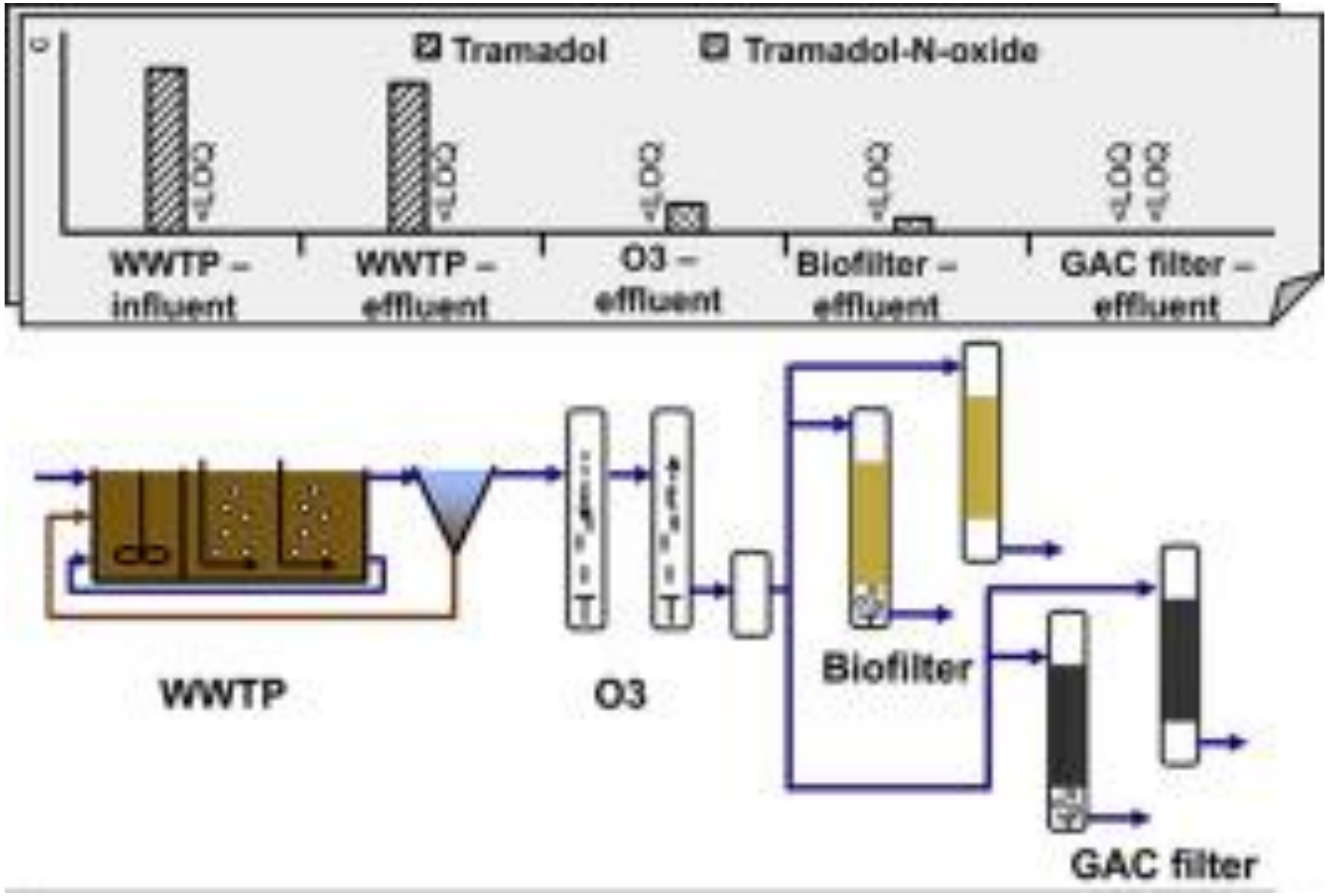
# $O_3$&GAC POST FILTRATION




*Knopp, G., Prasse, C., Ternes, T. A., & Cornel, P. (2016). Elimination of micropollutants and transformation products from a wastewater treatment plant effluent through pilot scale ozonation followed by various activated carbon and biological filters. Water research, 100, 580-592.*

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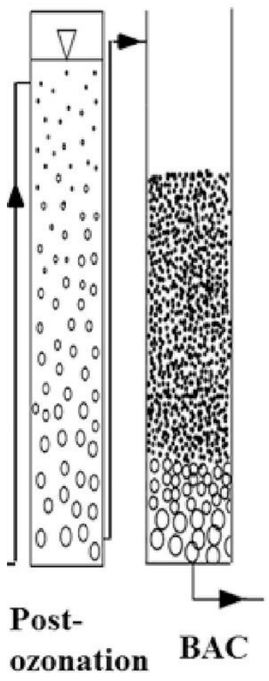
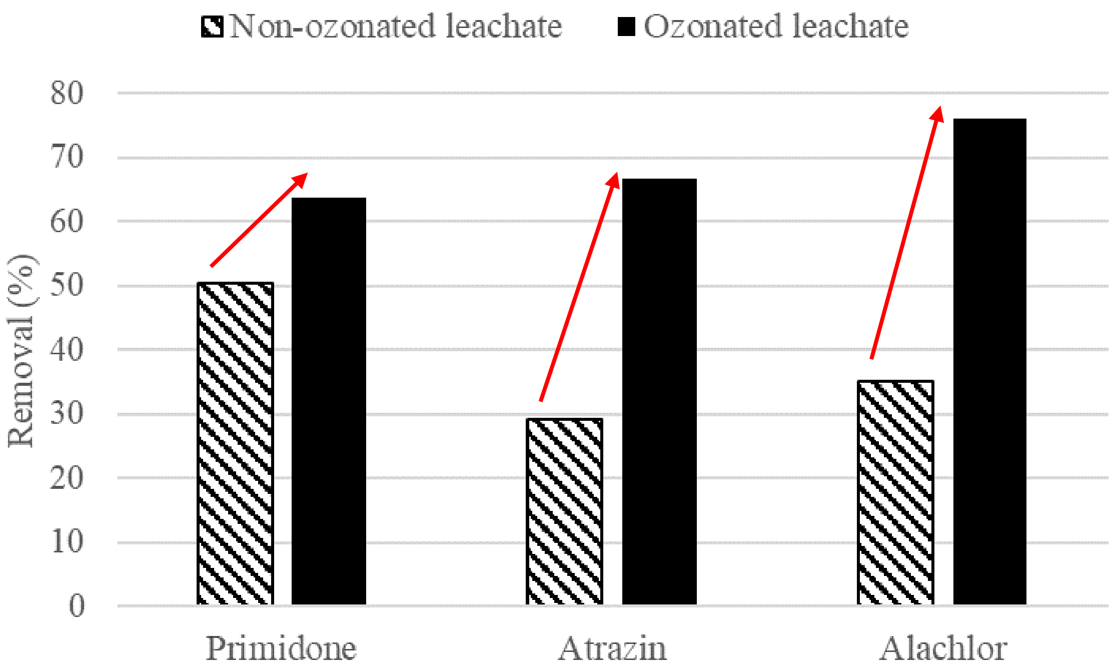
# $O_3$&GAC

- Combination improves removal
  - Removal @ 0,4 gAC/l dose

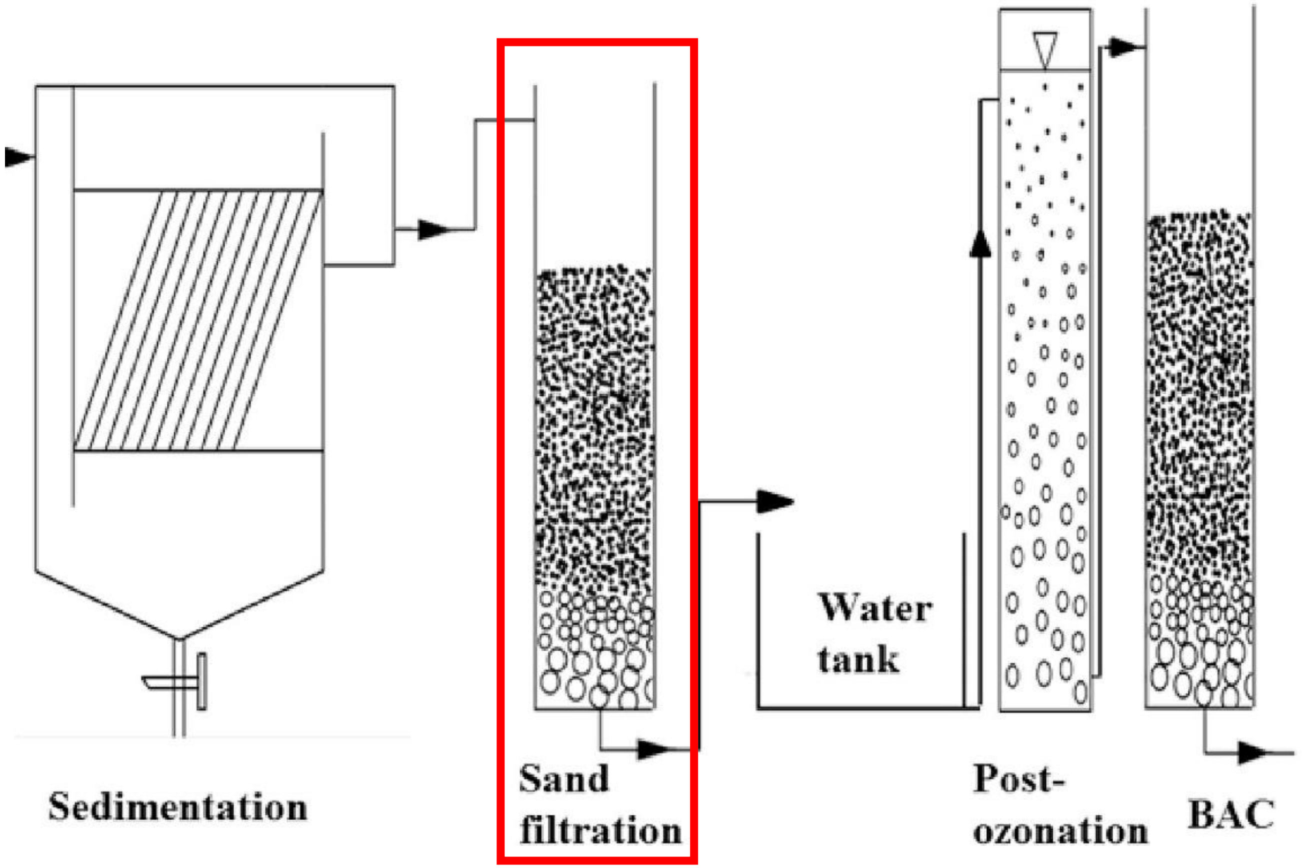



Increased polarity, but less bulk organic material so less load to the activated carbon

# PREFILTRATION

- Remove (part) of the scavengers…
  - Sand, AIEX or AC



# PRE-FILTRATION

– Remove (part) of the scavengers
  – increases µP removal -> less $O_3$ dose required

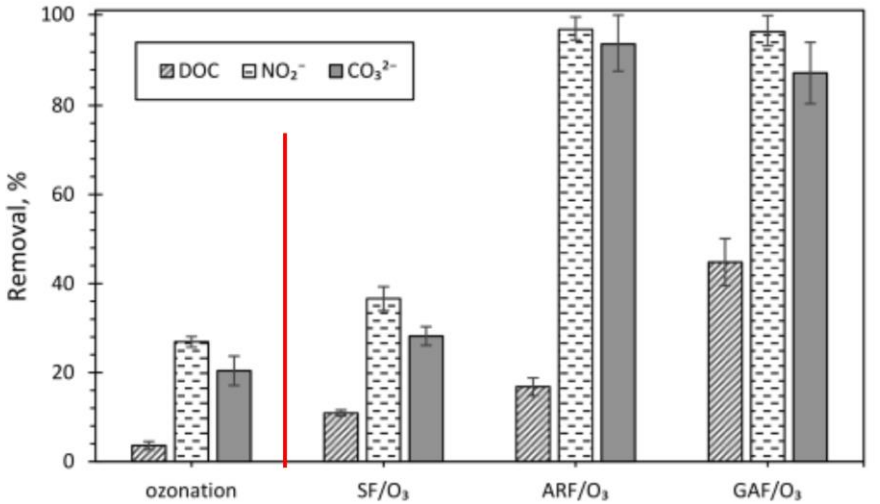



Figure 2. Removal of DOC, $NO_2^-$, and $CO_3^{2-}$ via ozonation and combined filtration–ozonation ($O_3$ dose = 0.1 g $O_3$/g DOC).

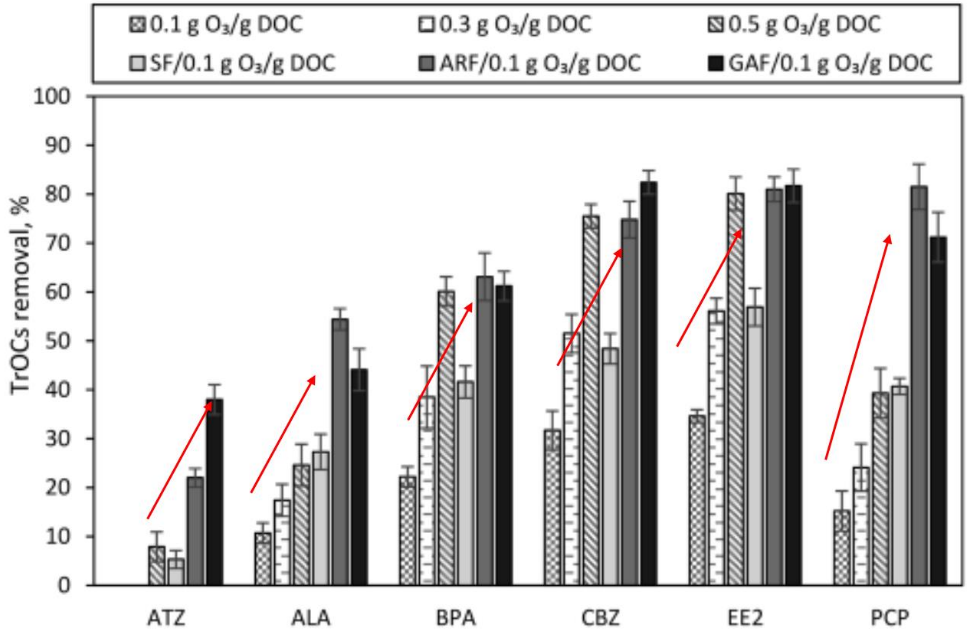



Figure 3. Elimination of TrOCs in effluent after ozonation and combined filtration–ozonation at different ozone doses.

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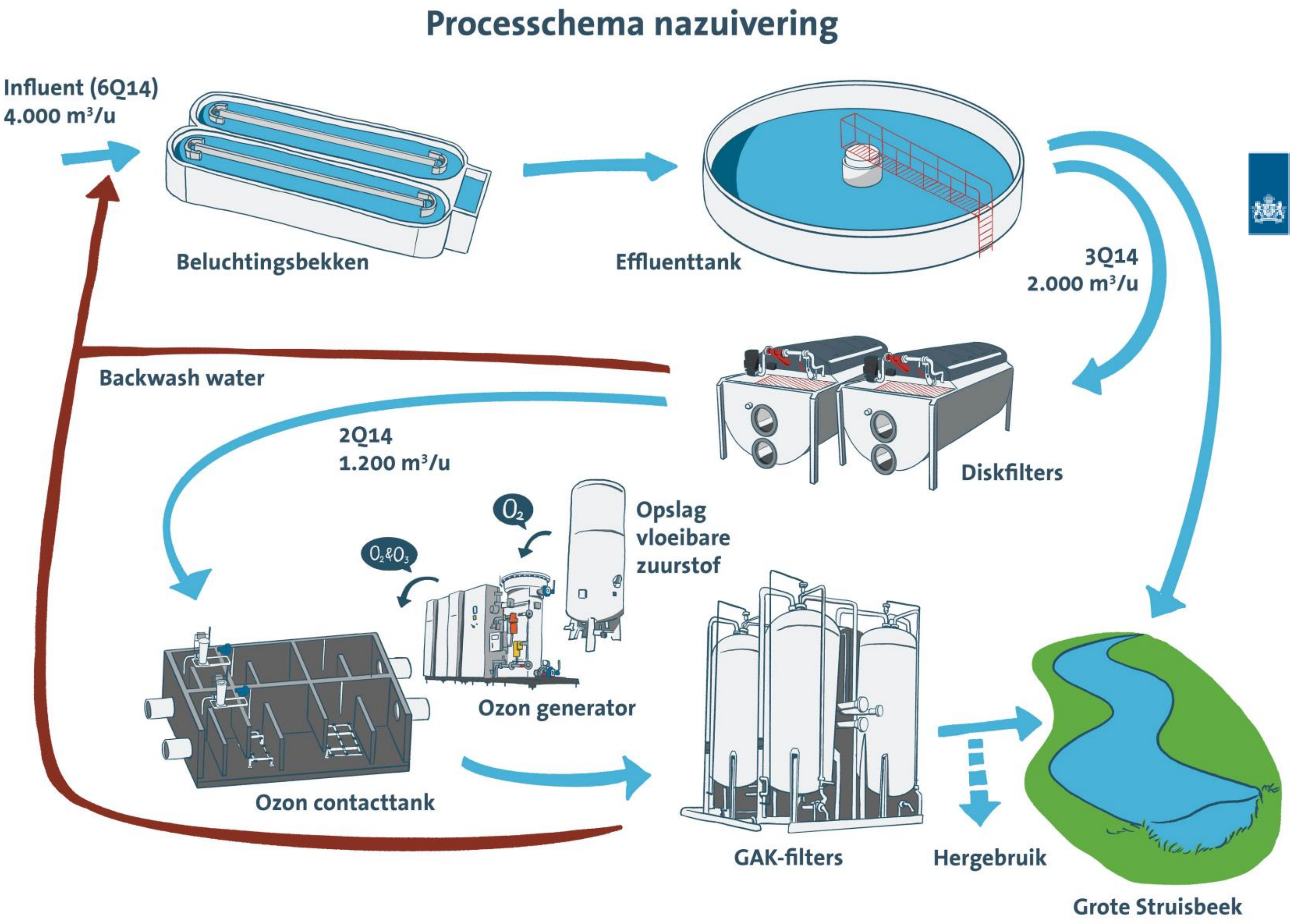
# FULL-SCALE @ AQUAFIN (AND DE DOMMEL)

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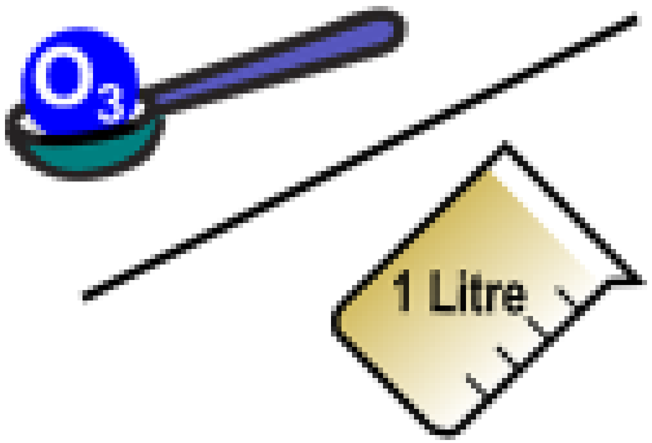
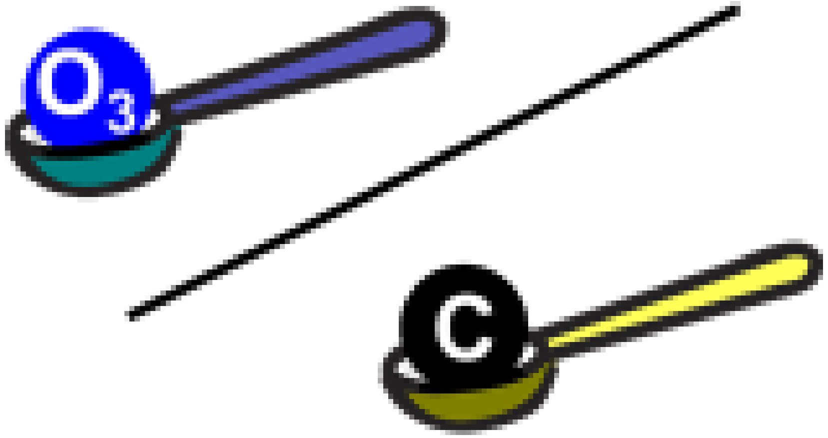
# DOSING OPTIMISATION

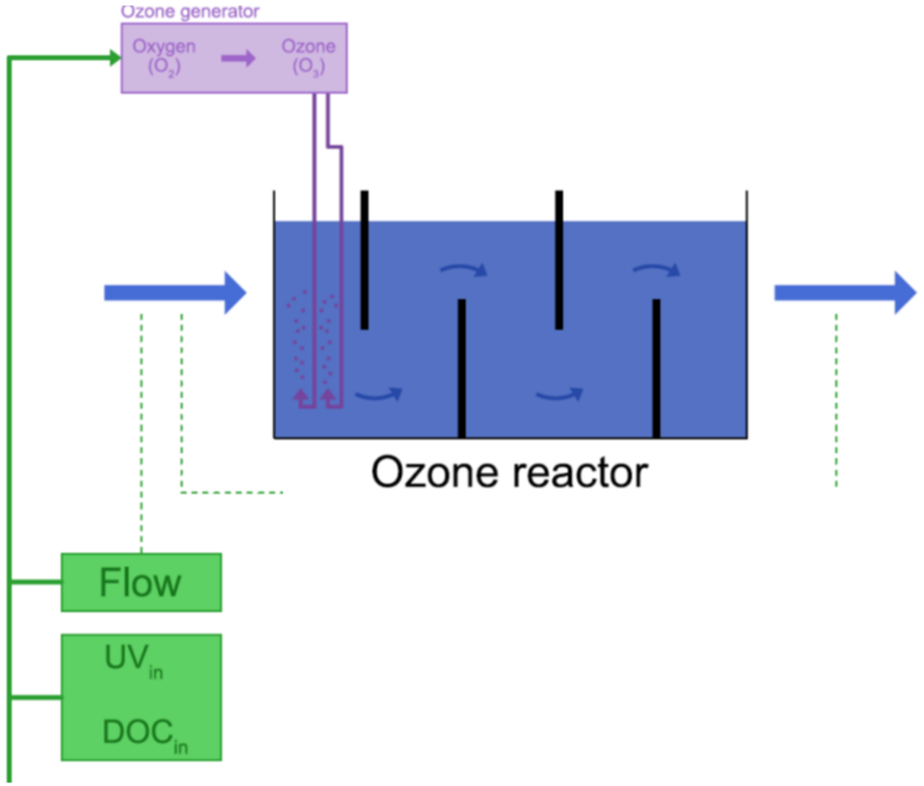
- Classic
  - Flow based
  - Load based



# DOSING OPTIMISATION

- Classic
  - Flow based
  - Load based

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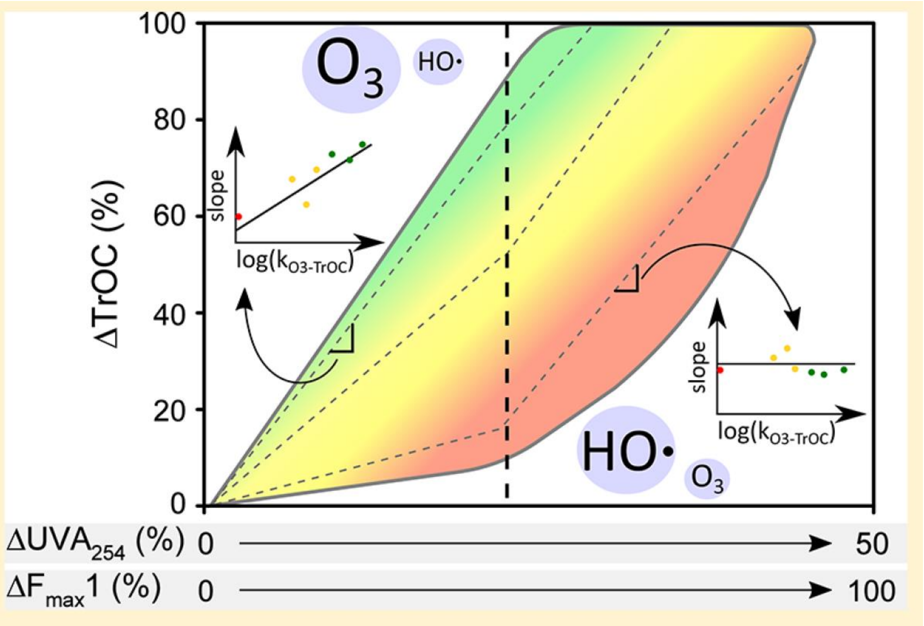
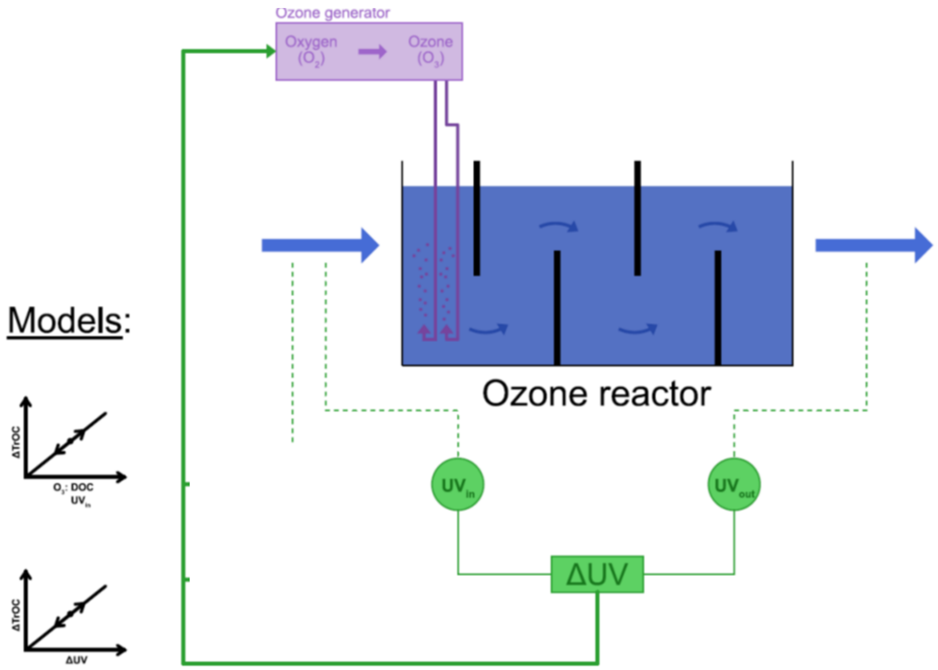
# DOSING OPTIMISATION

