Ozonation, coagulation and ceramic microfiltration for WWTP effluent reuse

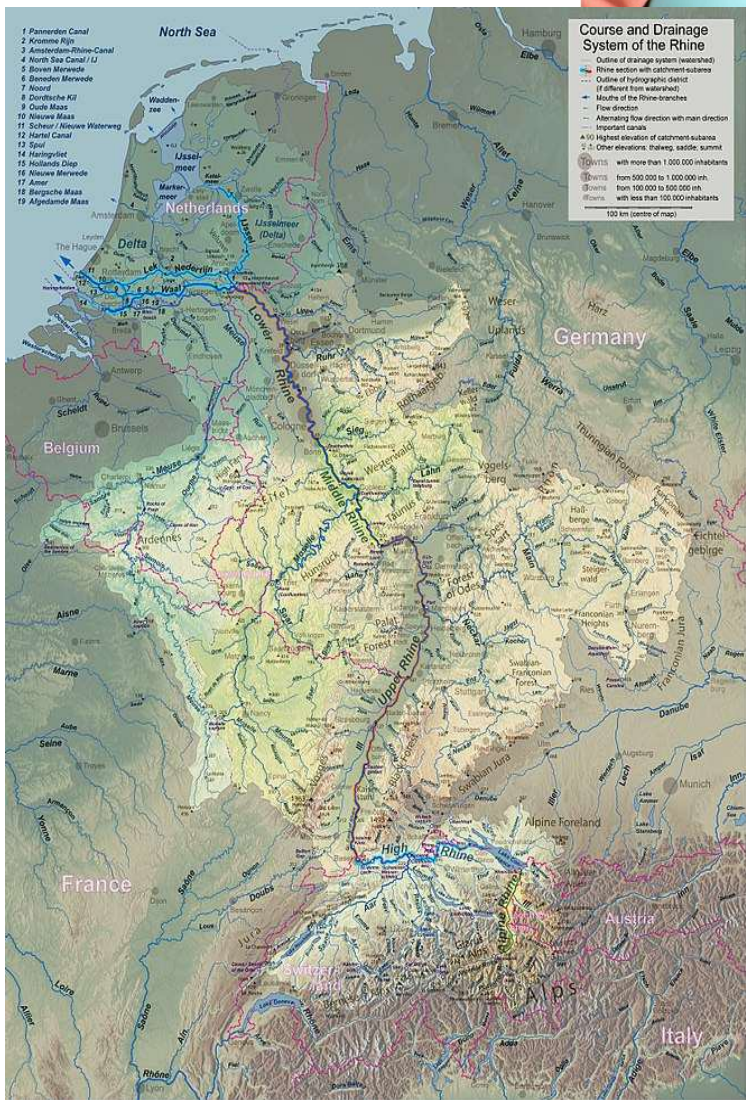
Martin Spruijt, PWNT

Dutch delta

- Freshwater in province of North-Holland:
  - Surface water (quality and quantity)

- Main water supply PWN:
  - Direct surface water treatment for drinking water production
  - Surface water treatment for dune infiltration
  - Surface water treatment for industrial process water

- Climate change:
  - Puts pressure on the source (quality and quantity)
  - Droughts