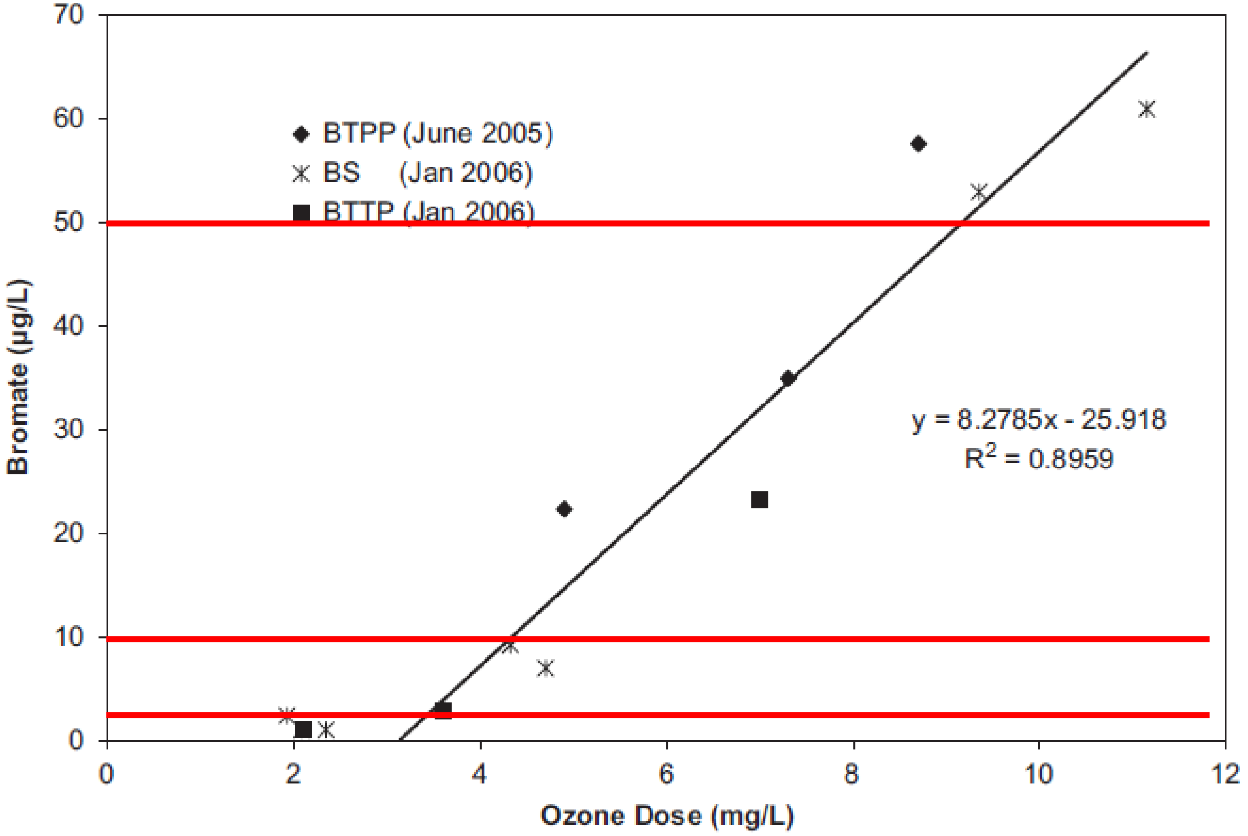
– Control based on $\Delta UV_{254}$



# DOSING OPTIMISATION

– Limited $O_3$ dose: limited $BrO_3^-$ formation




Waste water: limit 50 µg/l (?)

Potable water: limit 1-10 µg/l

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# DOSING OPTIMISATION

– $O_3$+AC: control based on $\Delta UV_{254}$

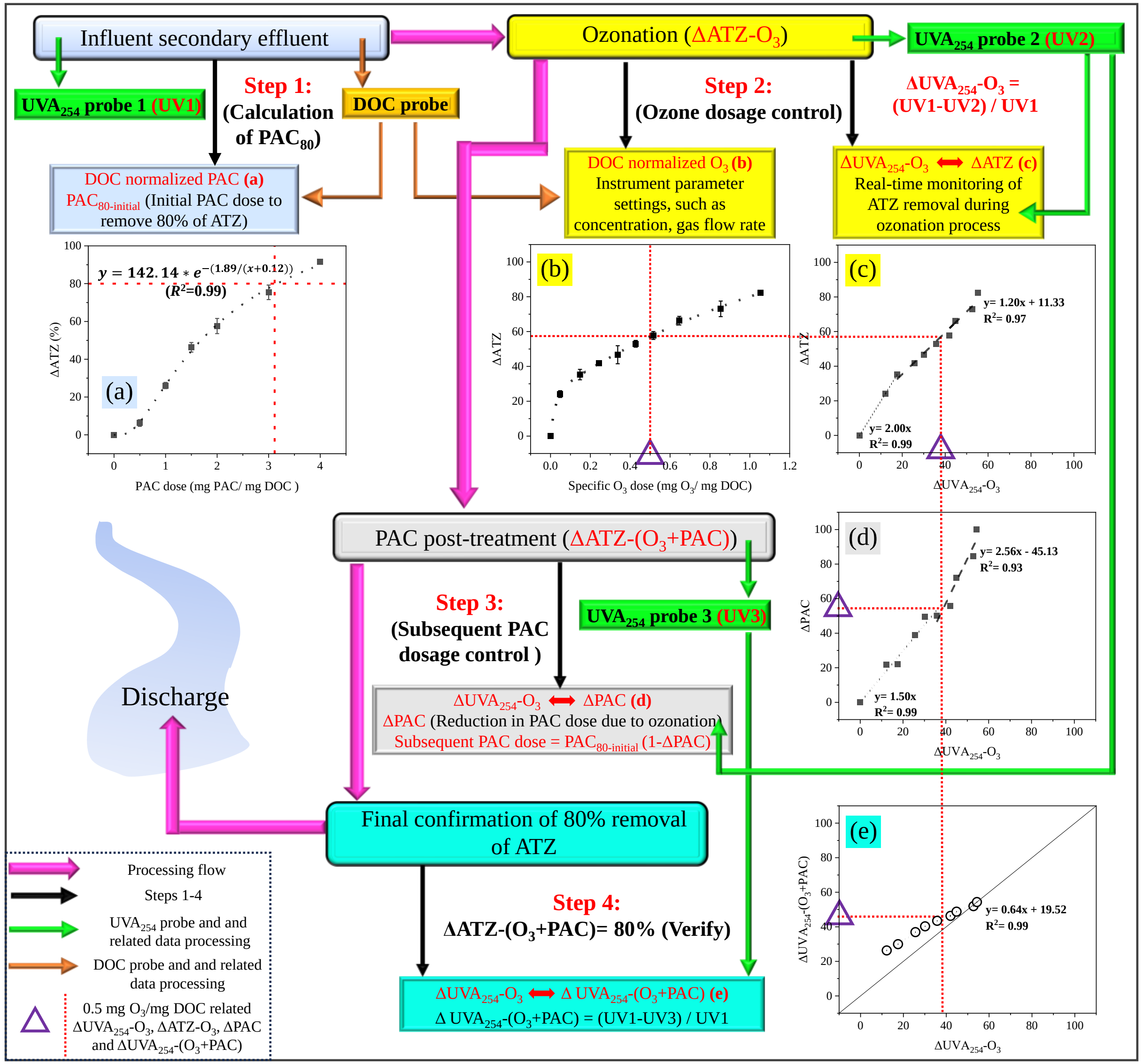

Water Research

Available online 9 October 2024, 122588

In Press, Journal Pre-proof  What's this?

Integrated spectral based monitoring, optimization and control of the combined ozonation and powdered activated carbon adsorption process to remove organic micropollutants from secondary effluent

Tao Zhang [a d e], Liuchun Zheng [b], Xuetong Yang [c], Kristof Demeestere [d e], Stijn W.H. Van Hulle [a e]

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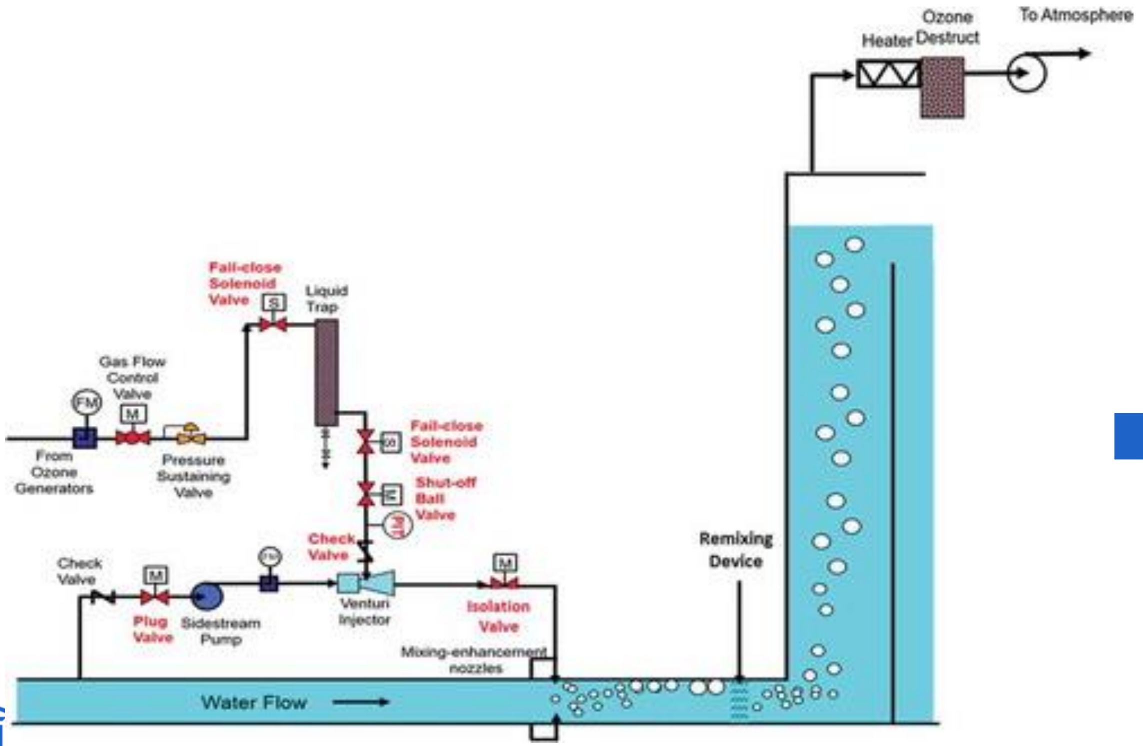
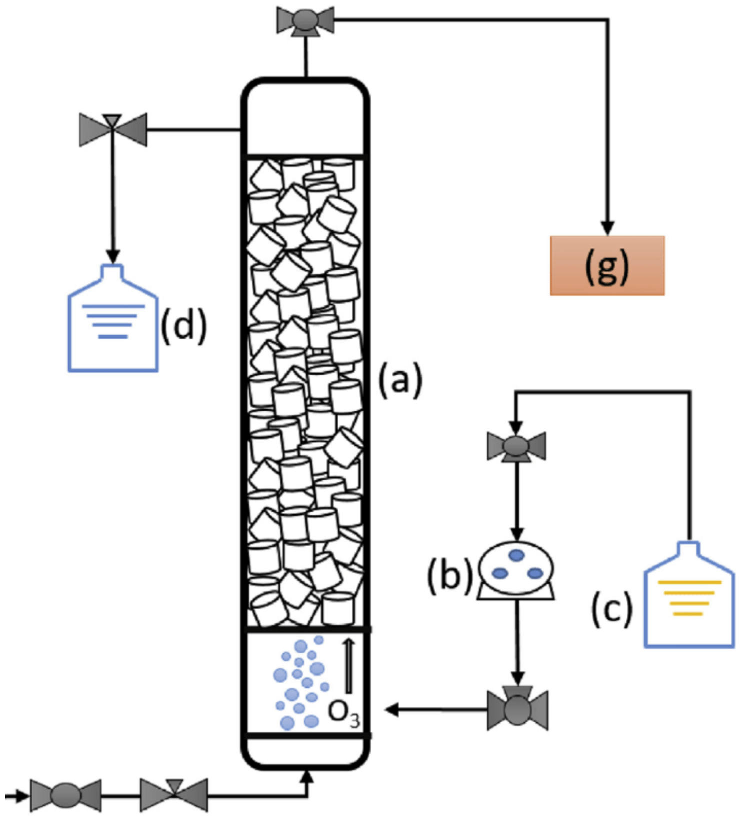
# DOSING OPTIMISATION

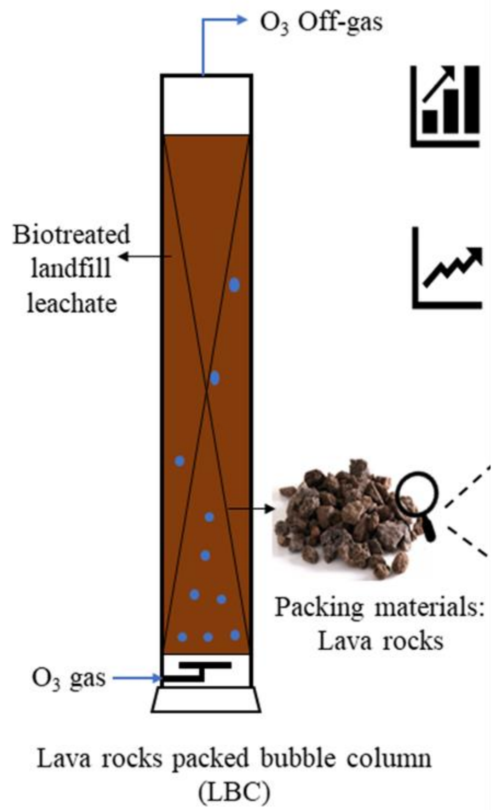
– Packing material: better mass transfer/removal



# DOSING OPTIMISATION

– Packing material: better mass transfer/removal



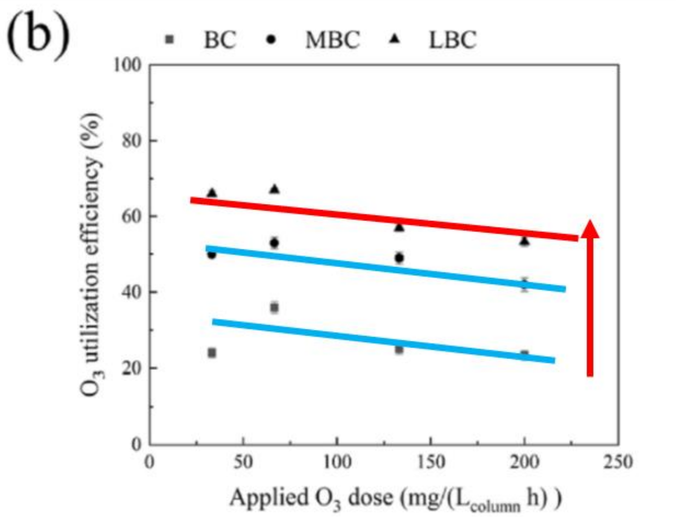




**Fig. 3.** Influence of the applied $O_3$ dose on the HA removal efficiency (a), the $O_3$ utilization efficiency (b) at steady state conditions in packed and non-packed bubble columns operating in the continuous mode. Initial HA concentration: 50 mg/L, initial pH: 7.0, T: 20 ± 1 °C, $O_3$ flow: 100 L/h, liquid flow: 12.6 L/h, applied $O_3$ dose: 33.3–200.0 mg/($L_{column}$ h).

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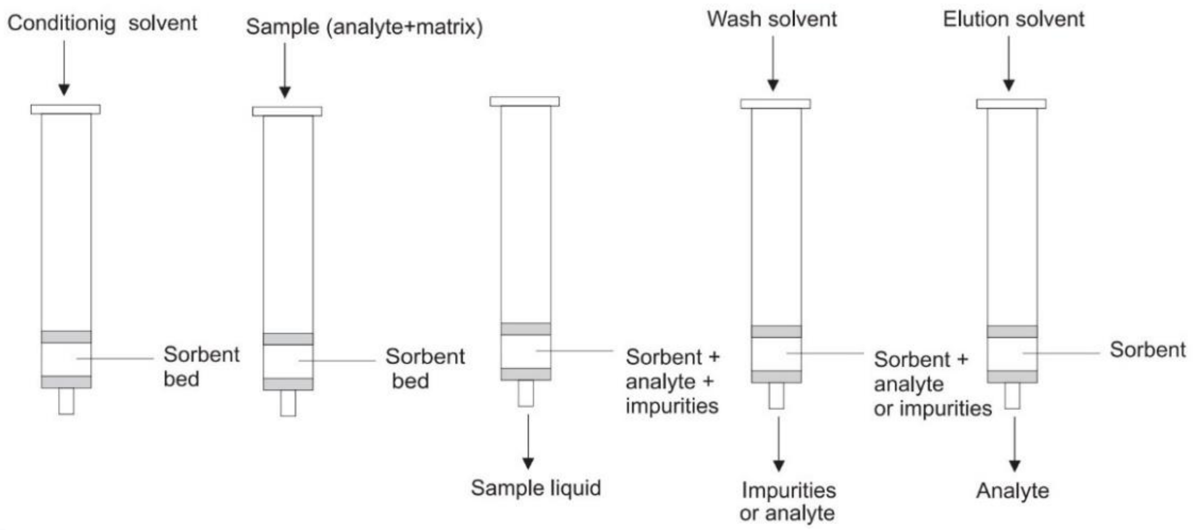
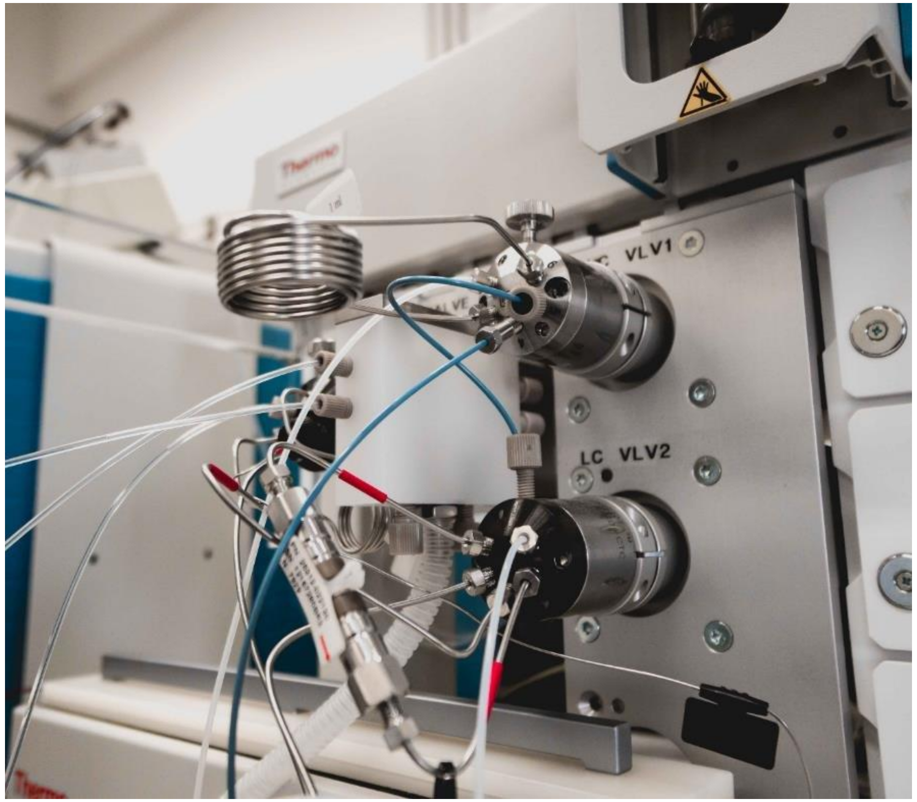
# ANALYTICS: SPE-LC-HRMS

- Simultaneous analysis of 24 micropollutants
  - Pharmaceuticals
  - Pesticides
  - Personal care products




Solid-phase microextraction




UHPLC-HRMS

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# ANALYTICS: SPE-LC-HRMS

| ERSA | Guide (NL) | Daniel | Micropollutant | Type | $K_{O3}$ ($M^{-1}$ $S^{-1}$) (pH =7) | $K_{\cdot OH}$ $10^9$ $M^{-1}$ $s^{-1}$) (pH =7) | log $K_{ow}$ |
|---|---|---|---|---|---|---|---|
| | | | Chloramphenicol | Antibioticum | 0.1 | 5.8 | 1.14 |
| | | | DEET | Insect Repellent | 0.12 | 5 | 2.02 |
| | | x | Alachlor | Pesticide | 2.5 | 7 | 3.52 |
| | | | Flumequine | Antibioticum | 6 | 8.3 | 1.6 |
| | | x | Atrazine | Pesticide | 6 | 3 | 2.61 |
| | | | Amantadine | Antidyskinetic | 8 | n.d. | 2.44 |
| | | x | Diuron | Pesticide | 16.3 | 7.1 | 2.85 |
| | | | Metronidazole | Antibioticum | 253 | 6.2 | -0.02 |
| | | | Bezafibrate | Lipid Regulator | 5.90E+02 | 7.4 | 3.8 |
| | | | Atenolol | Beta-Blocker | 2.00E+03 | 8 | 0.16 |
| | | | Amitriptyline | Antidepressivum | 2.50E+03 | 10.3 | 5.04 |
| x | (x) | x | Venlafaxine hydrochloride | Antidepressivum | 8.50E+03 | 8.2 | 3.2 |
| | x | | Sotalol | Beta-Blocker | 1.90E+04 | ~100 | 0.24 |
| | | | Ciprofloxacin | Antibioticum | 1.90E+04 | 4.1 | 0.28 |
| x | x | | Claritromycine | Antibioticum | 4.00E+04 | n.d. | 3.16 |
| | | | Levofloxacin | Antibioticum | 6.00E+04 | 5.2 | -0.39 |
| | x | x | propranolol | Beta-Blocker | 1.00E+05 | 10 | 2.98 |
| | x | | Trimethoprim | Antibioticum | 2.70E+05 | 6.9 | 0.91 |
| x | x | x | Carbamazepine | Anticonvulsant | 3.00E+05 | 8.8 | 2.45 |
| | | | Tetracycline | Antibioticum | 1.00E+06 | n.d. | -1.3 |
| | x | x | Sulfamethoxazole | Antibioticum | 2.50E+06 | 5.5 | 0.89 |
| x | x | x | Diclofenac | NSAID | 3.46E+06 | 7.5 | 0.7 |
| | | | Oxytetracycline | Antibioticum | 9.80E+06 | n.d. | -0.9 |
| | | | Lamivudine | Antiretroviral | n.d | n.d. | -1.4 |

** n.d. no data available*

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# QUESTIONS?

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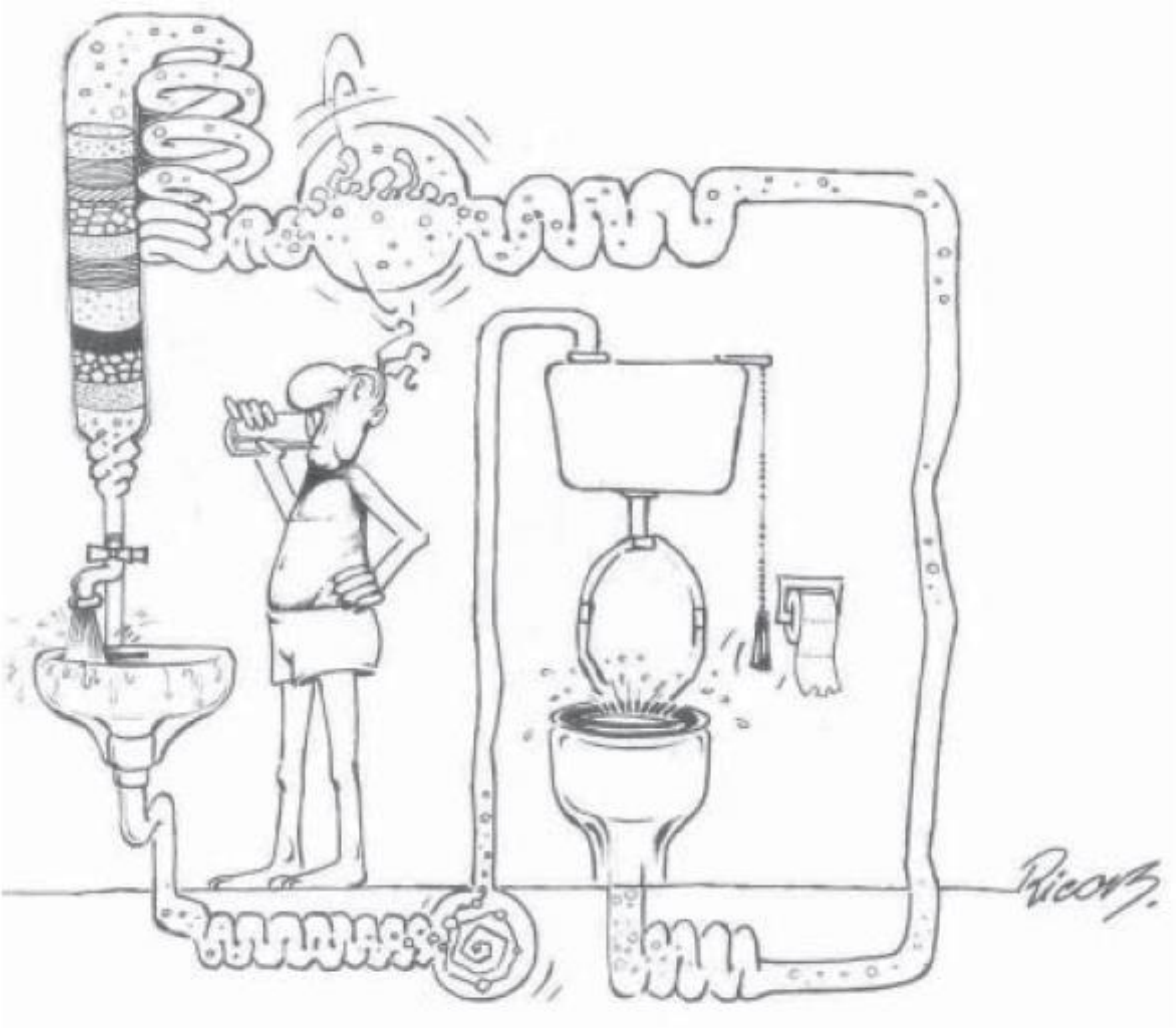


AM Team

# Modelling to remove the uncertainties around ozonation of secondary effluent

## Aquatech Amsterdam 2025

Eng. Pieter Vlasschaert
Pieter.Vlasschaert@am-team.com

AM-Team.com

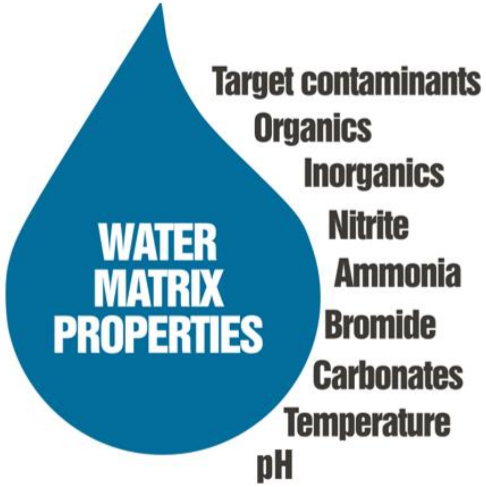
# Why modelling?



- Uncertainties when it comes to ozonation

**1**

**Every water matrix is unique...**

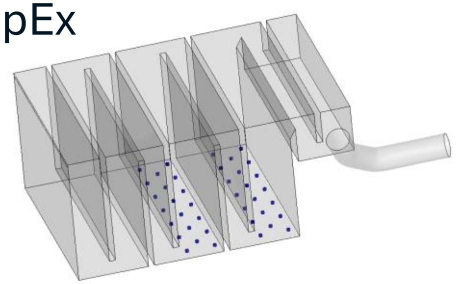



**2**

**Lab or pilot testing takes long and are expensive, while leaving many questions unanswered**

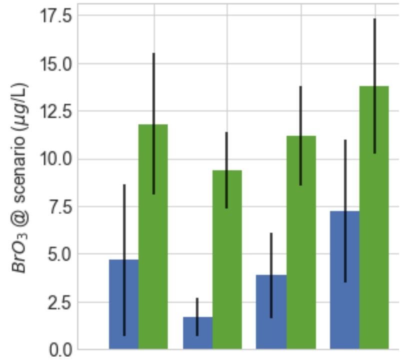
**3**

**Design is a balancing act**




**4**

**The key variables are hard and expensive to measure**



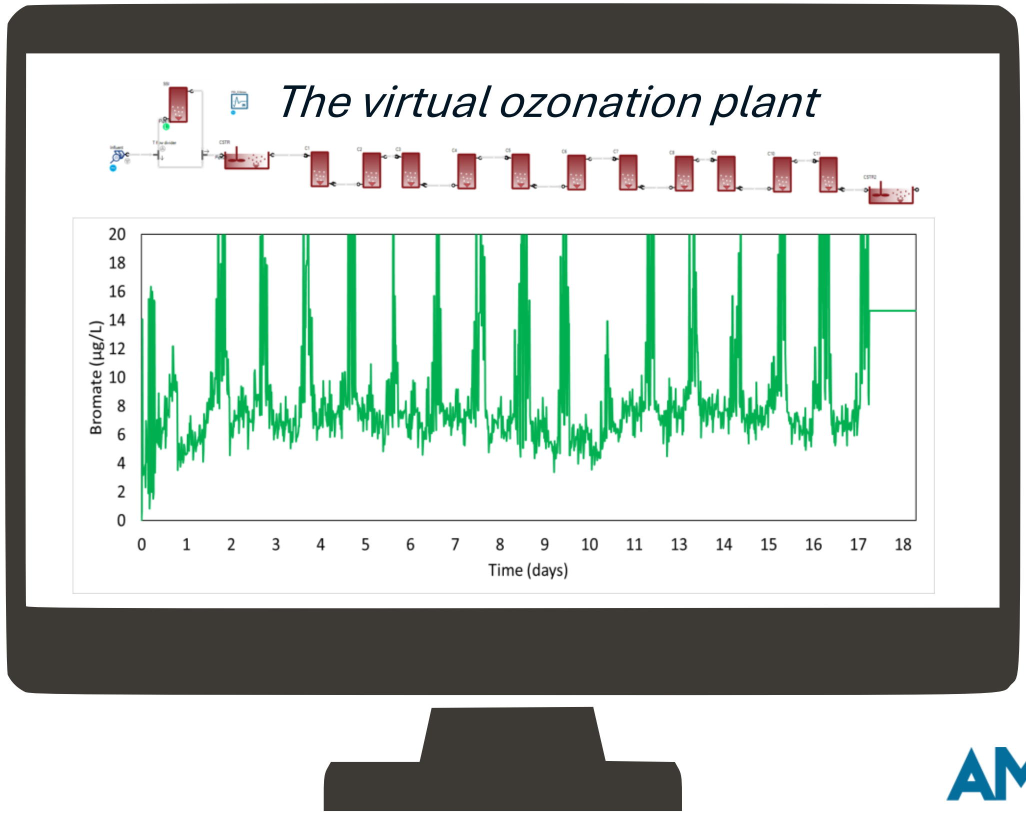
# Why modelling?

AM Team

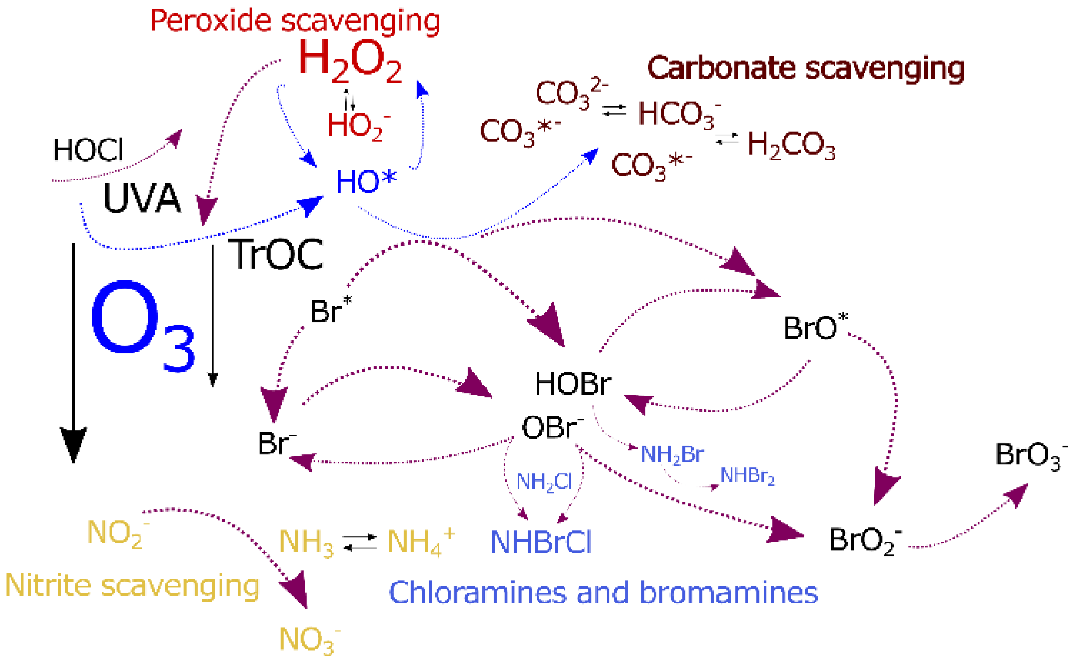
- AMOZONE model applied to > 35 reactors worldwide (USA, Hong Kong, Europe) for drinking water and wastewater

Water Europe Technology & Innovation — Digital Water Award AM OZONE

## Front end




## Backend

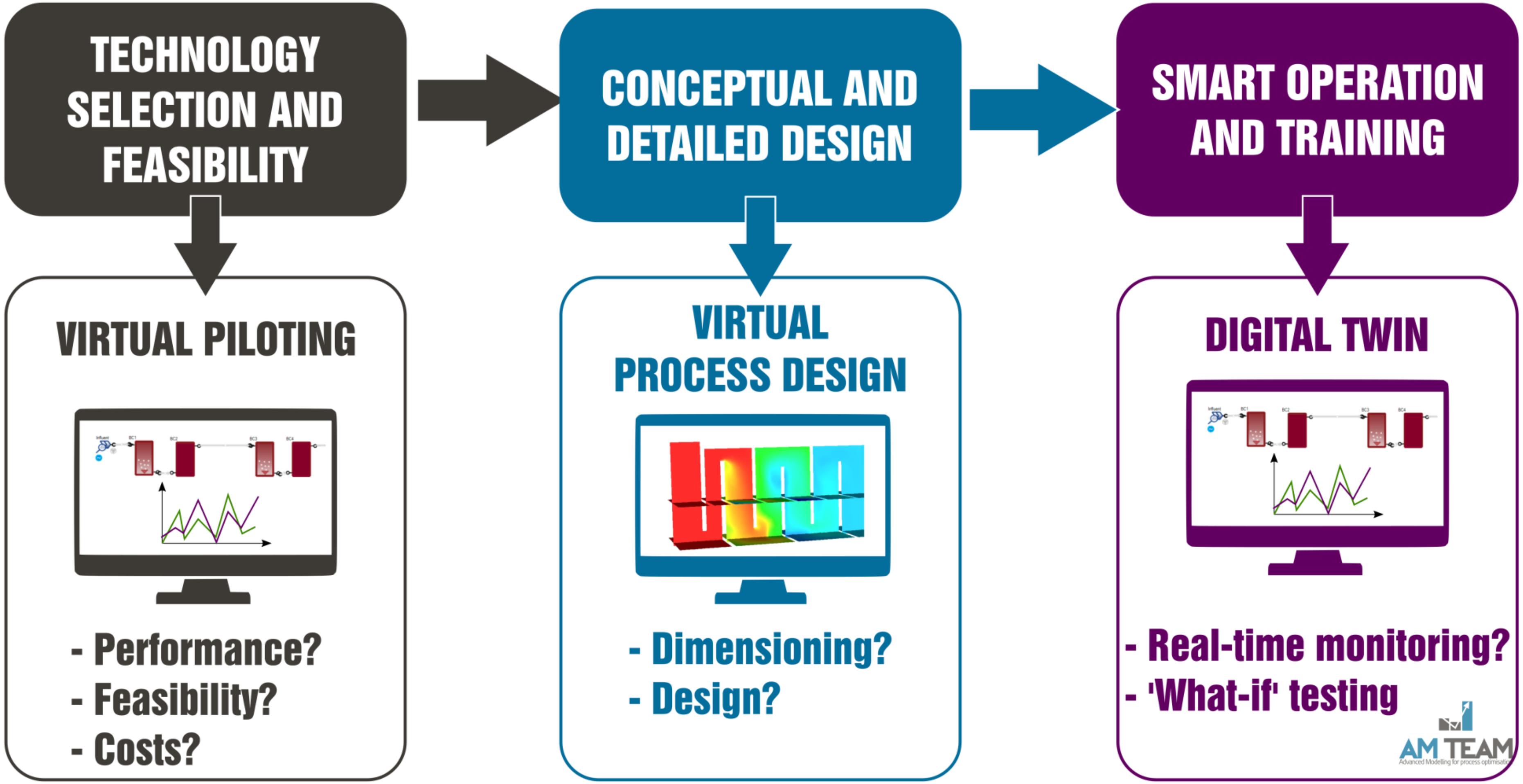



AM OZONE
A product of AM TEAM

# Why modelling?



- Applications AM OZONE A product of AM TEAM

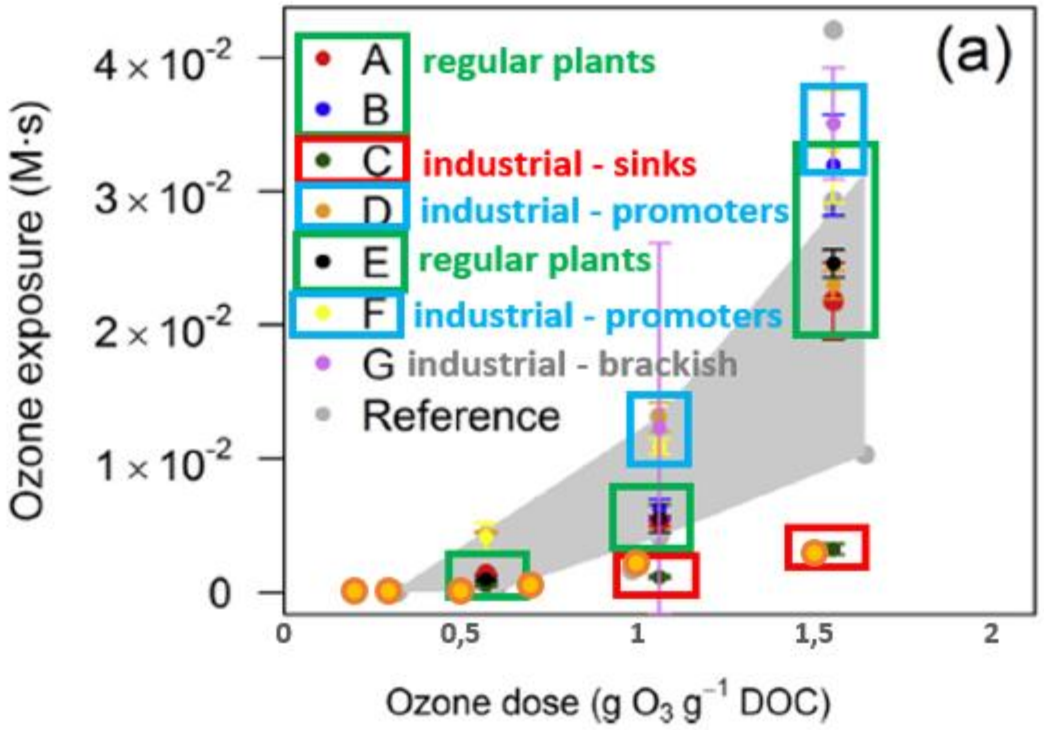


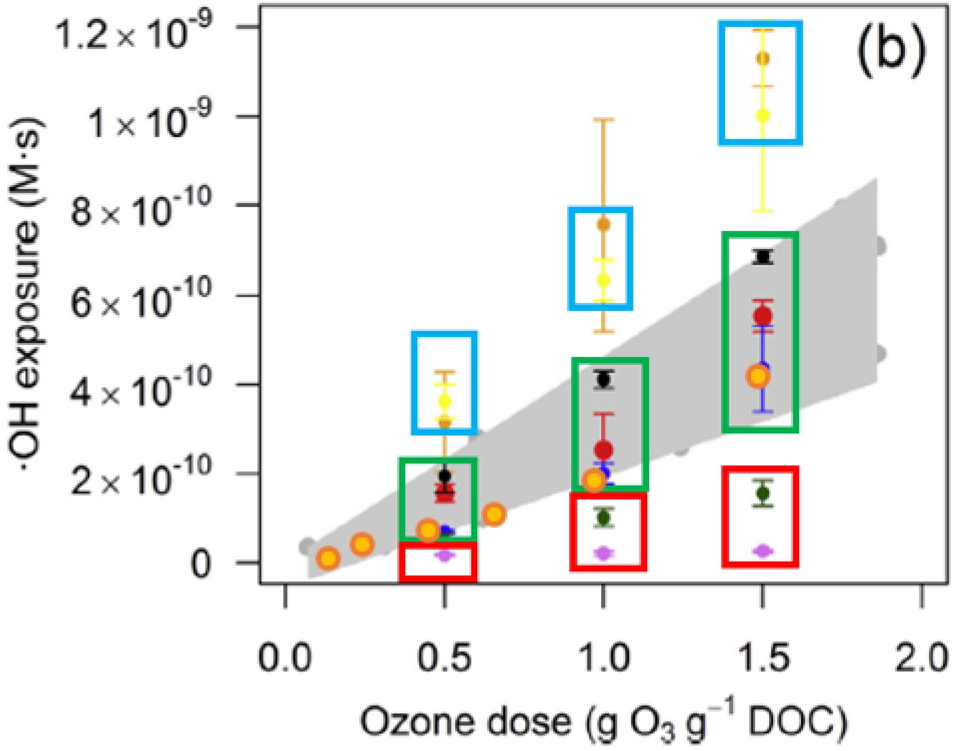
# Topic 1: Uncertainties with regard to the water matrix

# Topic 1: Uncertainties with regard to the water matrix

AM Team

- Different plants have different matrices
- Matrices are also dynamic




*Reference: Wildhaber Y. S. et al., 2015*

# Topic 2: Uncertainties with regard to scale-up (batch/pilot to full scale)

# Topic 2: Uncertainties with regard to scale-up (batch/pilot to full scale)



- As a starting point, people use:
  - Batch tests (lab)
  - Pilot tests (lab or onsite)

Key point #2:
**Be careful – Your assumptions matter!**

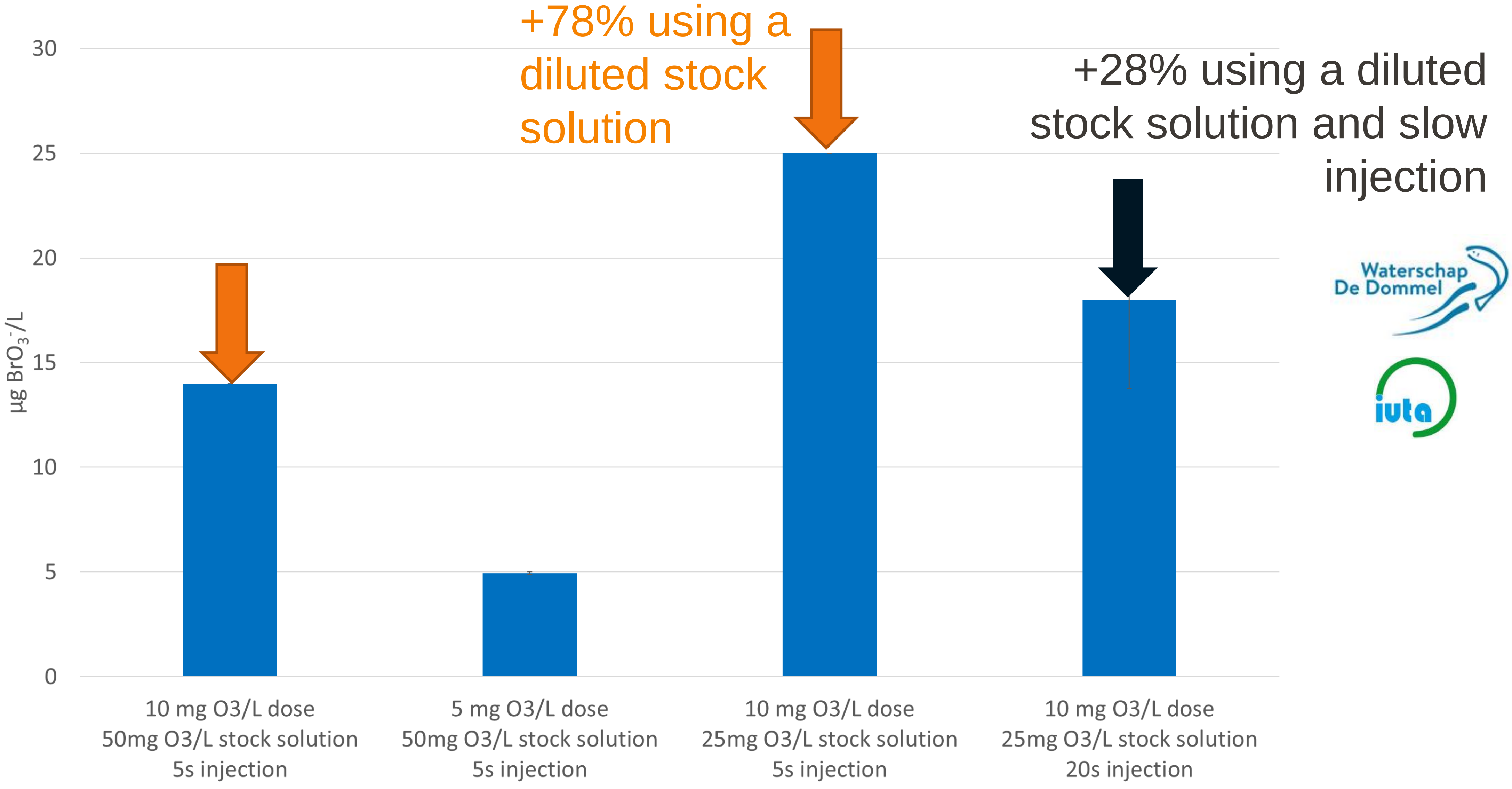
# Topic 2: Uncertainties with regard to scale-up (batch/pilot to full scale)



- What really happens in batch tests...

# Topic 2: Uncertainties with regard to scale-up (batch/pilot to full scale)

AM Team




Waterschap De Dommel

iuta

Batch and pilot tests are meant to gather information for future full-scale

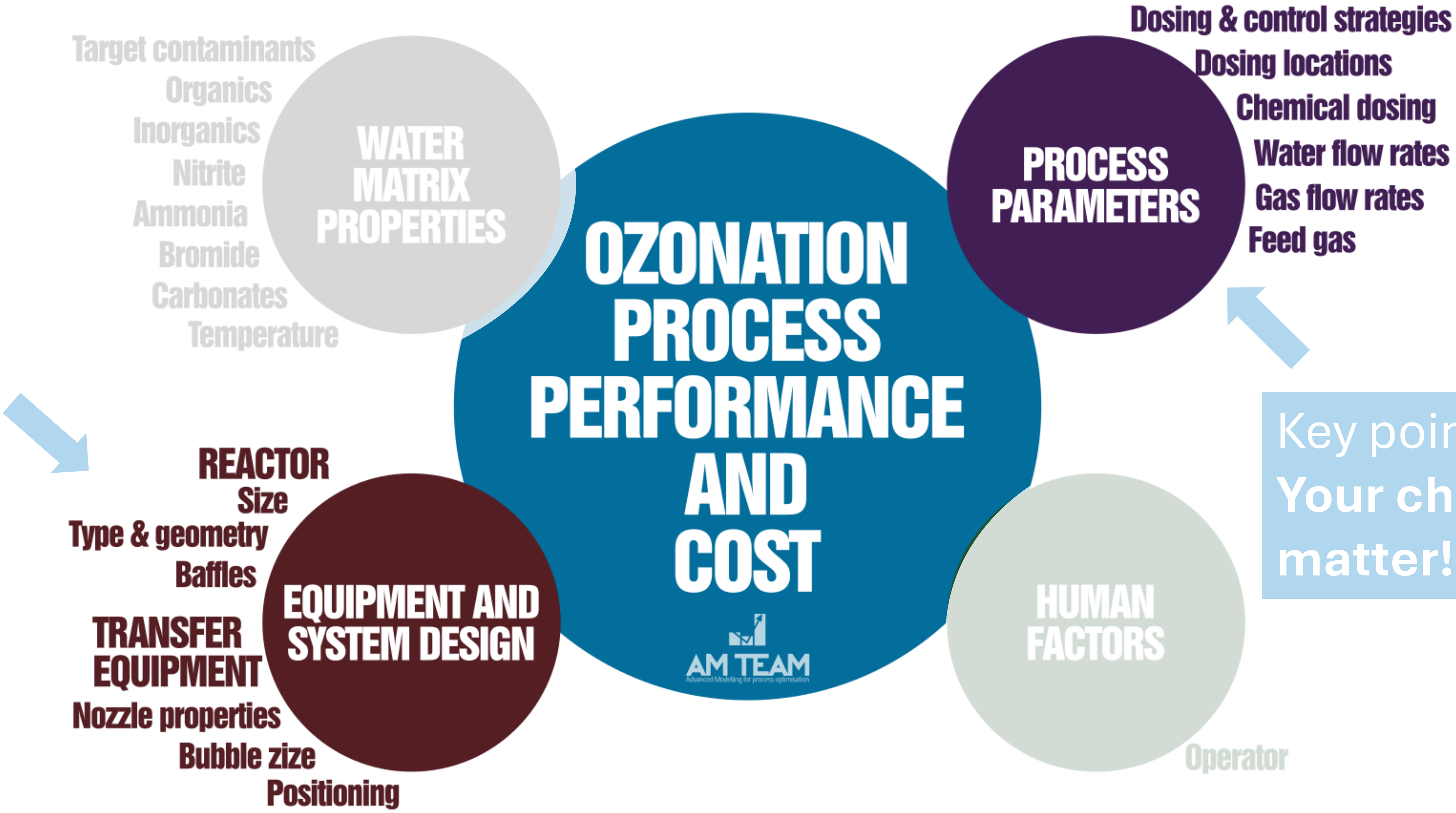
But batch and pilot scale designs are often not representative to make this extrapolation…

**Be careful – your assumptions matter!**

# Topic 3: Uncertainties with regard to design of full scale

# Topic 3: Uncertainties with regard to design of full scale





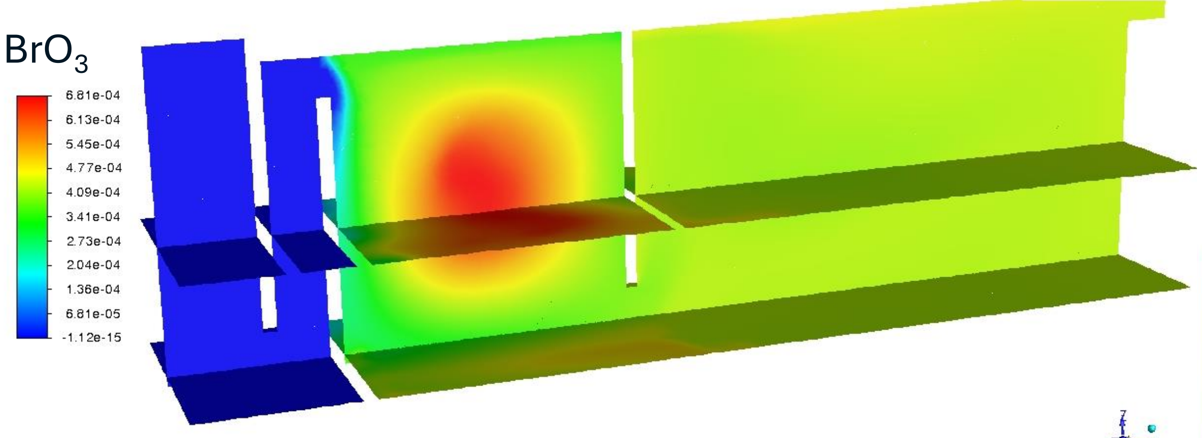

Key point #3:
**Your choices matter!**

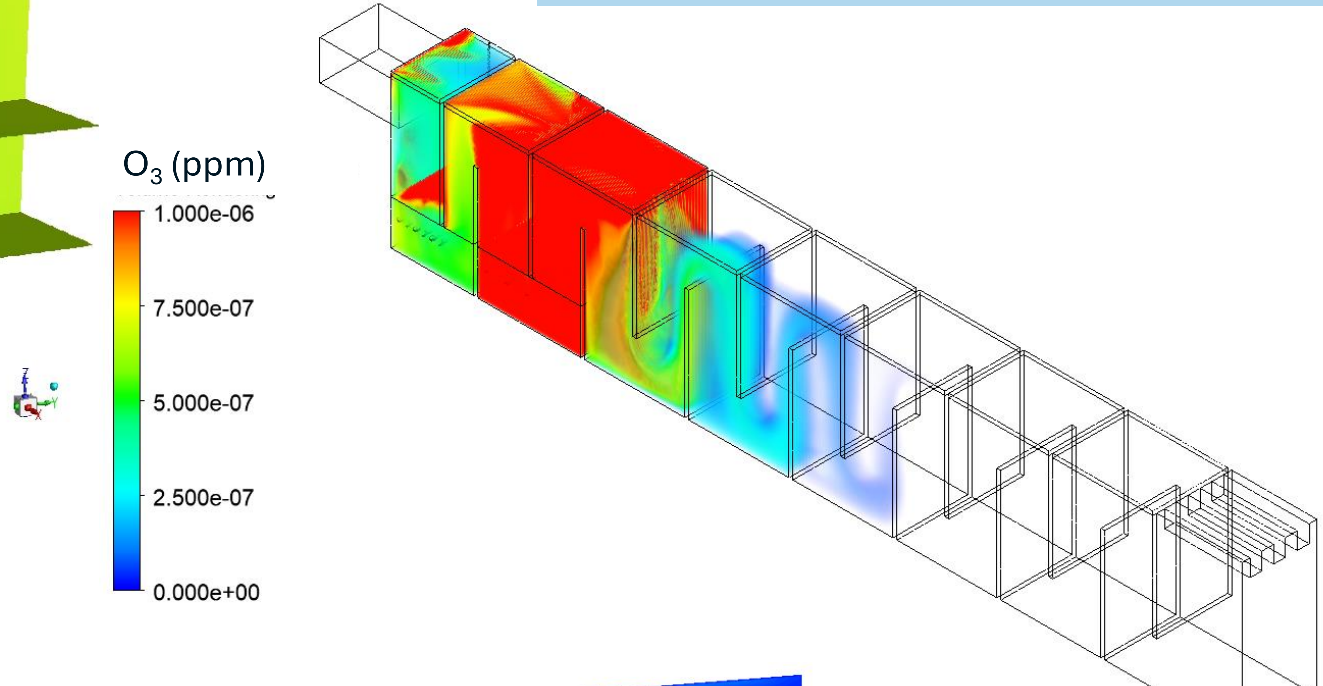
# Topic 3: Uncertainties with regard to design of full scale

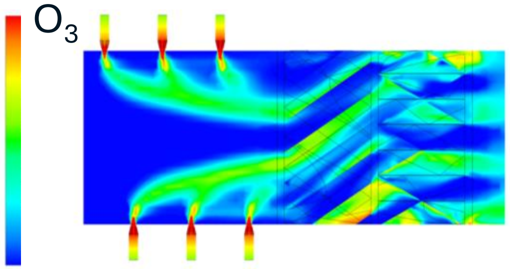
AM Team

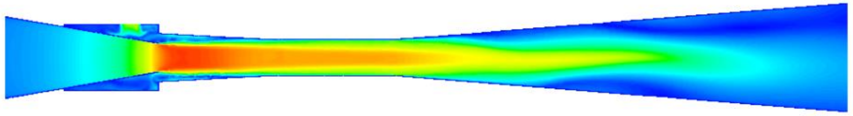
- Performance can be largely controlled by smart design
  - CFD+ AM OZONE (A product of AM TEAM)

**Key point #3:**
**Your choices matter!**



# Topic 4: Uncertainties with regard to operation

# Topic 4: Uncertainties with regard to operation

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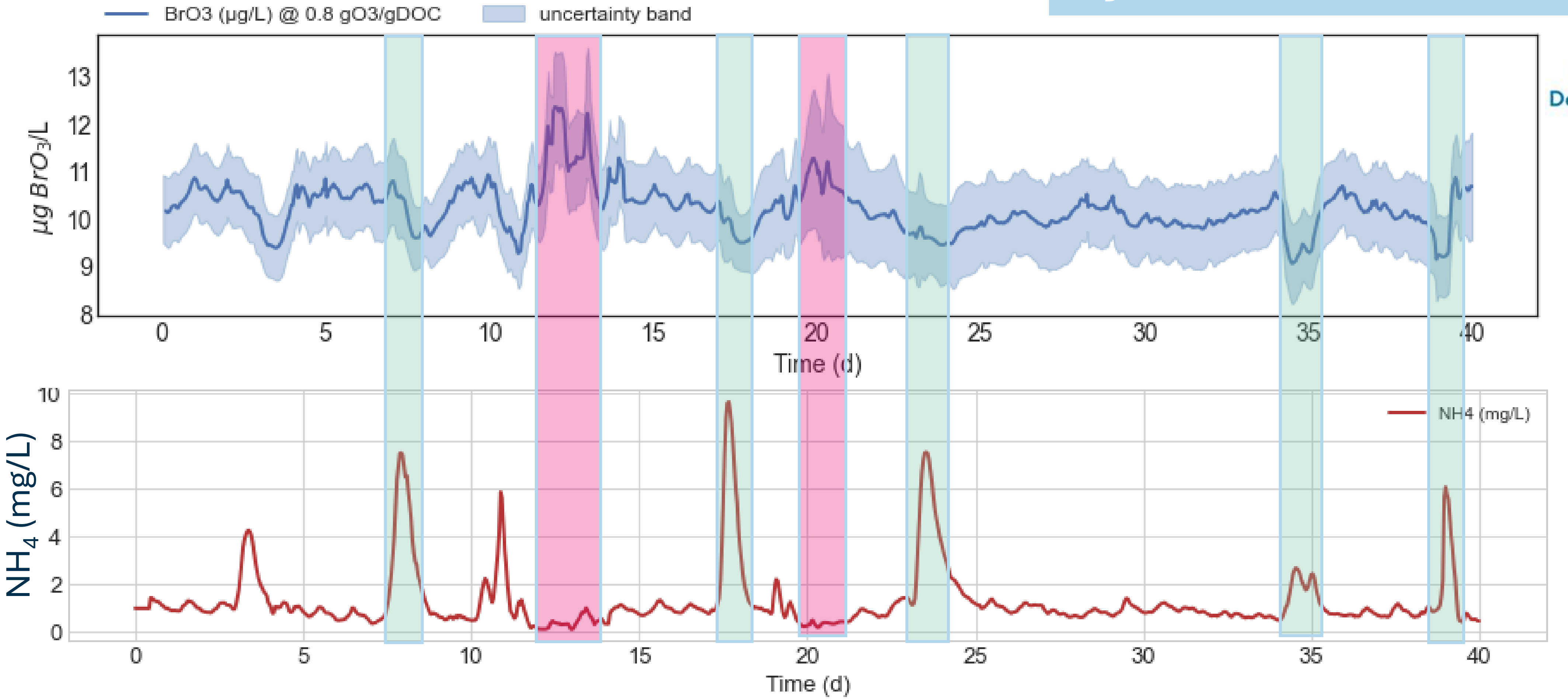
- Smart process control is possible

**Key point #4:**
**Dynamics matter!**




Waterschap De Dommel

# Thanks for listening!

Scan to connect

Pieter.Vlasschaert@AM-Team.com

# Micropollutant removal from urban wastewater

## Full scale implementation in Flanders

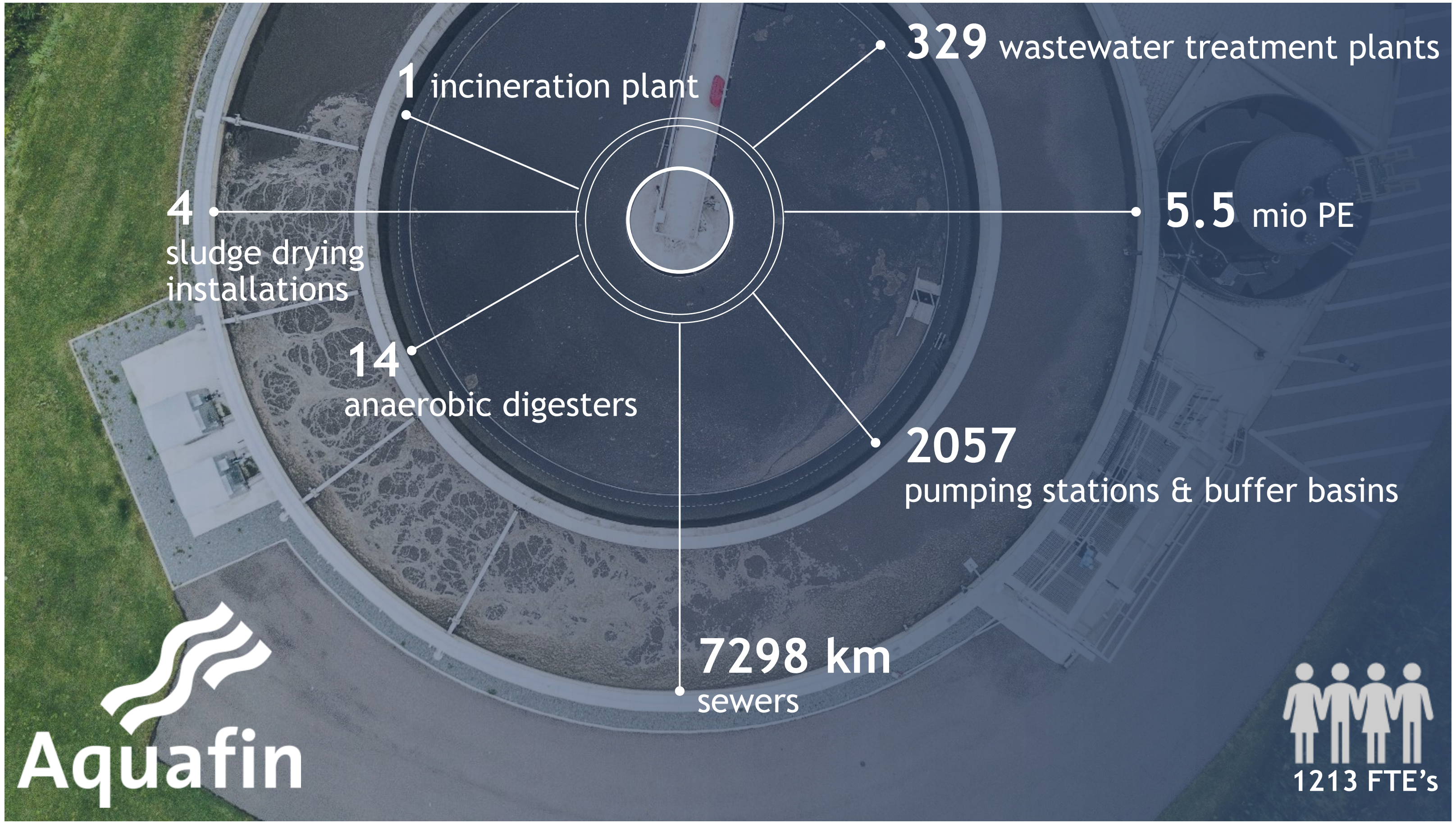
Birte Raes, Lennert Dockx (R&D)
March 11, 2025

# Aquafin

Wastewater transport, treatment and reuse

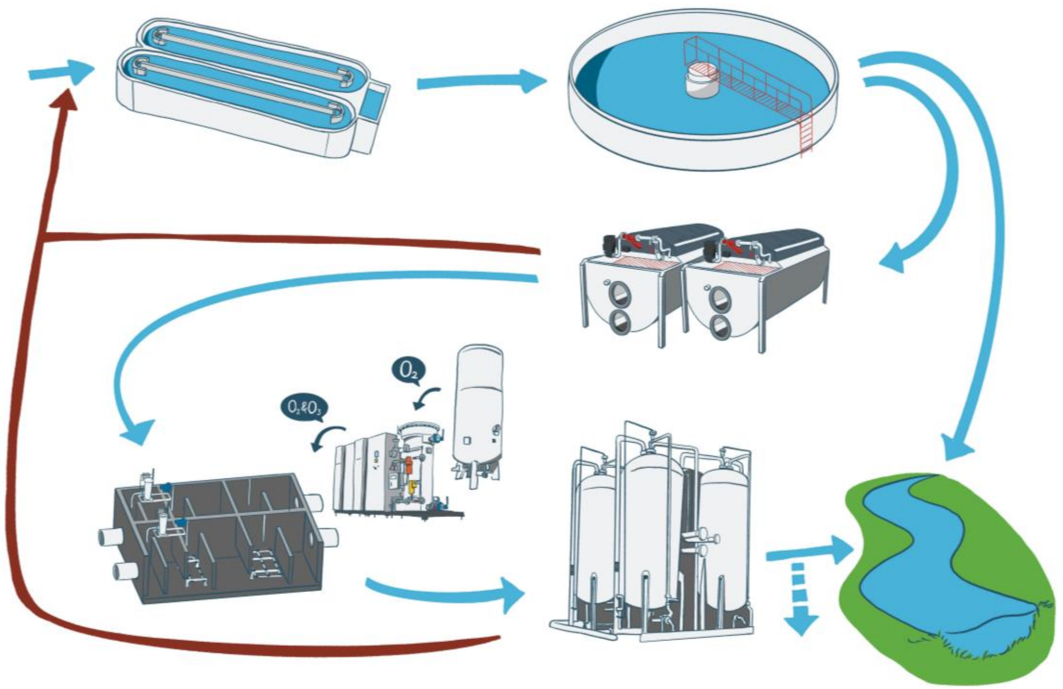
Rainwater management

Climate adaptation and mitigation



# WWTP of Aartselaar

- 54,000 PE (60 gBOD.(PE.d)$^{-1}$)
- First full-scale quaternary treatment in Flanders (capacity of 1200 m$^3$.h$^{-1}$)
    - Ozone + GAC
    - Available for research purposes (Interreg Vlaanderen – Nederland project)




Interreg Vlaanderen-Nederland
Gefinancierd door de Europese Unie
Schone Waterlopen door O3G

Ministerie van Economische Zaken en Klimaat
Provincie Noord-Brabant
provincie Oost-Vlaanderen

VLAKWA | vito
Waterschap De Dommel
Aquafin
AM TEAM
PURE BLUE
Universiteit Antwerpen
UNIVERSITEIT GENT
HZ UNIVERSITY OF APPLIED SCIENCES
CAPTURE

# Timeline UWWTD

**2024**
approval UWWTD

**2028**
extended producer responsibility*

**2030**
risk analysis
WWTP >10,000 PE*

**2033**
1st WWTP
>150,000 PE in operation

**2036**

**2039**

**2045**
6 WWTPs >150,000 PE
+ x WWTPs of risk in operation



*highly uncertain, depending on external factors

# Implications

## Environmental impact

- Energy
- GHG emissions
- Resources

# Implications


**+3-5%**

of total area

# A reflection on the broader scope of the UWWTD …
# … results in needs

### Future proof
Need for a combination of technologies results in the removal of a broad spectrum of micropollutants

### Area occupation
Need for compact installations

### Sustainability
Need for life cycle analysis to assess scope emissions and environmental footprint of resources

### Energy neutrality
Need for energy efficient technologies

### Nutrient removal
Need for a synergy between tertiary and quaternary treatment

### Project timeline
Need for plug-and-play solutions

### Cost effective technologies …
Extended producer responsibility and contribution from public money

### … and a chain approach
End of pipe is always the least favourable solution

# End

birte.raes@aquafin.be/lennert.dockx@aquafin.be

www.aquafin.be

Aquafin

AM Team

# Modelling to de-risk and accelerate: from lab-scale to full-scale

## Aquatech Amsterdam 2025

Eng. Pieter Vlasschaert
Pieter.Vlasschaert@am-team.com

AM-Team.com

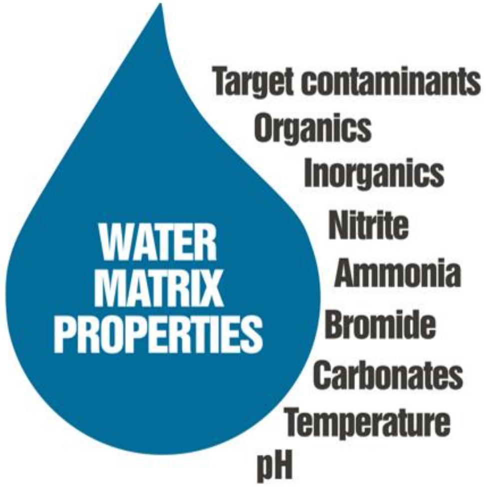
# Why modelling?

AM Team

- Uncertainties when it comes to ozonation

**1**

**Every water matrix is unique…**

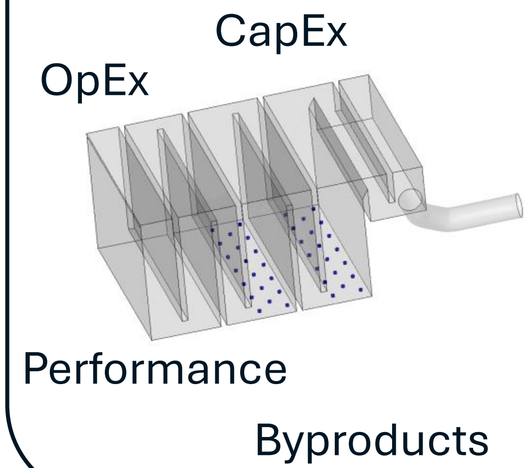



**2**

**Lab or pilot testing takes long and are expensive, while leaving many questions unanswered**

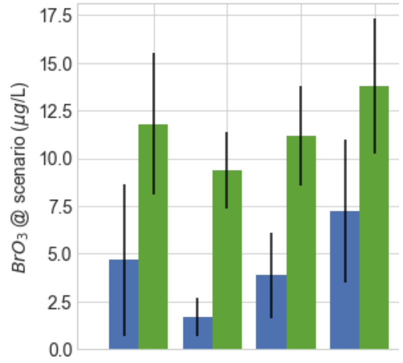
**3**

**Design is a balancing act**




**4**

**The key variables are hard and expensive to measure**

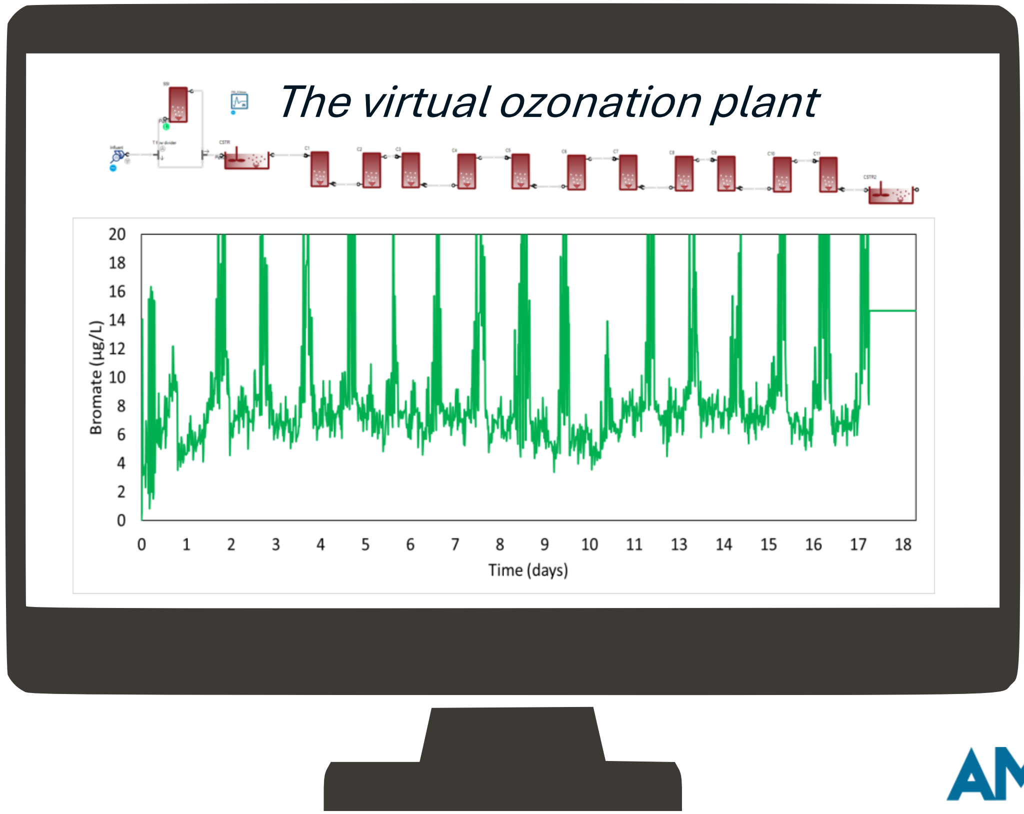


# Why modelling?

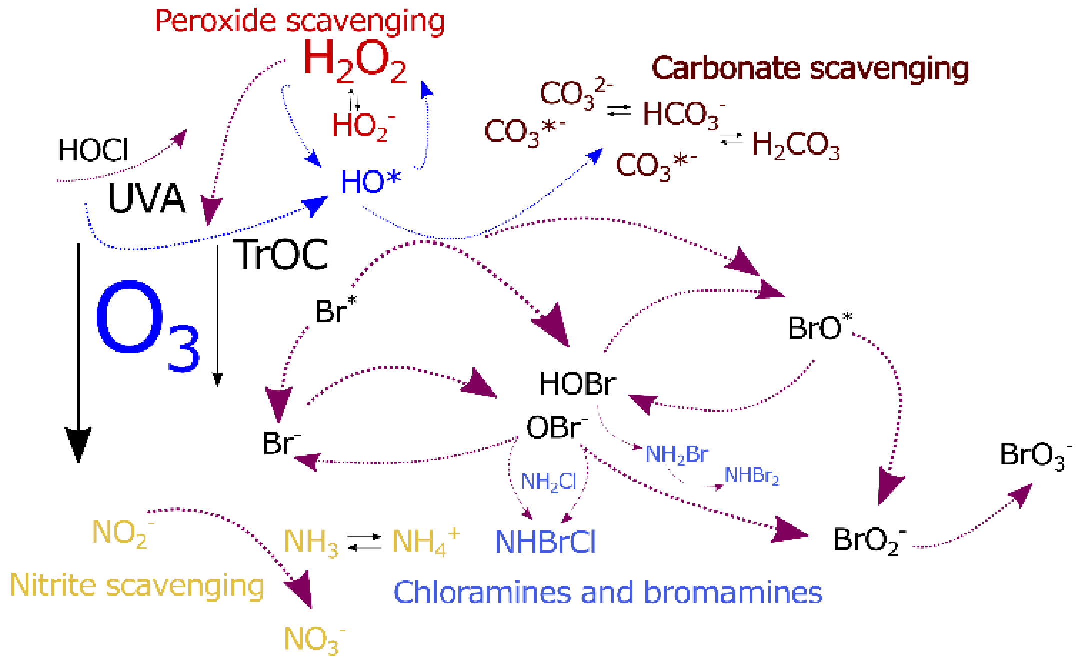
- AMOZONE model applied to > 35 reactors worldwide (USA, Hong Kong, Europe) for drinking water and wastewater

Water Europe Technology & Innovation — Digital Water Award AM OZONE

## Front end




## Backend




AM OZONE
A product of AM TEAM

# How does it work?



- A model is just like a real plant

**Water matrix data**

- DOC, COD, $UV_{254}$
- Conductivity
- Target pollutants
- $Br^-$
- Carbonates

**Process settings**

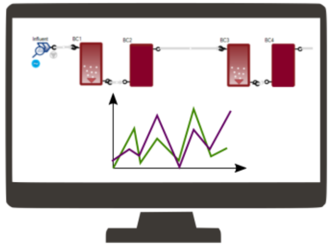
- $O_3$ dose
- Chemical dose
- Volume and flow rates
- …

# Where to apply?

- Applications AM OZONE
  A product of AM TEAM

**TECHNOLOGY SELECTION AND FEASIBILITY** → **CONCEPTUAL AND DETAILED DESIGN** → **SMART OPERATION AND TRAINING**

**VIRTUAL PILOTING**

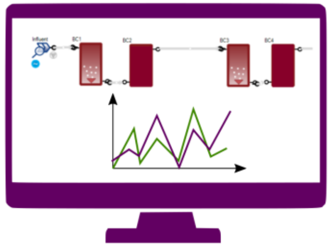


- Performance?
- Feasibility?
- Costs?

**VIRTUAL PROCESS DESIGN**

- Dimensioning?
- Design?

**DIGITAL TWIN**



- Real-time monitoring?
- 'What-if' testing

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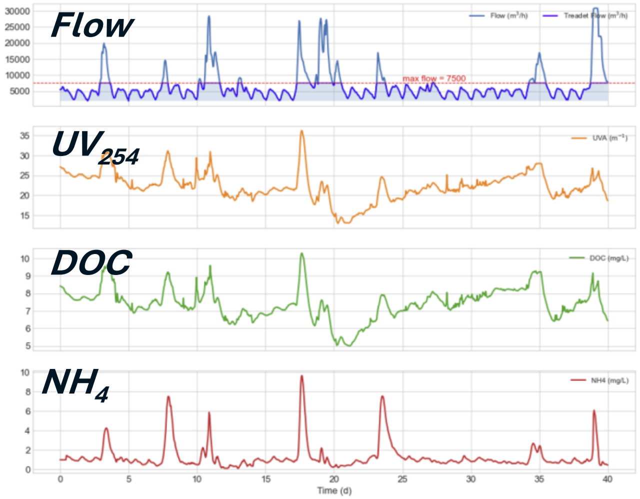
# Phase 1: Virtual piloting

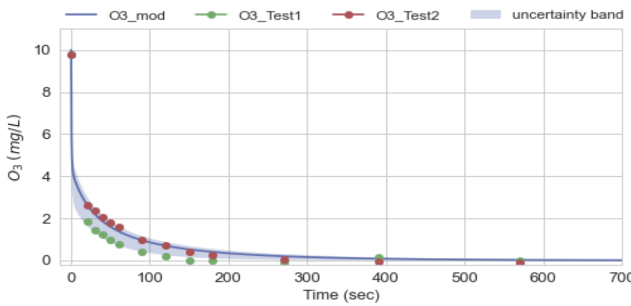
# Phase 1: Virtual piloting

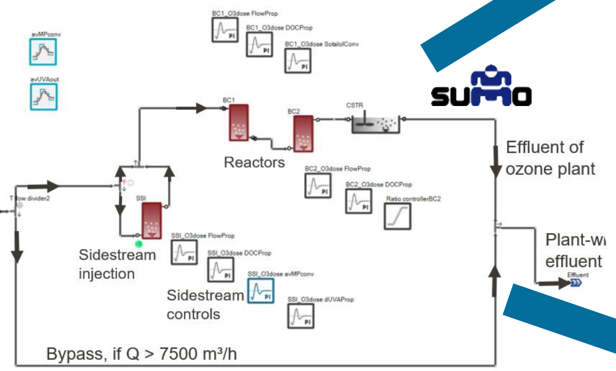
AM Team

## Effluent data




## Lab data




AM OZONE
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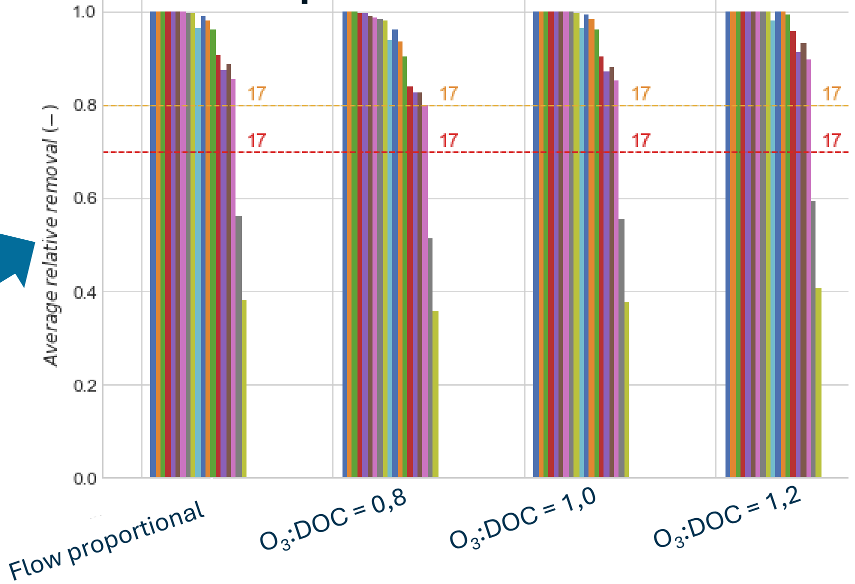
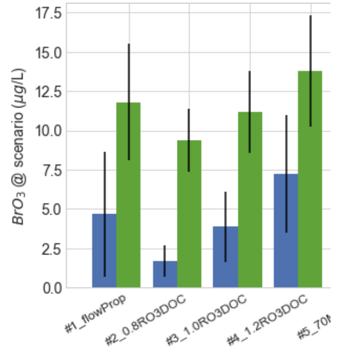
## What is optimal dose for MP-removal?



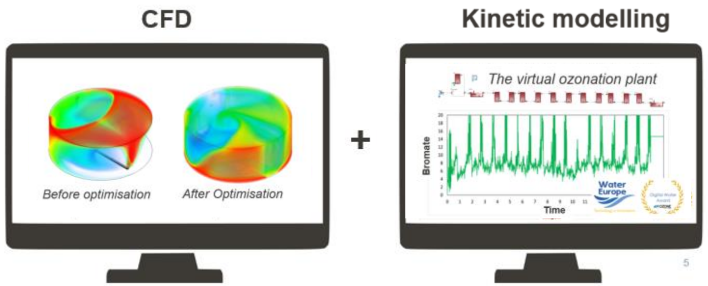

## What is the risk of $BrO_3$-formation?



# Phase 2: Virtual process design

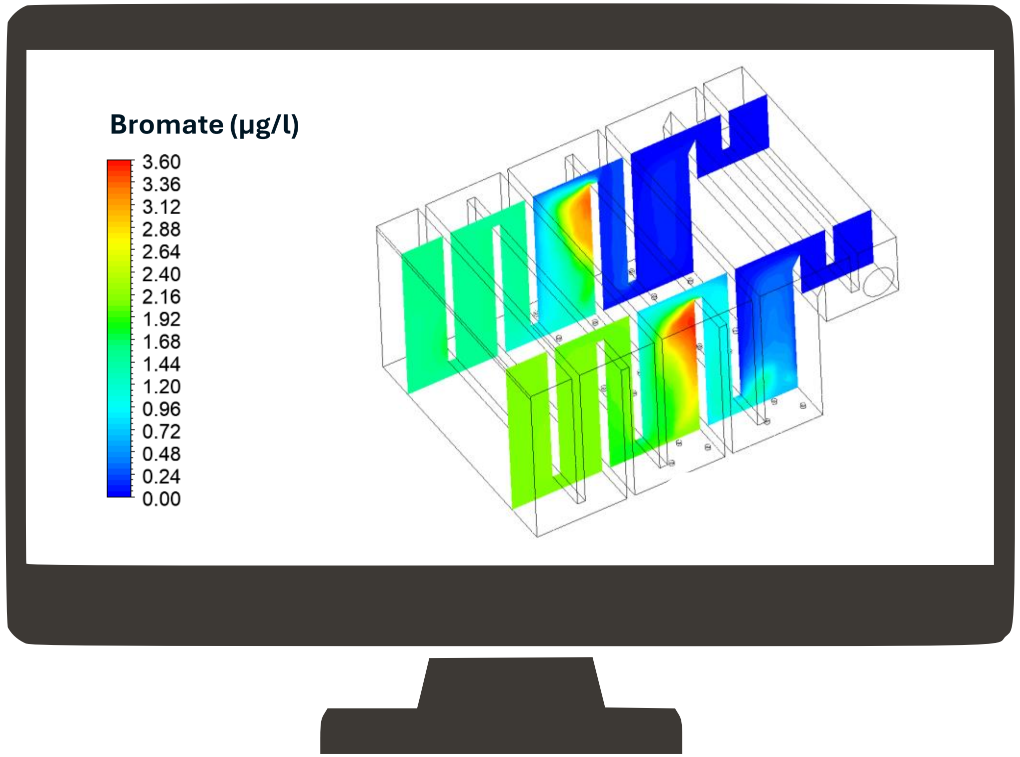
# Phase 2: Virtual process design

AM Team



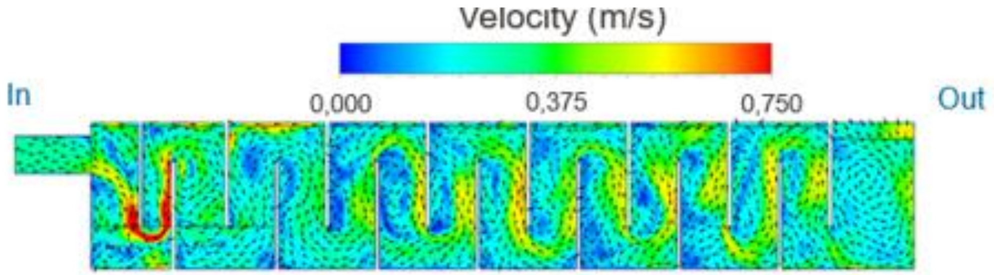

**Combining physics with chemistry**

**CFD + AM OZONE**
A product of AM TEAM

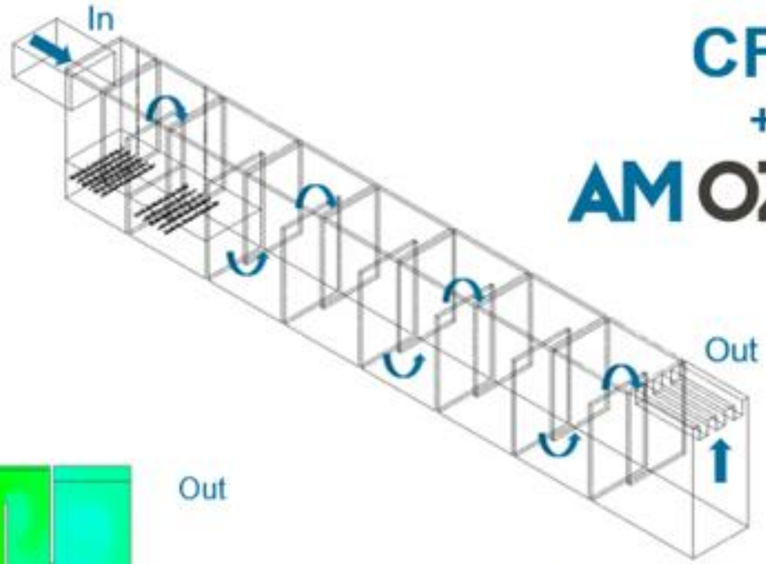


# Phase 2: Virtual process design

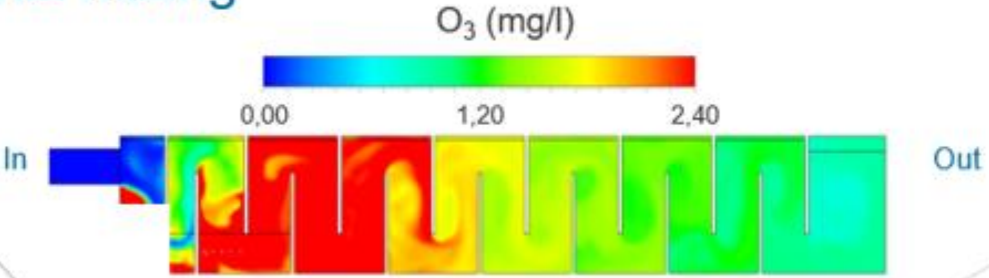
AM Team



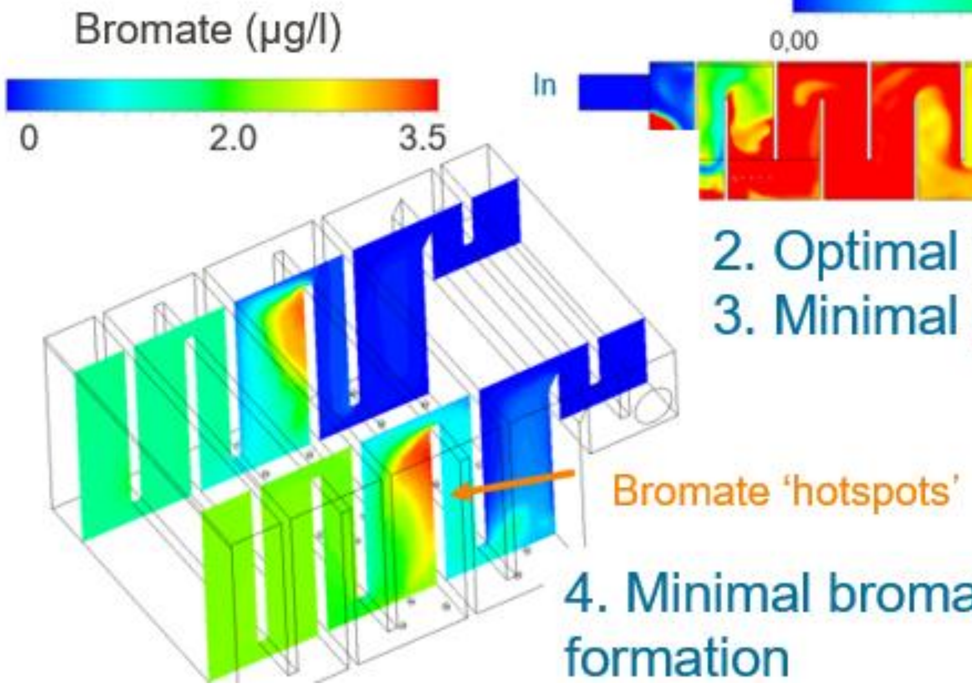

1. Optimal mixing



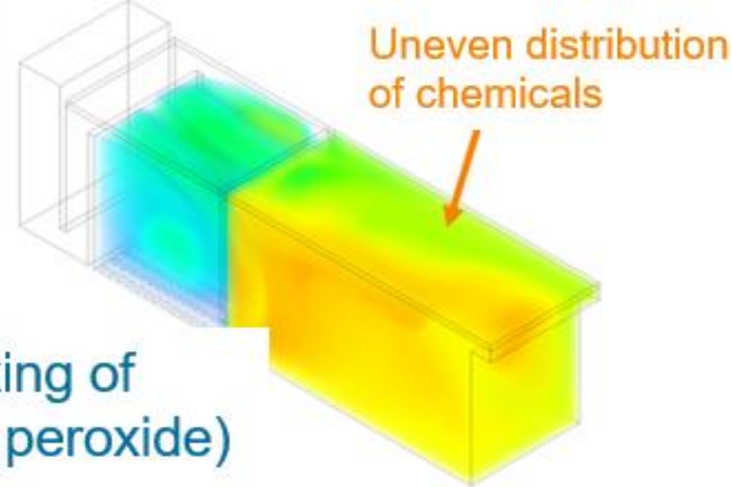

CFD
+
AM OZONE
A product of AM TEAM




2. Optimal transfer efficiency
3. Minimal CapEx




4. Minimal bromate formation

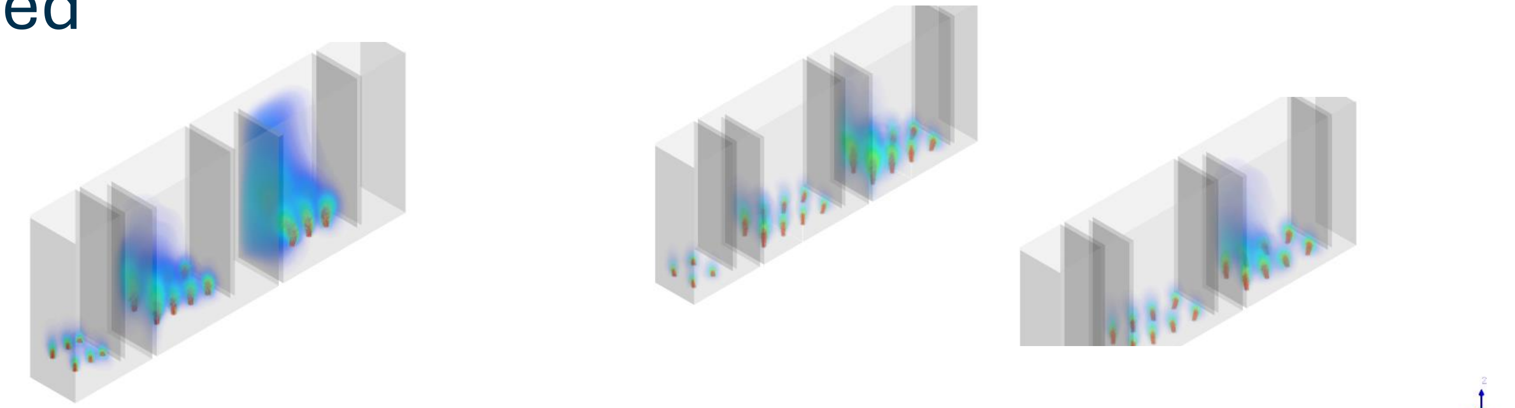



5. Optimal mixing of chemicals (eg peroxide)

# Phase 2: Virtual process design

AM Team

- Multiple designs were tested



| Date | Simulation # | Configuration | number of diffusers | Peroxide 1:1 mol-$H_2O_2$/mol-$O_3$ | Baffles | Bromate [ug/L] | Benzotriazole removal [%] | Venlafaxine removal [%] |
|---|---|---|---|---|---|---|---|---|
| report | 1 | counter-current | 25-45-45 | no | high-baffled | 1.8 | 71.5 | 81.8 |
| 22-Nov | 2 | counter-current | 2+2-8-8 | no | high-baffled | 3.7 | 67.9 | 78.3 |
| 22-Nov (appendix) | 3 | counter-current | 8-2+2-8 | no | high-baffled | 3.7 | 68.3 | 78.7 |
| 25-Nov | 4 | counter-current | 5-12-12 | no | high-baffled | 3.1 | 66.4 | 76.0 |
| 25-Nov | 5 | counter-current | 5-12-12 | no | high-baffled | 3.3 | 63.7 | 73.2 |
| report | 6 | counter-current | 5-12-12 | no | low-baffled | 3.0 | 60.2 | 68.8 |
| 25-Nov | 7 | co-current | 5-12-12 | no | high-baffled | 3.2 | 75.9 | 86.5 |
| 02-Dec | 8 | co-current | 5-12-12 | no | low-baffled | 3.2 | 75.0 | 85.4 |
| 02-Dec | 9 | counter-current | 5-12-12 | yes (inlet) | low-baffled | 1.8 | 60.2 | 55.8 |
| report | 10 | co-current | 5-12-12 | yes (inlet) | low-baffled | 1.1 | 75.0 | 82.0 |
| report | 11 | co-current | 5-12-12 | yes (nozzle) | low-baffled | 1.7 | | |

# Phase 2: Virtual process design

AM Team

**Optimised co-current configuration:**

- Better and uniform ozone contact with the water
- **Same MP removal and -30% bromate formation**

# Phase 3: Digital twin for smart operations

# Phase 3: Digital twin for smart operations

AM Team

- Ongoing work at Hapert

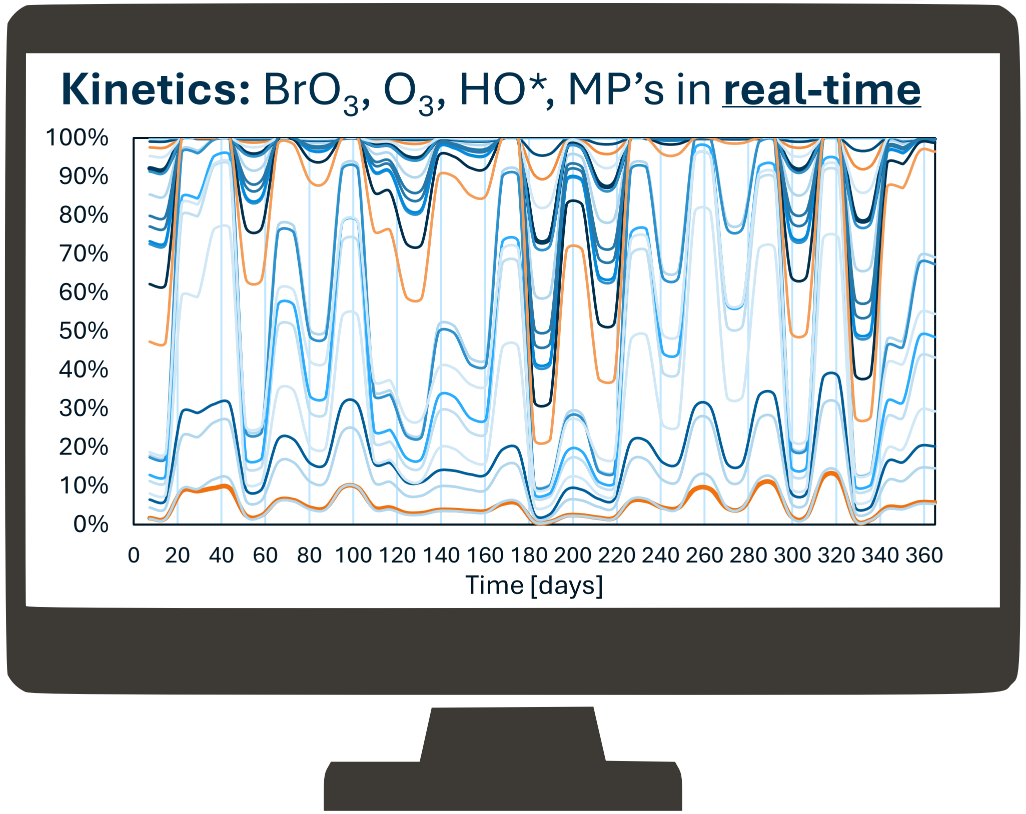
Predict what cannot be measured,
based on what can be measured

Data in

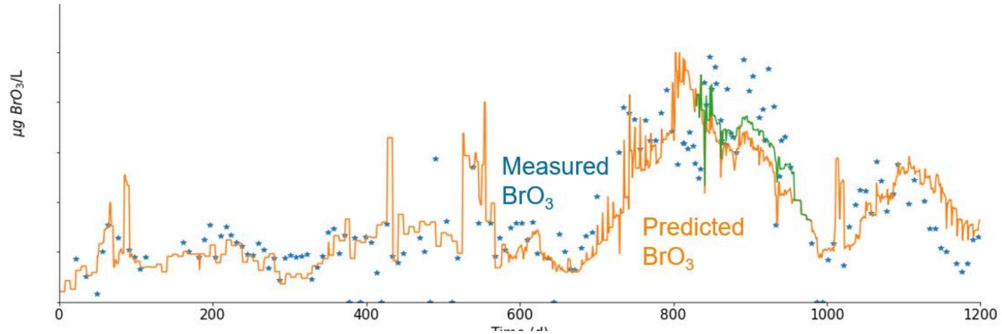
pH, EC,
T, UVA,
NH4

Information out

1min
$BrO_3$, $O_3$,
MP's, ...




Waterschap De Dommel

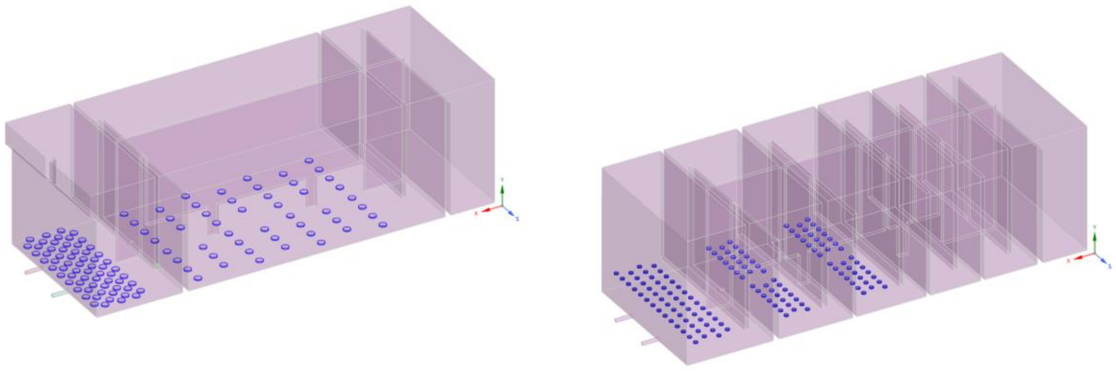


# Conclusions

# Conclusions

AM Team

- 3 step sequence applied:
  - Virtual piloting (PLANNING)
  - Virtual process design (DESIGN)
  - Digital twin (OPERATIONS)



- CFD-AMOZONE lets you look through the contactor walls

- Subtle differences in design can make a big difference

- Ideal reactor design: big difference between drinking water ozonation and secondary effluent ozonation!

# Thanks for listening!

Scan to connect

Pieter.Vlasschaert@AM-Team.com

Waterschap De Dommel

Aquatech 2025

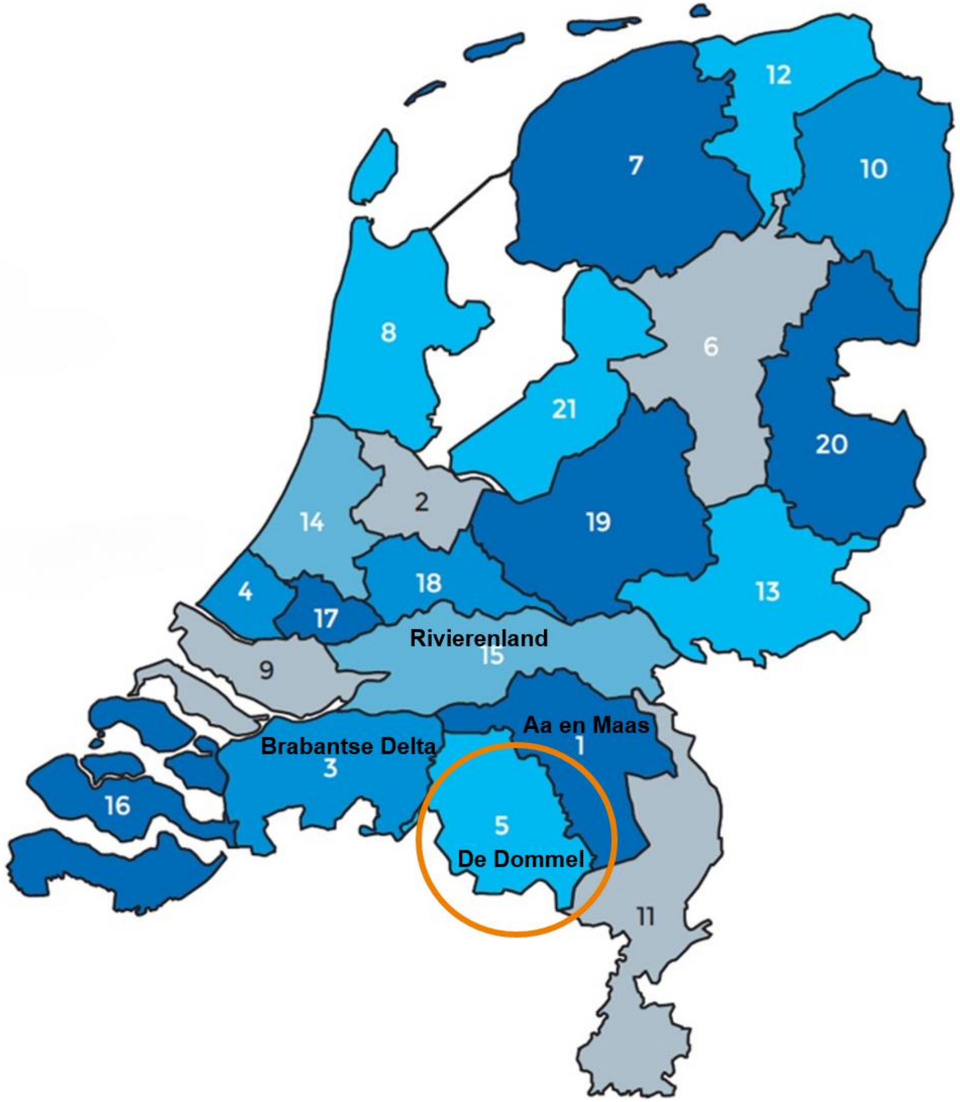
# Innovation Partnership WWTP Tilburg

Frank de Groot - Waterboard De Dommel

Interreg Vlaanderen-Nederland
Gefinancierd door de Europese Unie
Schone Waterlopen door O3G

# Waterboard De Dommel

- Local, functional government for water management
- Responsible for:
  - Quality and quantity of local surface water
  - Water safety (dry feet)
  - Treatment of wastewater
- Operating 8 wastewater treatment plants

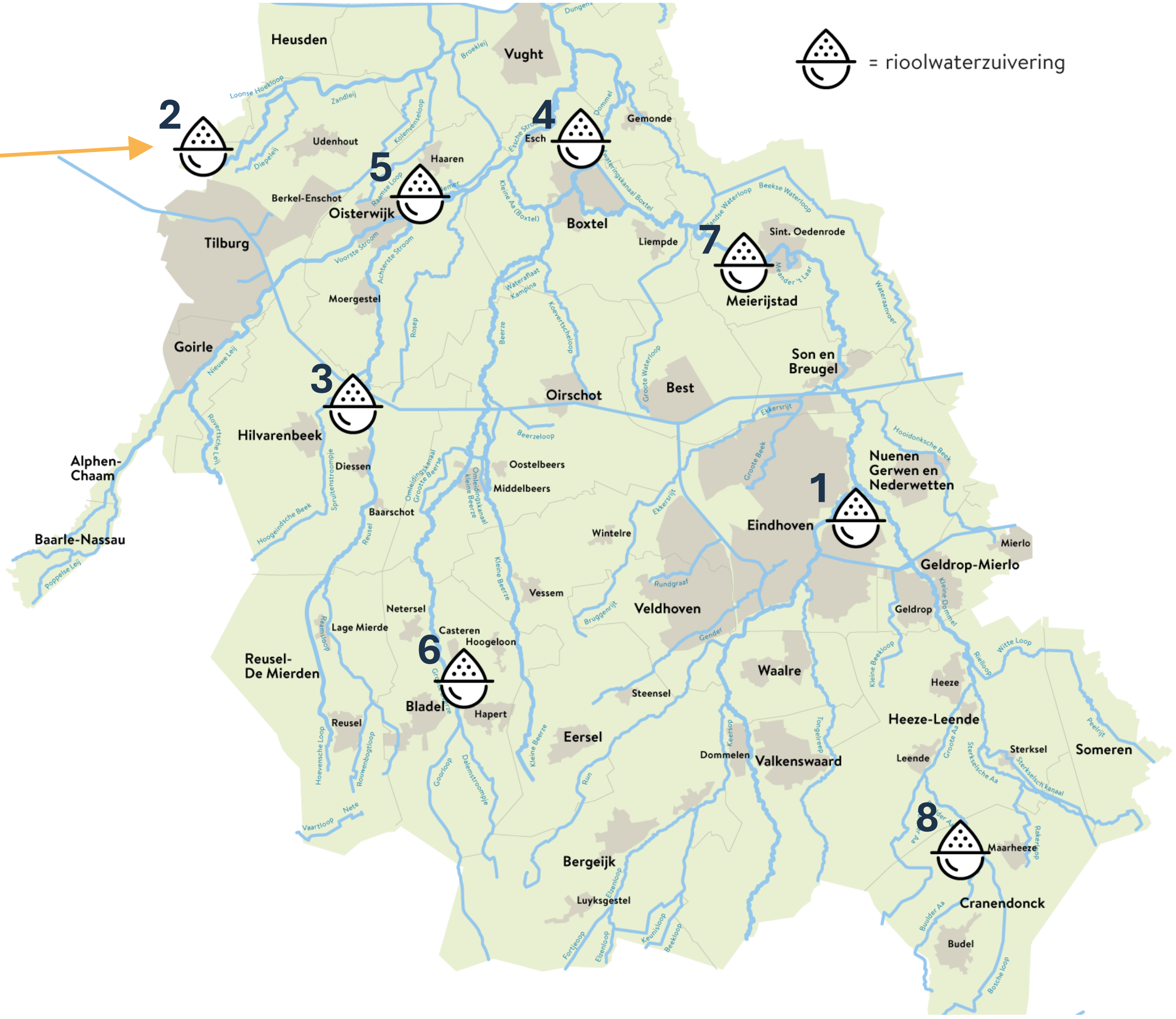


Waterschap De Dommel

# Waterboard De Dommel

## Our 8 wastewater treatment plants (WWTPs)

1. Eindhoven
2. **Tilburg**
3. Biest-Houtakker
4. Boxtel
5. Haaren
6. Hapert
7. Sint-Oedenrode
8. Soerendonk



# Waterboard De Dommel

Waterschap De Dommel

## WWTP Tilburg

- Capacity
  - Biological capacity: 406.500 p.e.
  - Hydraulic capacity: 2.165 $m^3/h$ (DWF) / 12.585 $m^3/h$ (RWF)
- Discharges at sensitive water body
  - In dry periods effluent the main water source of water body
- Need for improvment of effluent water quality
  - Extended removal of nutriënts (N & P)
  - Removal of organic micropollutants (OMPs)
- Challenges
  - High RWF / DWF ratio
  - Ongoing renovation works at WWTP Tilburg
  - Lowering our impact on climate change and environment
  - Managing costs for investment and operation

# Waterboard De Dommel

- **How to tackle the challenges for WWTP Tilburg**

➢ Partnering in Interreg project '**Schone Waterlopen door O3G**'

- Research and demonstration of ozone/GAC for efficient removal of OMPs

➢ Start of project '**Innovation Partnership WWTP Tilburg**'

- Public-Private development of quaternary treatment step for extended removal of nutrients and OMPs
- Test and monitor new technology at pilot scale
- When succesful realisation as full-scale 4th quaternary treatment step at WWTP Tilburg

# Innovation Partnership WWTP Tilburg

**Innovation Partnership (IPS)**

i. A public procurement method for,

ii. development of a new, innovative ór significantly improved product, technology, process or service,

iii. which is not yet commercially available in the market.

**How we apply IPS for project WWTP Tilburg**

- Development of a new, improved and optimized combination of existing technologies for,
- Extended removal of both nutrients and OMPs,
- Looking for innovation in:
  - Higher removal efficiencies
  - Lower usage of energy and (raw) materials ($CO_2$ footprint)
  - Lower CAPEX and OPEX
  - More flexible and robust system

# Innovation Partnership WWTP Tilburg

- **The innovation partners**

➢ Waterboard De Dommel

➢ Nijhuis Water Technology

➢ Witteveen+Bos

# Innovation Partnership WWTP Tilburg

## Project Objectives

- Extended removal of nutrients (N< 3,6 mg/l and P< 0,23 mg/l)
- Removal of OMPs acc. to the new European UWWTD (≥ 80%)
- Stay below Dutch limit for bromate in surface waters (< 1 mg/l $BrO_3^-$)
- Minimizing $CO_2$ footprint of quaternary treatment step
- Minimizing Total Cost of Ownership (TCO) of quaternary treatment step

N & P

OMPs

$BrO_3^-$

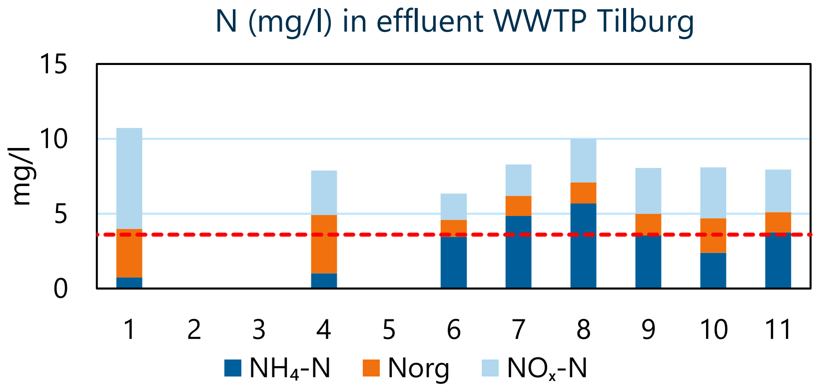
$CO_2$

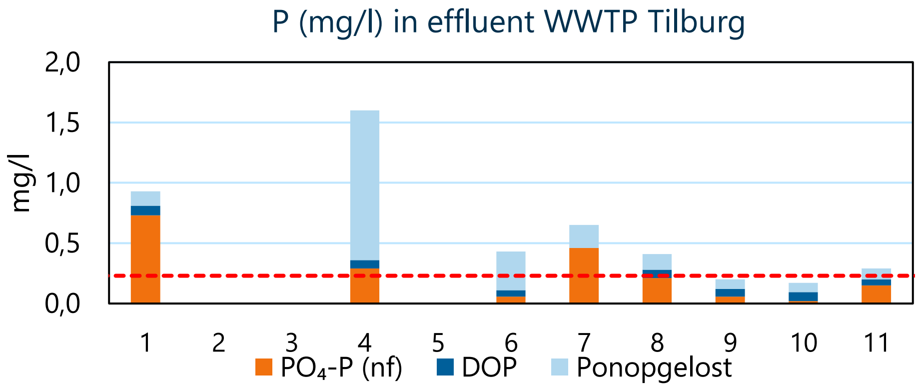
TCO

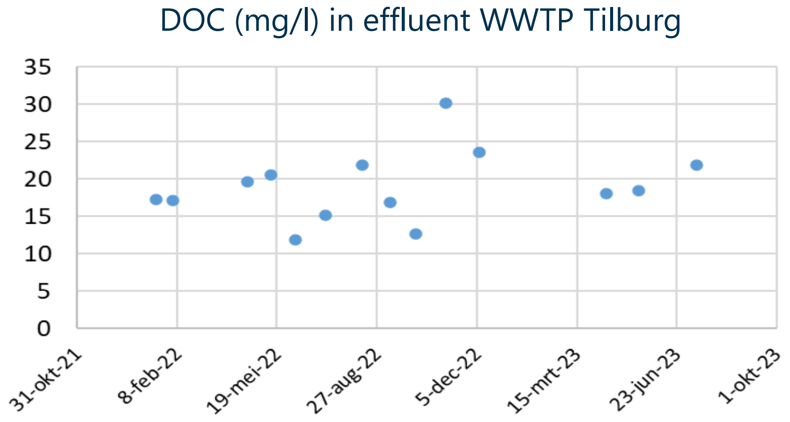
nijhuis Witteveen + Bos Waterschap De Dommel

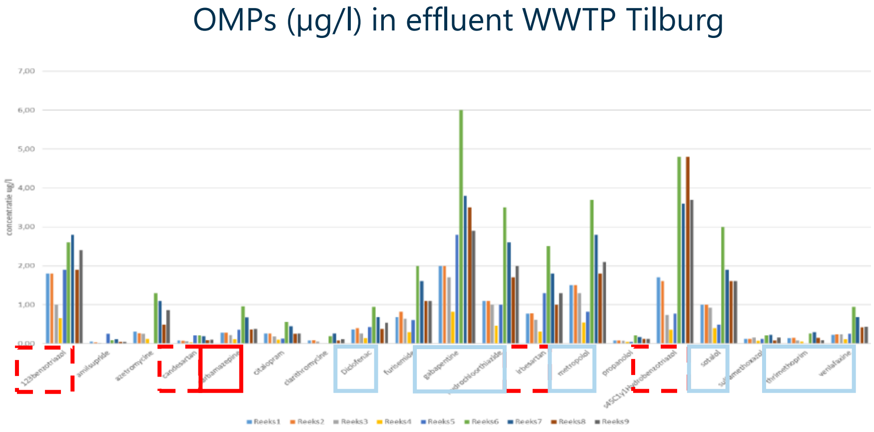
# Innovation Partnership WWTP Tilburg

**What is needed**: analysis of current effluent quality



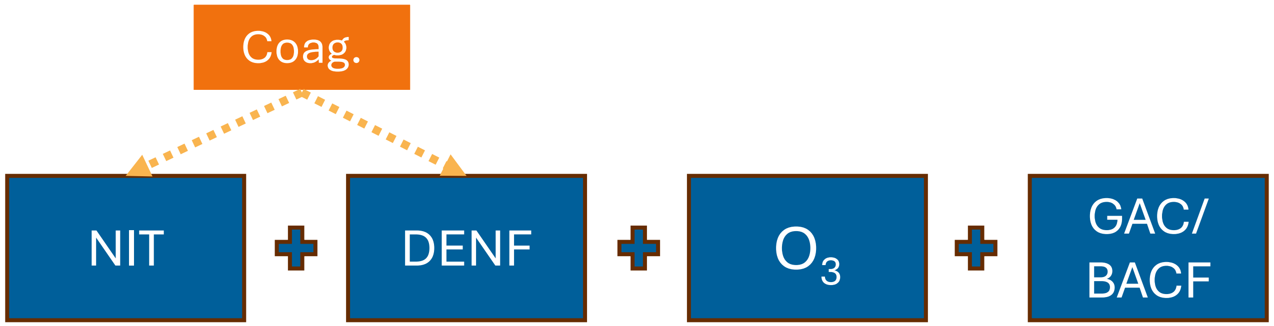



# Innovation Partnership WWTP Tilburg

**What is needed**: basic blocks of proposed technology solution

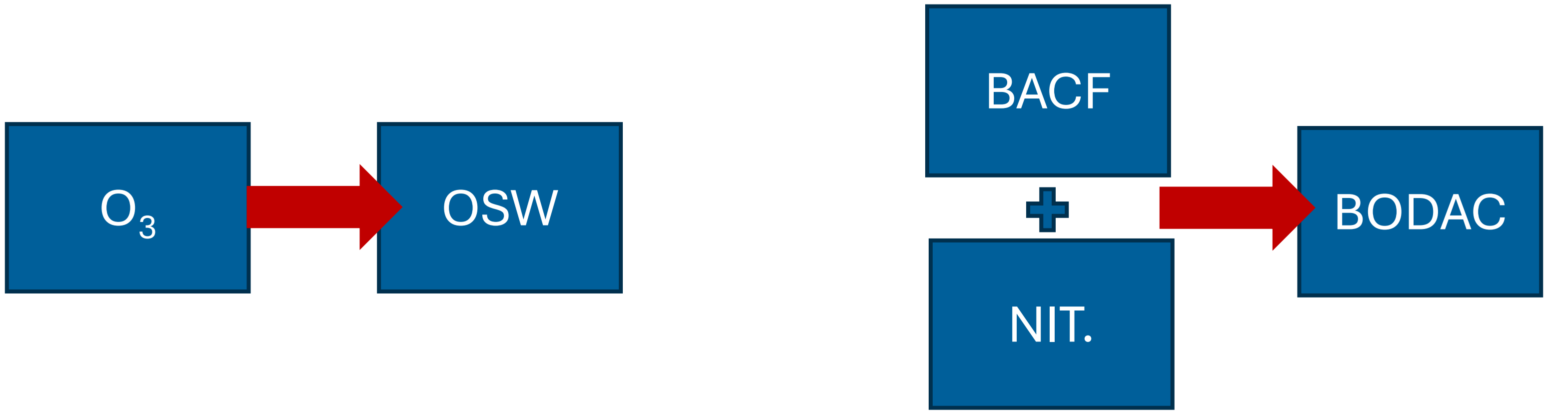
- **Nitrification + denitrification** > needed for N-requirement
- **Coagulation + media filtration** > needed for removal of P (and DOC)
- **Ozonation + GAC/BACF** > needed for removal broad range of OMPs, with BACF also removal of $NH_4$ due to aerobic conditions in filter



# Innovation Partnership WWTP Tilburg

**What is needed**: Innovation needed to minimize $CO_2$ footprint and TCO

- **Ozone** > implementation of Ozone Strong Water (OSW)
- **BACF + Nitrification** > implementation of BODAC
- **Denitrification** > maximizing filtration velocity for high-rate denitrification
- **Coagulant** > sustainable coagulant (BioFloc) as alternative for metal salts



# Innovation Partnership WWTP Tilburg

## Ozone Strong Water (OSW)

- ➢ Innovative ozone injection concept by Air Liquide
- ➢ OSW separates and optimizes main process steps of ozonation:
  - Mass Transfer
  - Mixing
  - Reaction
- ➢ Successfully proven on demo scale (TRL 7) at WWTP Duisburg-Vierlinden (Germany)
- ➢ Results in lower ozone input and reduced reaction time/volume for same OMP degradation and no degassing in reaction tank

Fig. a: conventional ozonation with diffusers

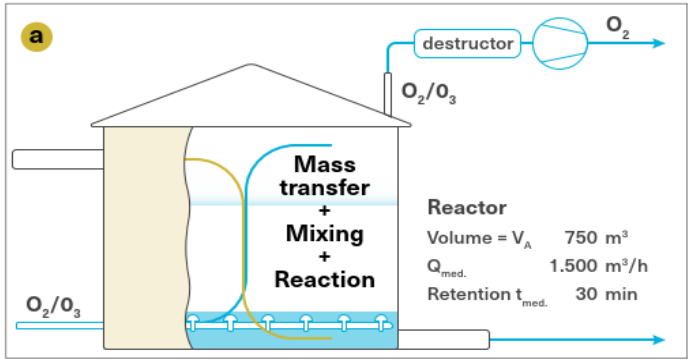
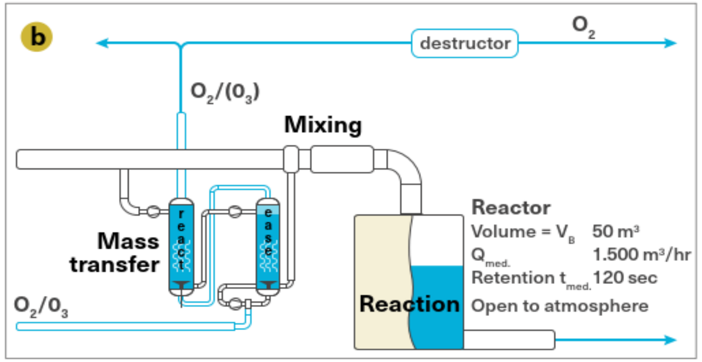



Fig. b: Ozone Strong Water



# Innovation Partnership WWTP Tilburg

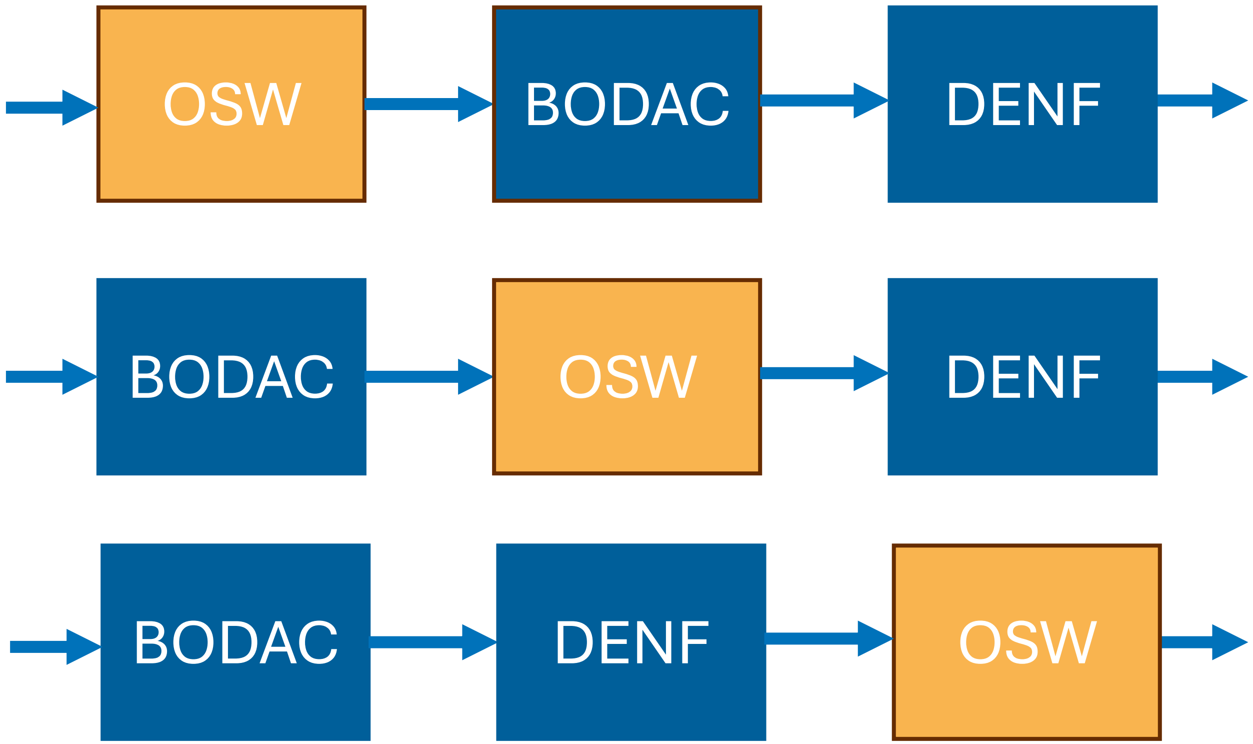
**BODAC: B**iological **O**xygen **D**osed **A**ctivated **C**arbon

- Activated carbon filter with aerobic biofilm
- Originally developed as a pre-treatment for RO proces at Ultra-Pure Water Factory Emmen (NL)
- In addition also a promissing technology for removal of OMPs:
  - combined effect biodegradation by the biofilm, enhanced by adsorption and desoprtion
  - removal efficiency > 70-80%
  - long filter lifetime: 14+ years without regeneration or renewal of carbon
- Results in low $CO_2$ footprint and operating cost and combined with ozonation high, flexible and robust removal of OMPs

# Innovation Partnership WWTP Tilburg

**What is the best order of process steps?**

- Three different configurations:



nijhuis

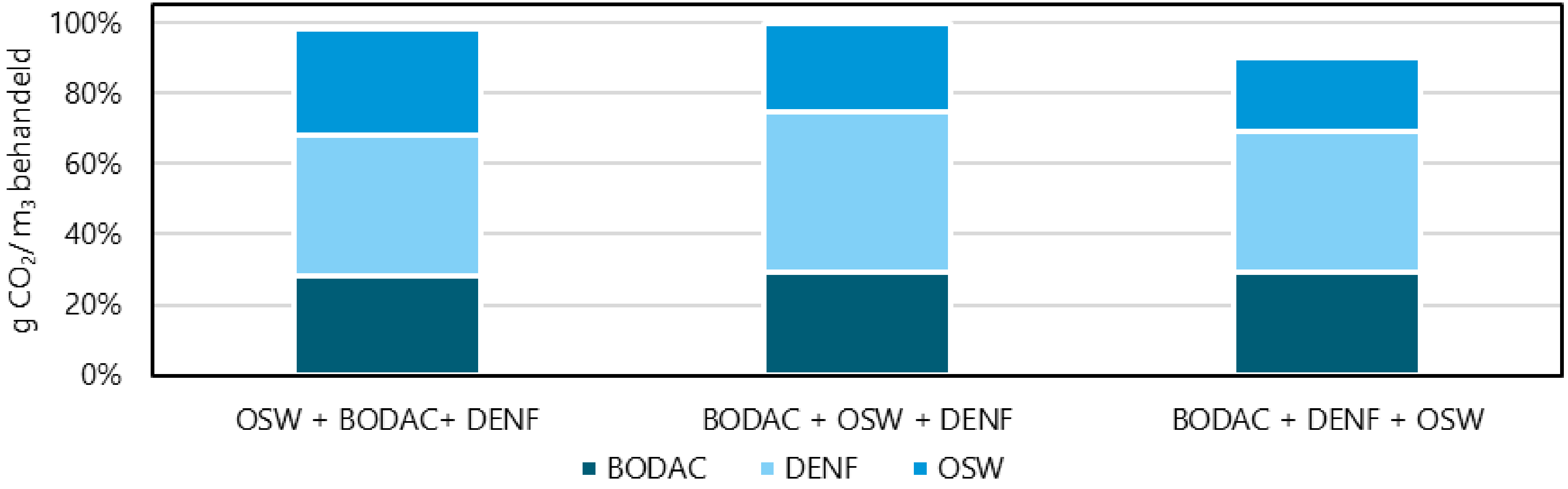
Witteveen + Bos

Waterschap De Dommel

# Innovation Partnership WWTP Tilburg

## What is the best order of process steps?

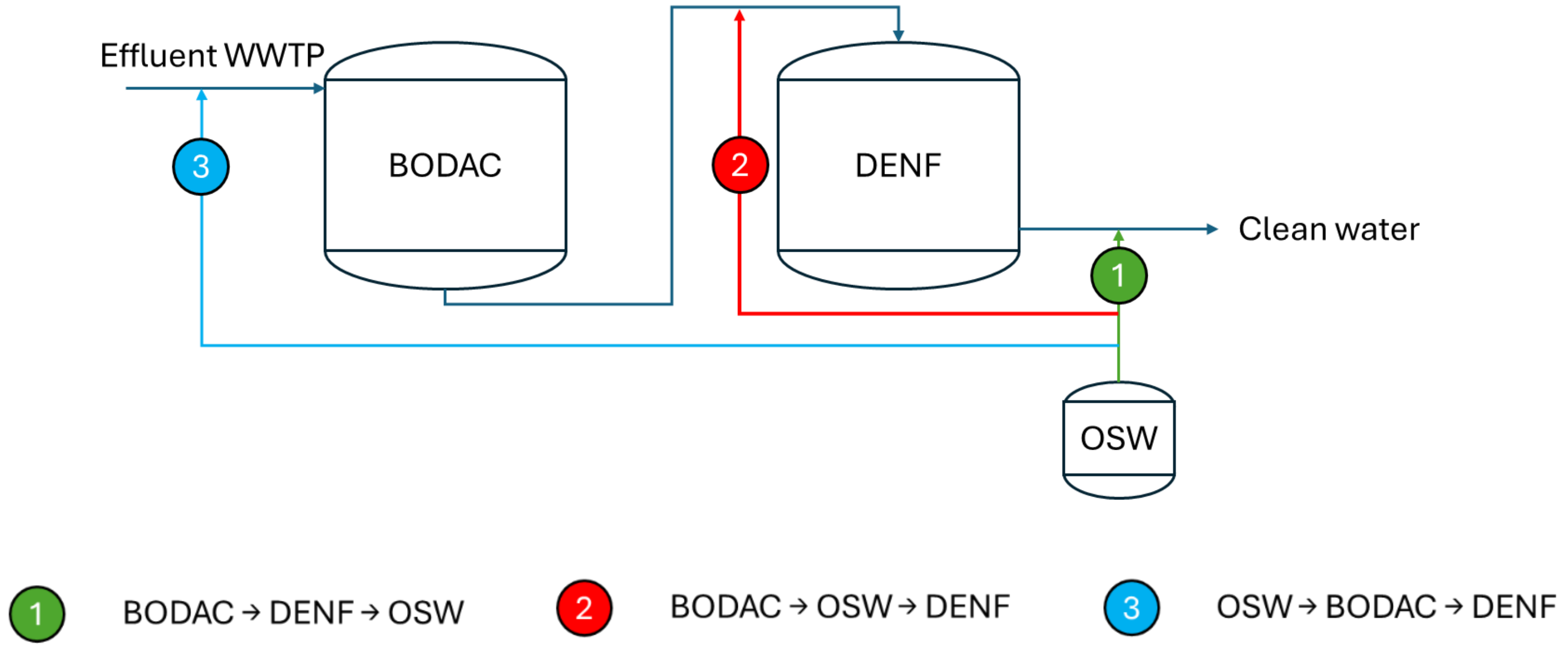
- First estimate of TCO and $CO_2$ footprint
  - All configurations score about the same on TCO
  - Config. BODAC + DENF + OSW scores best on $CO_2$-footprint
- Risk: ozonation at the end might result in too high $BrO_3^-$ in effluent!



# Innovation Partnership WWTP Tilburg

- **What is the best order of process steps?**

➢ Flexible pilot installation able to run all three configurations



# Innovation Partnership WWTP Tilburg

**Where do we stand?**

- Technology research & development just finished
- Pilot enginering & construction in progress
- Pilot testing & monitoring will run from august 2025 – july 2026

**Thanks you and see you next year at Aquatech 2026**

- **with first result of the pilot?!?**

Interreg
Vlaanderen-Nederland

Gefinancierd door
de Europese Unie

Schone Waterlopen door O3G

# HydrOzone$^{++}$ & Biofiltration

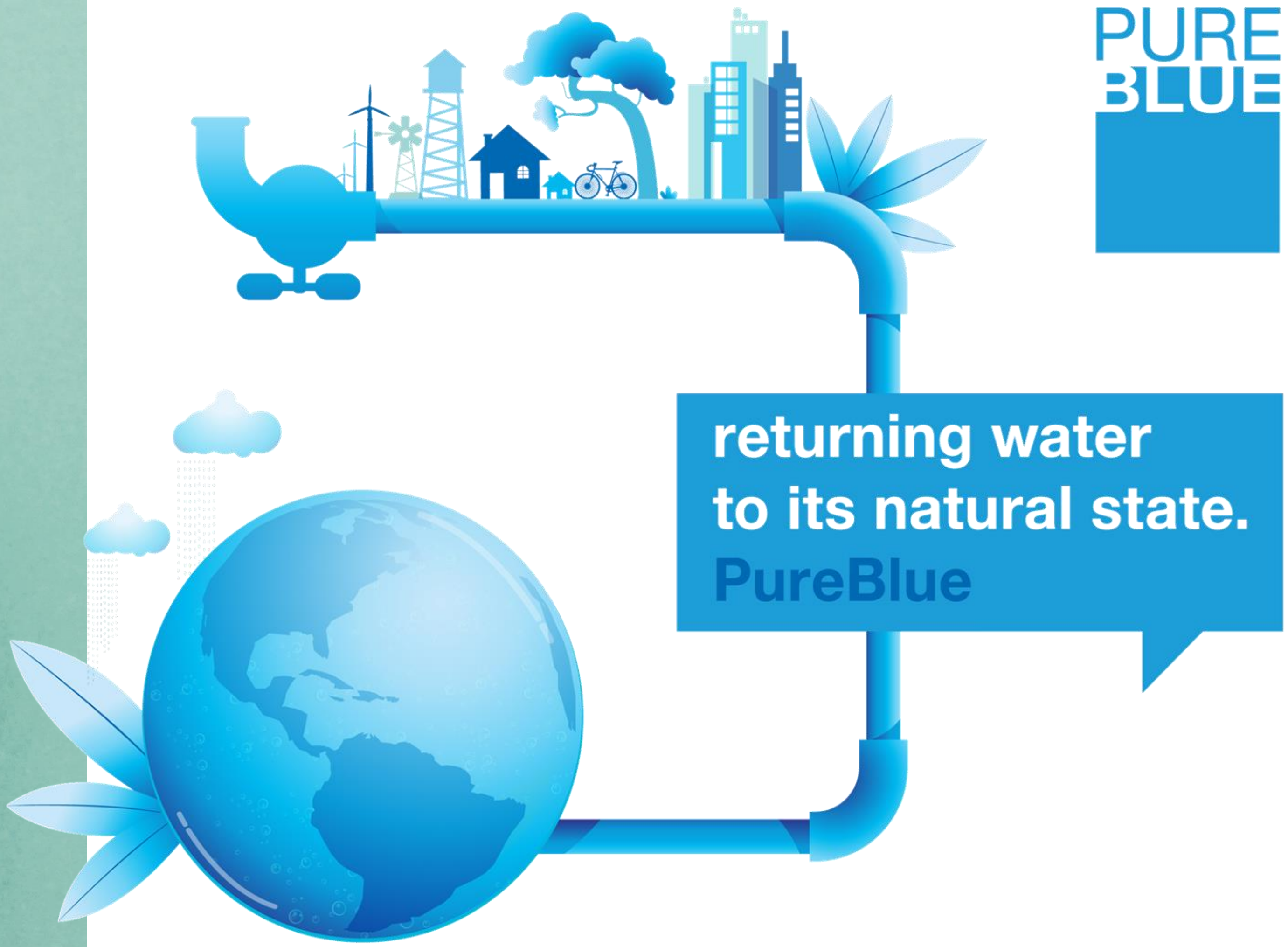

**Angelo de Mul**

**ademul@pureblue.nl**


Aquatech 2025, March 11, Amsterdam

PURE BLUE

# Our mission



# Recover.
# Reuse.
# Redesign.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Interreg
Vlaanderen-Nederland

Gefinancierd door de Europese Unie

# Schone Waterlopen door O3G

- Optimization simultaneous micropollutant & nutrient removal (combi KRW – ERSA)
- Combining HydrOzone$^{++}$ with GAC, BAC or other biofilter mechanism
- Location: Flanders/Netherlands
- Start Q3 – 2025

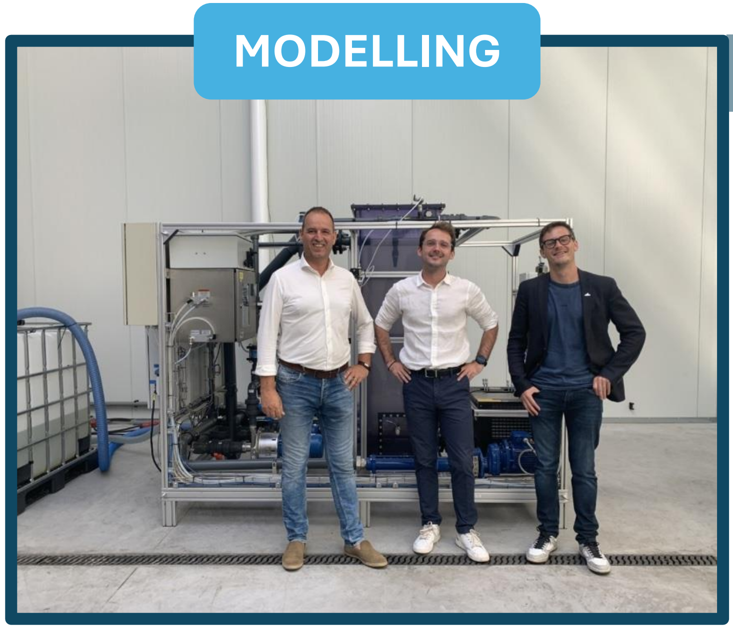
# Pilot research micropollutant removal with ozone

- TKI research RWZI Panheel 2015-2017
- TKI EF4F RWZI Walcheren 2020-2024
- TKI Belissima RWZI Walcheren 2019-2024
- Interreg Crossroads R2T AM Team 2020-2022
- **IPMV Stowa (2023-49) 2020-2023**
- Interreg ‘ Schone Waterlopen door O3G’ 2023-2026
- Europe Horizon Marie-Sklodowska-Curie: Nanaqua
- WWTP Leiden-Noord, WWTP Hapert, WWTP

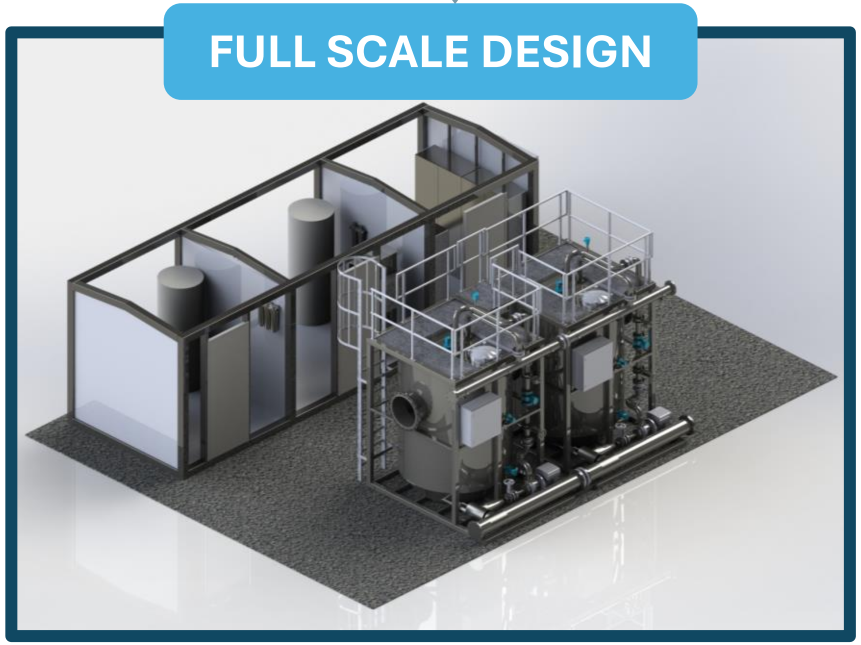
Horstermeer, WWTP Hulst



# Optimization and scale-up HydrOzone++ for WWTP








- ➢ Maximize OMP reduction
- ➢ Minimize Bromate
- ➢ Minimize Footprint
- ➢ Minimize $O_2$ concentration
- ➢ **LOWEST TCO**

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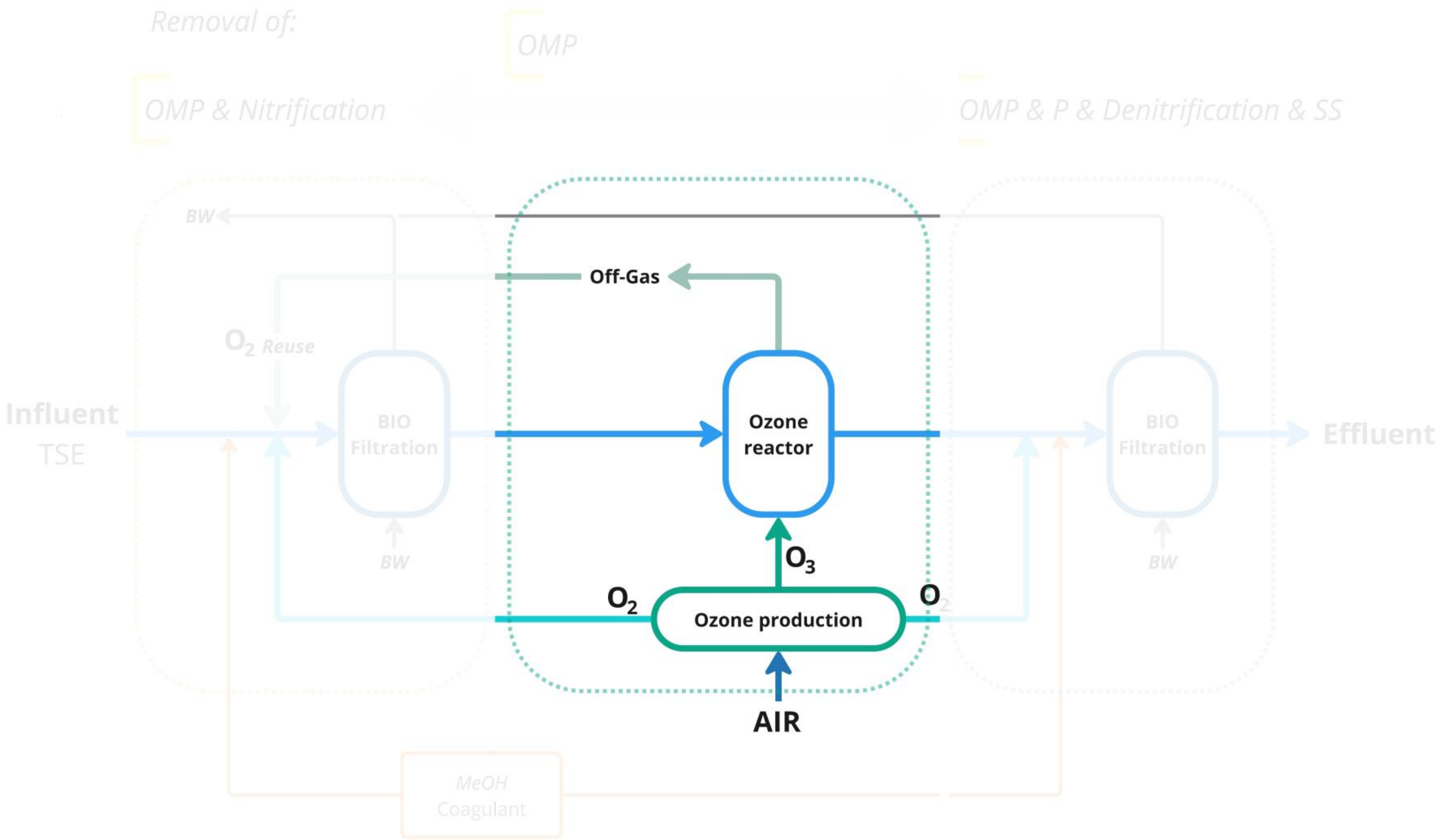
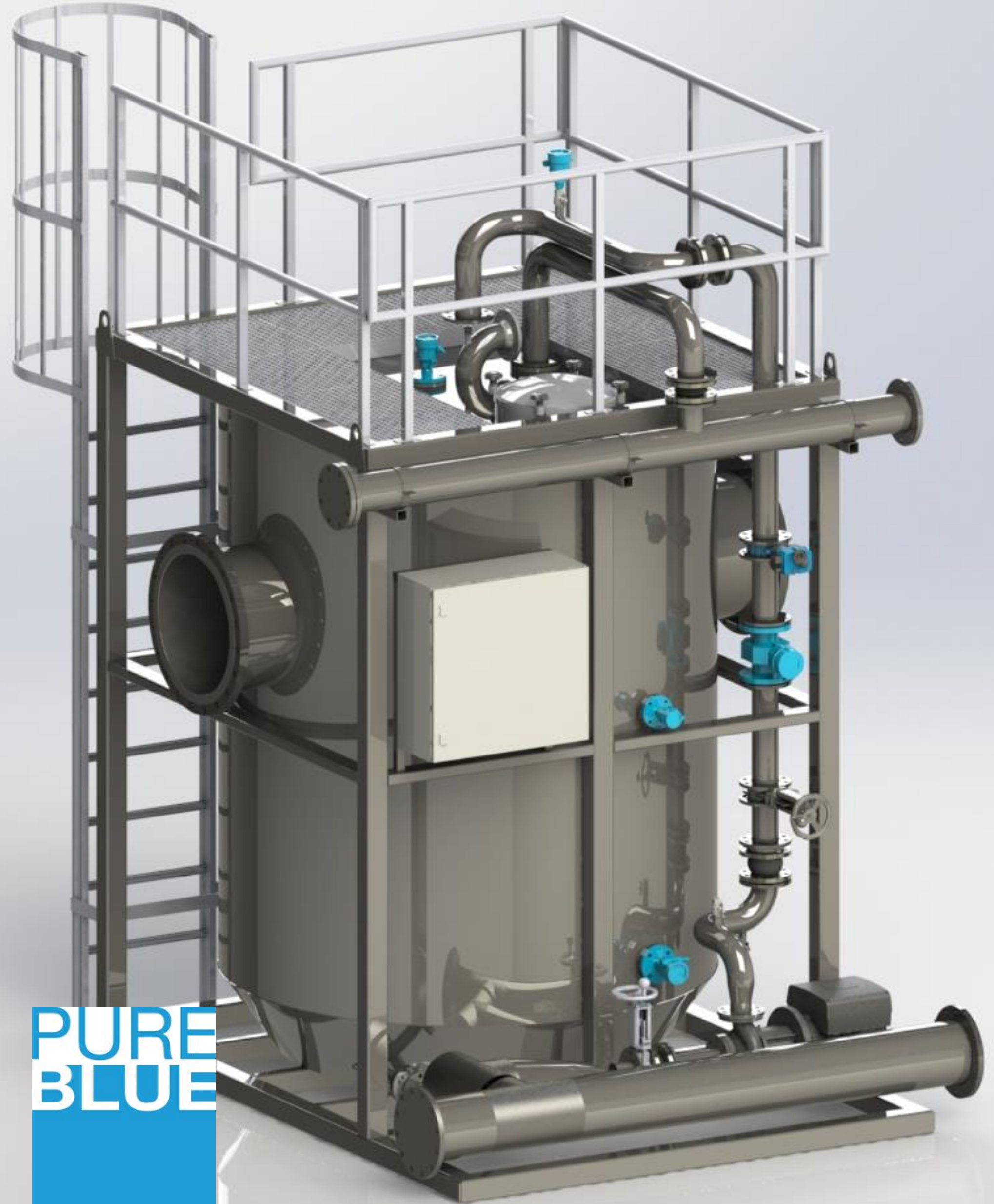
HYDRO3ZONE++

# Where we are now





- Standardized ozone reactor
  - Modular and scalable
  - Plug & play
  - Mobile and compact
  - **TCO reduction**

- Objectives
  - OMP removal
  - Bromate mitigation
  - **Avoiding excessive oxygen dissolution for combinations with (an)aerobic biofilters**

- Advantages of side stream injection
  - Small footprint
  - Flexibility through 24h flow variation

# Modularity

**Ozone Dose**

**Flow capacity**

1x1 units

0,35-0,45 g $O_3$/g DOC

Flow 40- 350 m3/h

Removal OMP with hybrid combinations e.g. O3 + BAKF

1x2 units

0,35-0,45 g $O_3$/g DOC

Flow 40-350 m3/h

OMP removal with stand-alone ozonation

2x1 units

0,35-0,45 g $O_3$/g DOC

Max flow 700 m3/h

Removal OMP with hybrid combinations e.g. O3 + BAKF

1x2 units

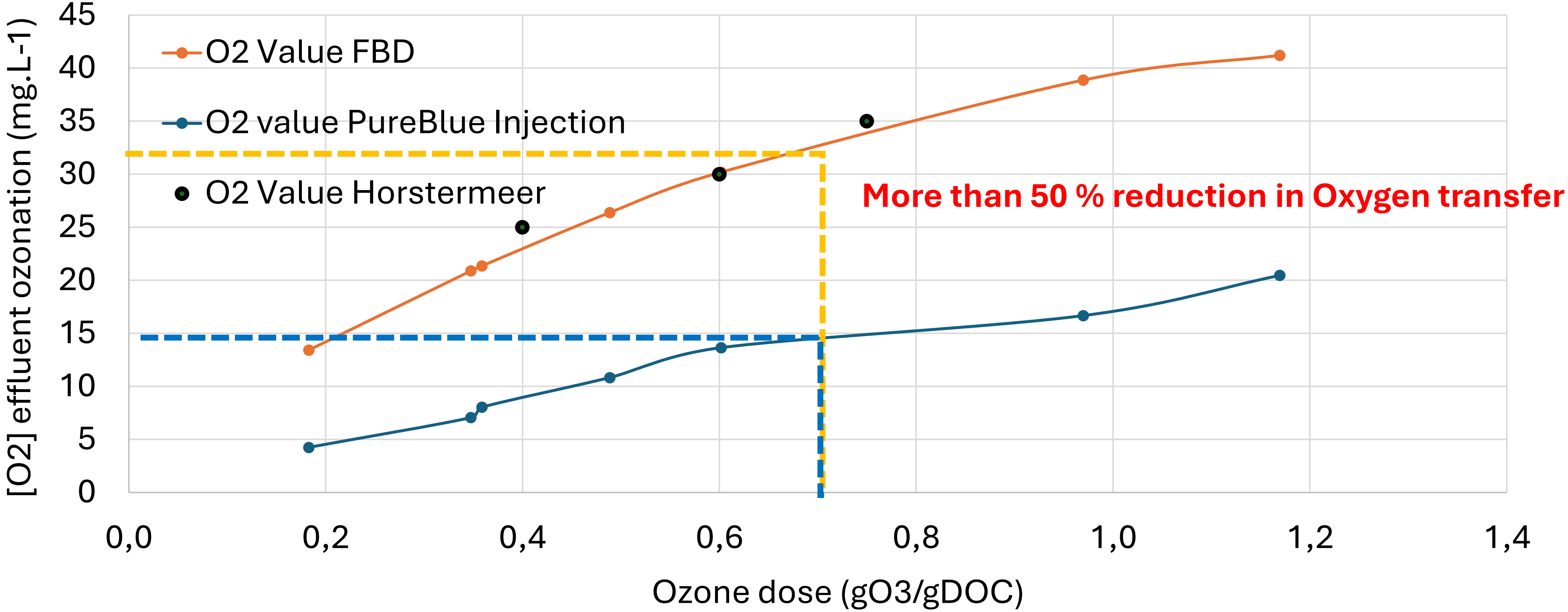
0,35-0,45 g $O_3$/g DOC

Max flow 350 m3/h

OMP removal with stand-alone ozonation

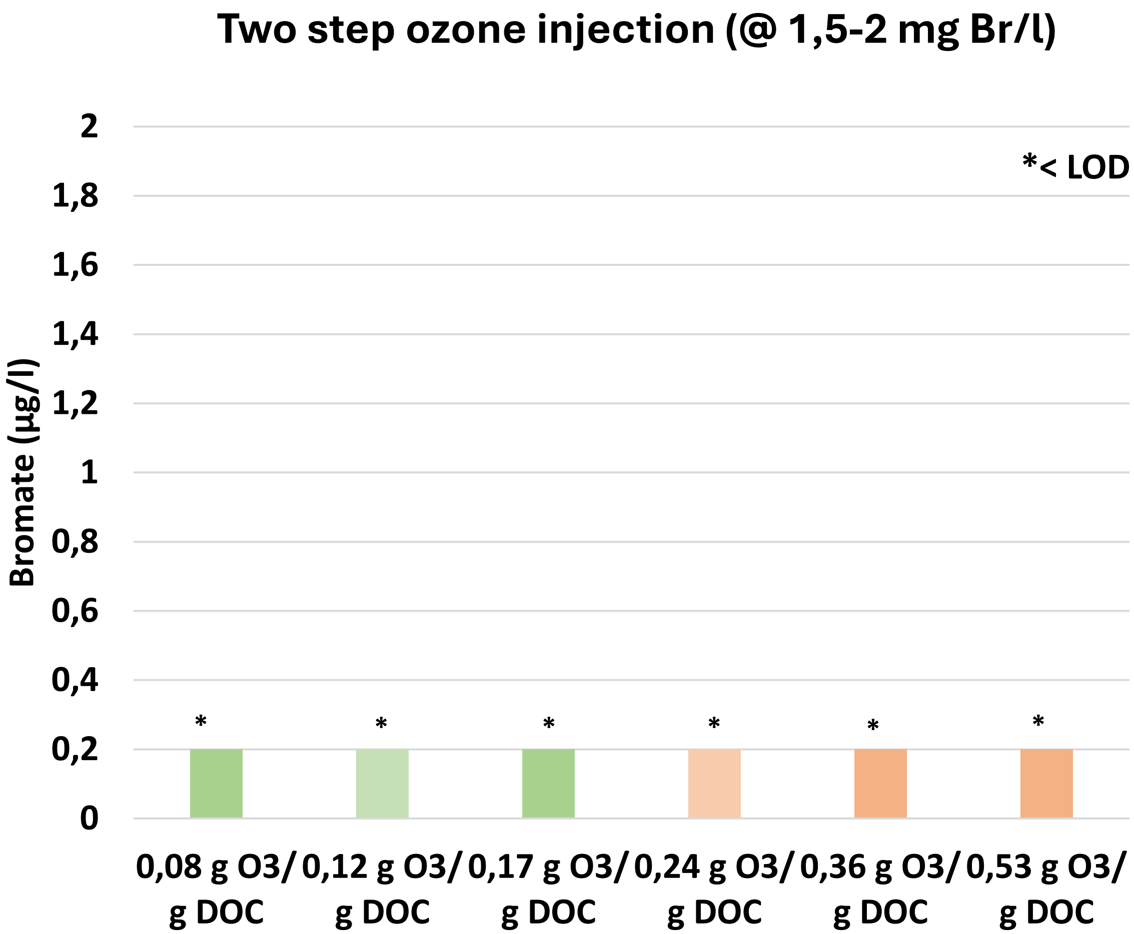
# MAXIMIZE ozone transfer MINIMIZE oxygen transfer

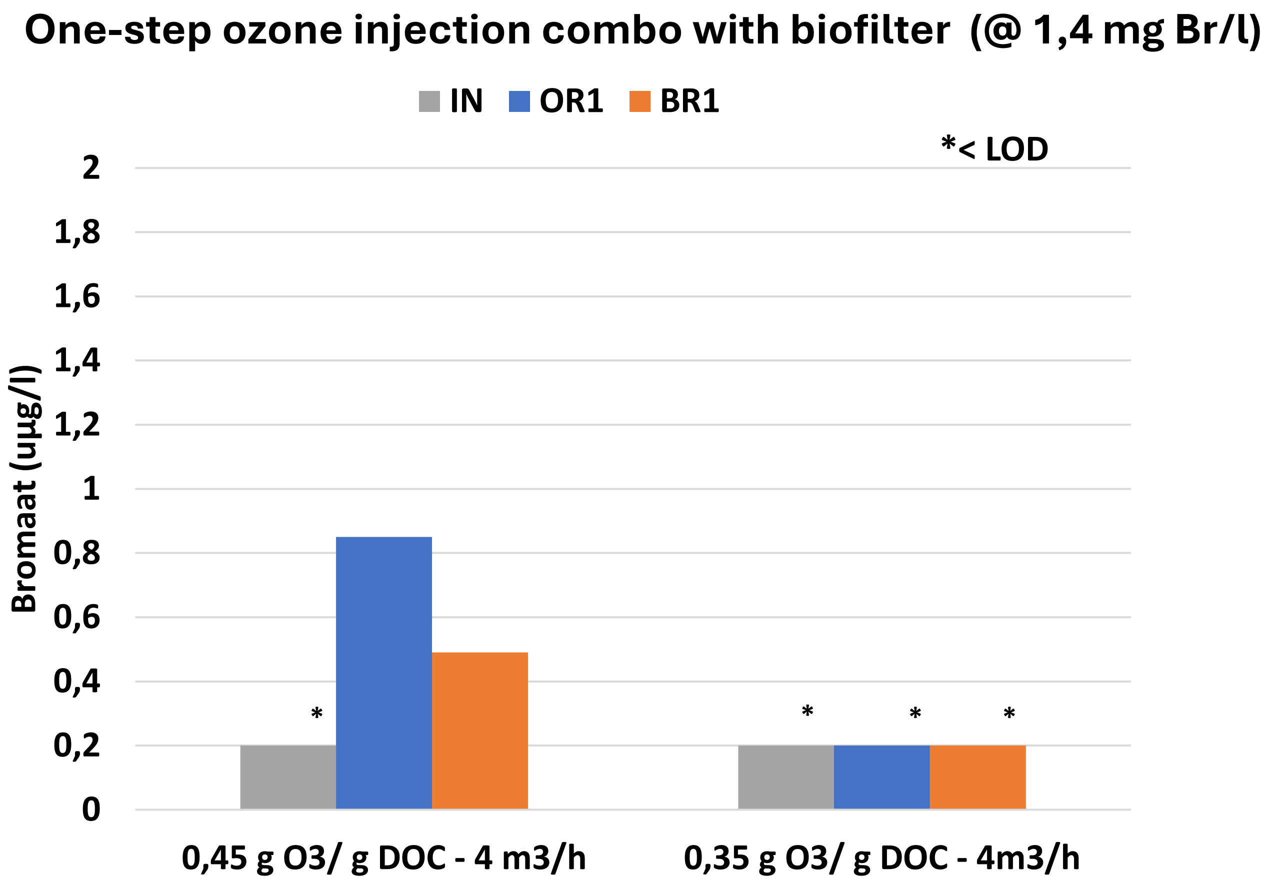
## $O_2$ transfer




| | | |
|---|---|---|
| **MINIMAL OXYGEN TRANSFER TO WATER** | **=** | **HIGHER OXYGEN RECOVERY POTENTIAL IN OFFGAS**<br>**+**<br>**LOWER CARBON REQUIREMENTS FOR POST DENITRIFICATION** |

# Bromate formation

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- No bromate formation even at extremely high bromide concentrations (1500-2000 µg/l)
- Multiple step ozone injection is more effective at higher ozone doses > 0,45 g O3/g DOC + potential for bromate reduction when anaerobic biological filter is applied downstream

# Impact of higher/ lower dissolved oxygen at 0,7 $gO_3/gDOC$

| | | PureBlue injection | Fine bubble diffusers |
|---|---|---|---|
| Dissolved oxygen | $mg.L^{-1}$ | 15 | 32 |
| $O_2$/carbon | mg $O_2$/mg C | 0,75 | 0,75 |
| Carbon needed (from graph) | $mg.L^{-1}$ | 20 | 43 |
| Price carbon | €/g carbon | 0,002 | 0,002 |
| Total carbon cost | €/$m^3$ | 0,040 | 0,087 |
| **Extra cost for FBD** | | **0,047€/$m^3$** | |

PURE BLUE This results in **270 k euro** in **annual savings** for a WWTP of 100 k IE

# Modular ozone generation and dissolution

- ➢ Biarritz, France
- ➢ Ozone capacity 6 kg $O_3$/h
- ➢ High organic load and low flow rate ⇔ WWTP effluent

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# MOST COST-EFFICIENT OZONE INJECTION IN THE MARKET

## CAPEX

Extremely compact

Modular

Standardized units

No need for intensive civil works

Plug & play

## OPEX

Less pumping energy (compact reactors)

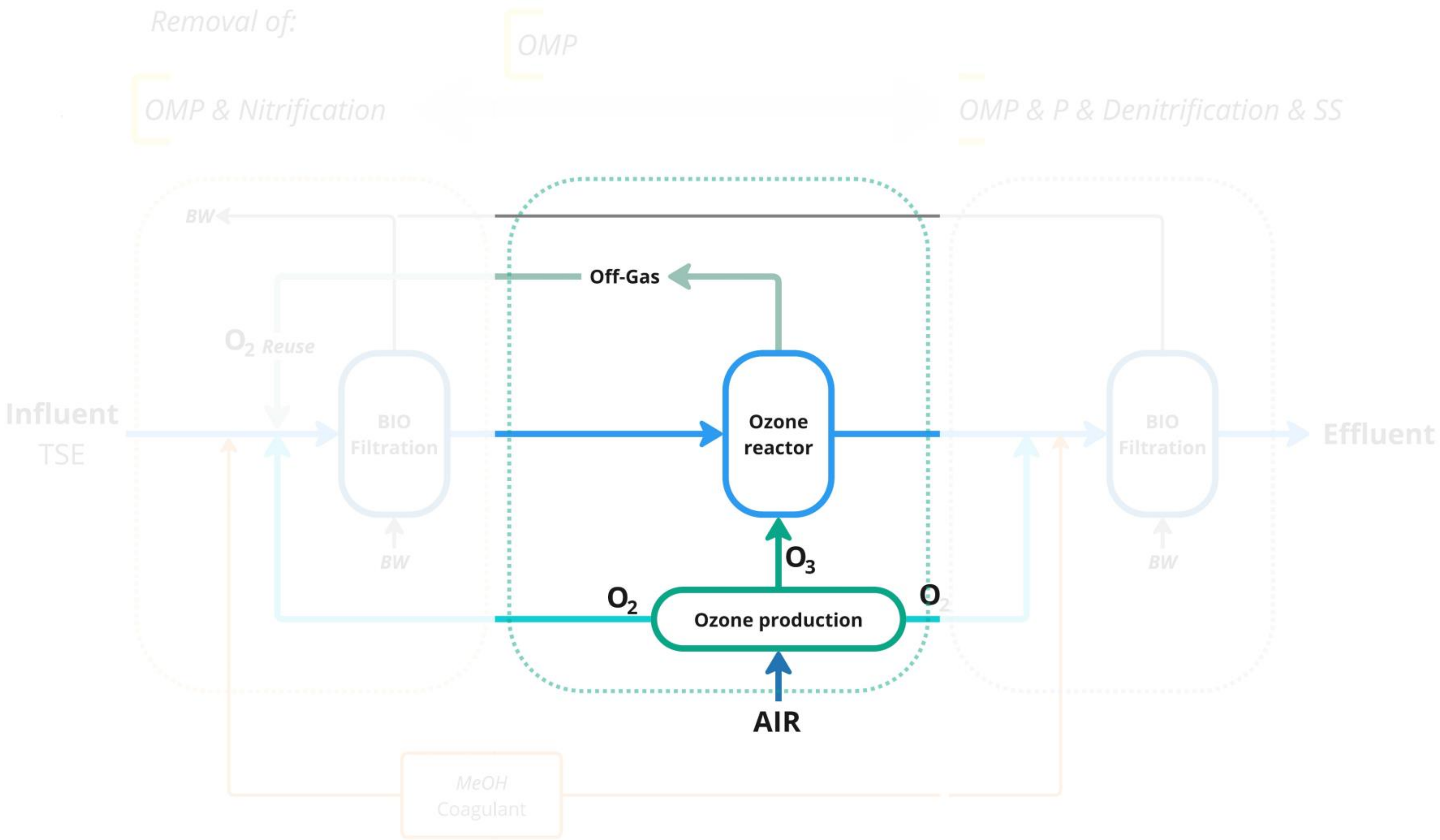
Low oxygen transfer resulting in less carbon source for post-denitrification

Higher oxygen recovery potential for reuse in aerobic biofilters

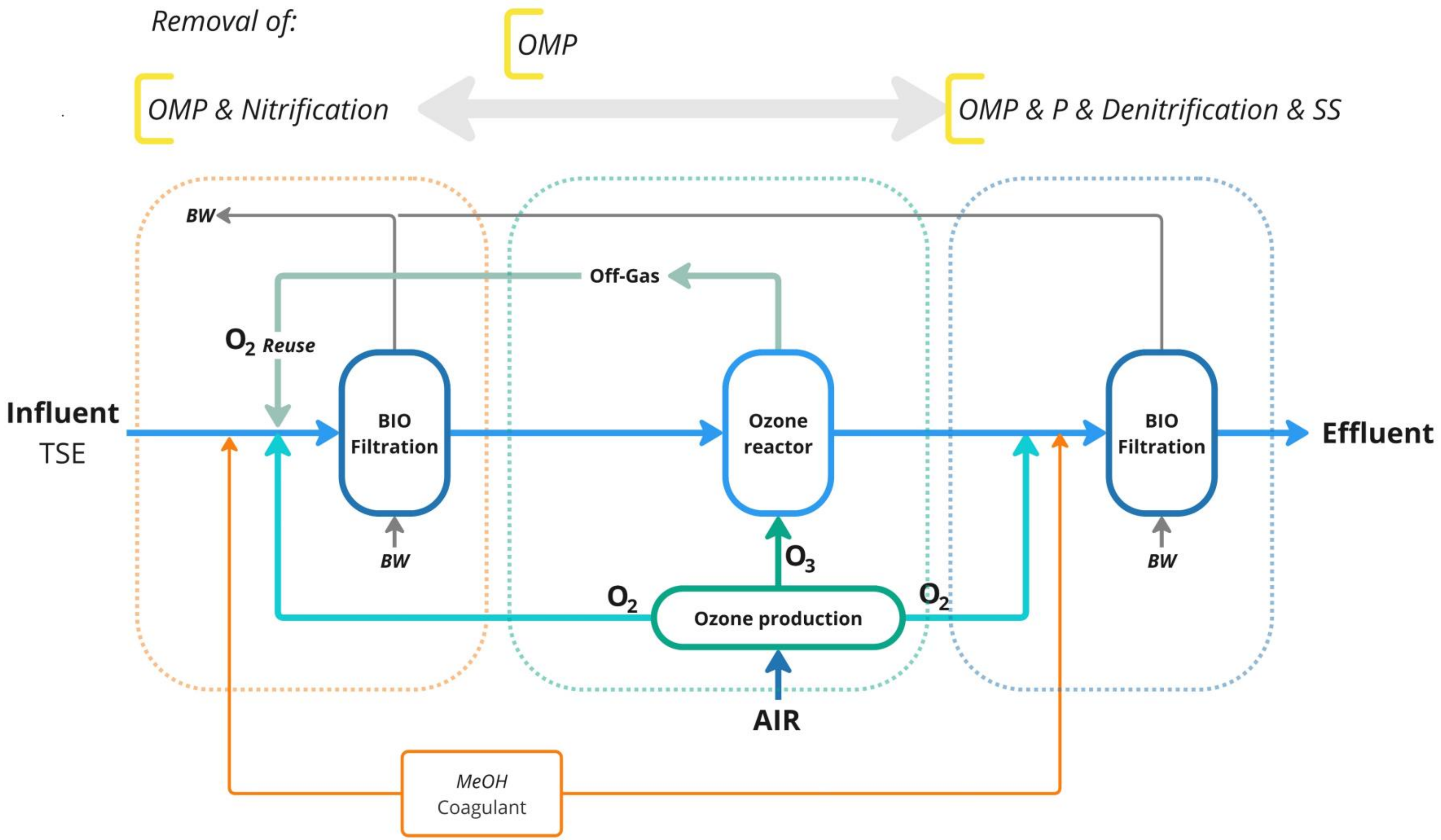
Lesser maintenance

No need for pH correction or other chemical additives to prevent bromate formation

# So, Where we are now



# Research and development objective within O3G



# NANAQUA

Training doctoral researchers in nanotechnology-enabled water treatment

## EU Horizon Europe Marie Skłodowska-Curie DN Project

***"Hybrid Biofilm Systems Enhanced with Nanostructured Materials for Micropollutant Biodegradation"***

KU Leuven
Beneficiaries, Consortium, Coordinator

University of Santiago de Compostela
Beneficiaries, Consortium

University of Salerno
Beneficiaries, Consortium

Norgenotech
Beneficiaries, Consortium

University of Glasgow
Beneficiaries, Consortium

Atlantic Technological University
Beneficiaries, Consortium

REMONDIS
Associated Partners, Consortium

Inopsys
Associated Partners, Consortium

SUEZ
Associated Partners, Consortium

TU Delft
Beneficiaries, Consortium

PureBlue Water
Beneficiaries, Consortium

University of Tartu
Beneficiaries, Consortium

BACO
Associated Partners, Consortium

Watchfrog
Associated Partners, Consortium

BIOTEC
Associated Partners, Consortium

Western Sydney University
Associated Partners, Consortium

University of California, Irvine
Associated Partners, Consortium

watercircle.be
Associated Partners, Consortium

# Take home message

- Interreg pilot will focus on combining HydrOzone$^{++}$ with GAC/BAC and/or other biofiltration steps
- Ozonation technology for micropollutants with lowest TCO in the market
- Focus on bromate mitigation and oxygen transfer limitation
- Modularity, scalability and standardization enables a high applicability on WWTP's with different sizes and needs

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Interreg
Vlaanderen-Nederland

Gefinancierd door de Europese Unie

## Schone Waterlopen door O3G

# Thank you!


Angelo de Mul

ademul@pureblue.nl


Aquatech 2025, March 11, Amsterdam

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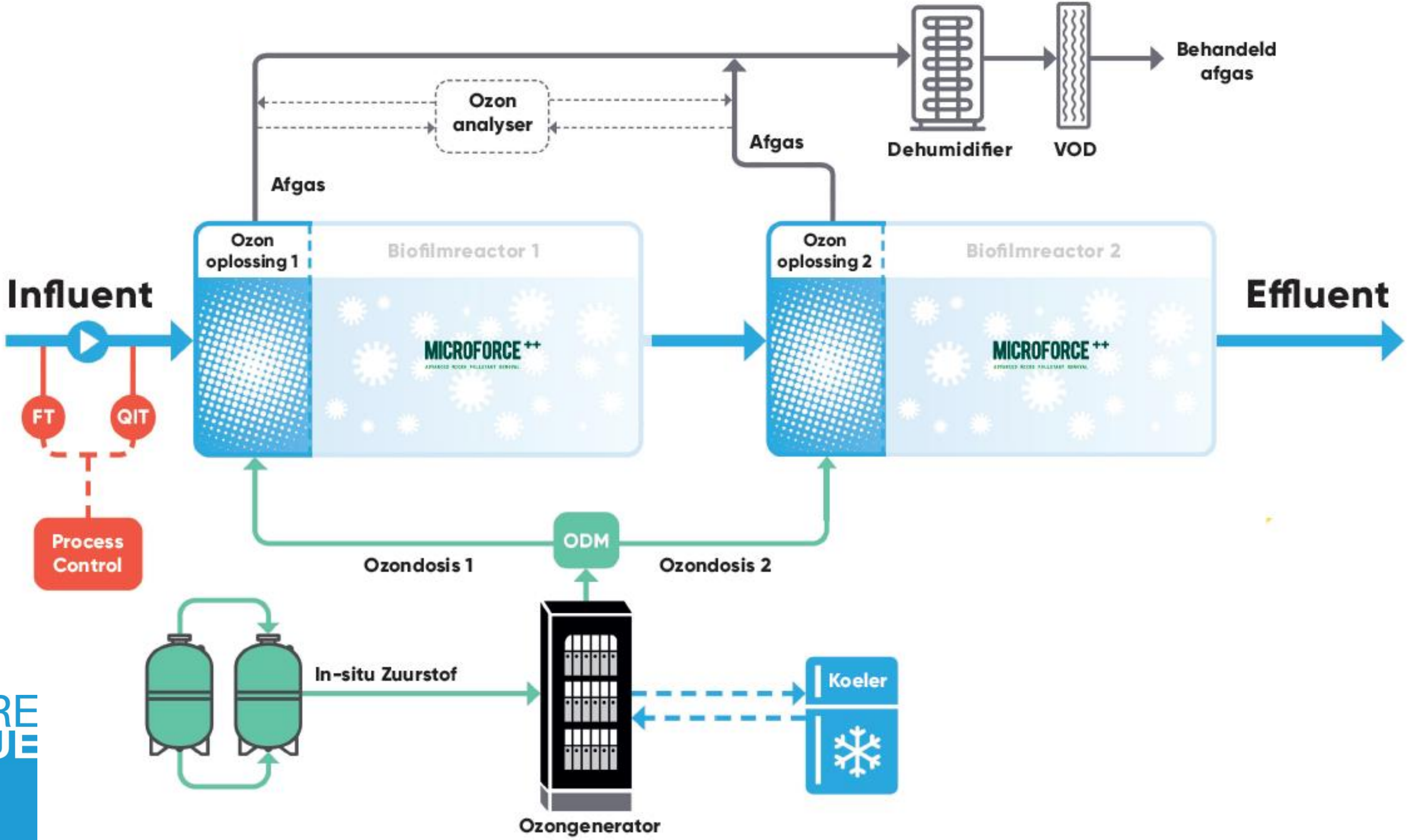
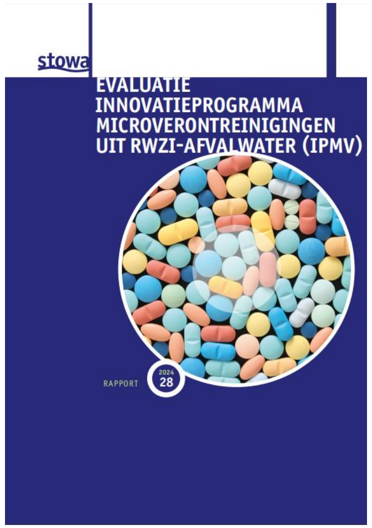


Behandeld afgas
Ozon analyser
Afgas
Dehumidifier
VOD
Afgas
Ozon oplossing 1
Biofilmreactor 1
Ozon oplossing 2
Biofilmreactor 2
Influent
Effluent
MICROFORCE++
MICROFORCE++
FT
QIT
Process Control
ODM
Ozondosis 1
Ozondosis 2
In-situ Zuurstof
Koeler
Ozongenerator

# Samenvattende tabel

| Techniek | Overall rendement 7/11 (%) | $CO_2$ (g $CO_2$/ $m^3_{rwzi\text{-}influent}$) | Kosten (EUR/$m^3_{rwzi\text{-}influent}$) | Bijvangst | TRL |
|---|---|---|---|---|---|
| Referentie PACAS | 80-85 | 184 | 0,05 – 0,15 | | 9 |
| Referentie GAK | 80-85 | 253 | 0,17-0,27 | | 9 |
| Referentie Ozon | 80-85 | 77 | 0,05-0,15 | | 9 |
| PAK+doek | ca. 80 | 135 | 0,16- 0,26 | P-verwijdering mogelijk | 7 |
| PACAS Nereda | 80-85 (84) | 195 | 0,07 – 0,17 | | 8 |
| BODAC | ca. 80 | 81 | 0,13 – 0,23 | $NH_4$ verwijdering, P-verwijdering mogelijk | 6-7 |
| BioGAK | ca. 80 | 50 | 0,10 – 0,20 | $NH_4$ verwijdering, P-verwijdering mogelijk | 6-7 |
| $O_3$-STEP | ca. 80 | 125 | 0,16 – 0,26 | $NO_3$ en P-verwijdering mogelijk | 8 |
| UpflowGAK-Carboplus | 80-85 | 161 | 0,12 – 0,22 | P-verwijdering mogelijk | 8 |
| UpflowGAK-Dynacarbon | 80-85 | 187 | 0,20 – 0,30 | P-verwijdering mogelijk | 8 |
| ZF+UV/$H_2O_2$ | 75-80 | 574 | 0,80 – 0,90 | | 5-6 |
| $O_3$+ultrasound | 85-90 | 74 | 0,05 – 0,15 | | 5 |
| PAK+$O_3$ | ca. 85 | 144 | 0,13 – 0,23 | | 7-8 |
| Microforce | > 80 | 69 | 0,16 – 0,26 | $NH_4$ verwijdering | 6 |
| Aurea ($BO_3$) | ca. 85 | 66 | 0,11 – 0,21 | $NH_4$ verwijdering, P verwijdering mogelijk | 6 |
| DEX-filter | 80-85 | 135 | 0,19 – 0,29 | Mogelijk $NH_4$, $NO_3$ en P-verwijdering ** | 5 |
| AdOx | ca. 75* | 71 | 0,10 – 0,20 | | 5 |
| NF+UV/$H_2O_2$ | 85-90 | 183 | 0,40 – 0,50 | Hoogwaardig hergebruik effluent mogelijk | 5 |
| $O_3$+keramischeMF | ca. 80 | 167 | 0,58 – 0,68 | Hoogwaardig hergebruik effluent mogelijk | 6 |



# Schone waterlopen door O3G

KWALITATIEVER OPPERVLAKTEWATER DANKZIJ EEN INNOVATIEVE TECHNIEK

Vragen? Veerle.depuydt@vito.be

Check: https://interregvlaned.eu/schone-waterlopen-door-o3g/over-ons

Interreg Vlaanderen-Nederland
Gefinancierd door de Europese Unie
Schone Waterlopen door O3G
Ministerie van Economische Zaken en Klimaat
Provincie Noord-Brabant
provincie Oost-Vlaanderen
VLAKWA | vito
Waterschap De Dommel
Aquafin
AM TEAM Advanced Modelling for process optimisation
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Universiteit Antwerpen
UNIVERSITEIT GENT
HZ UNIVERSITY OF APPLIED SCIENCES
CAPTURE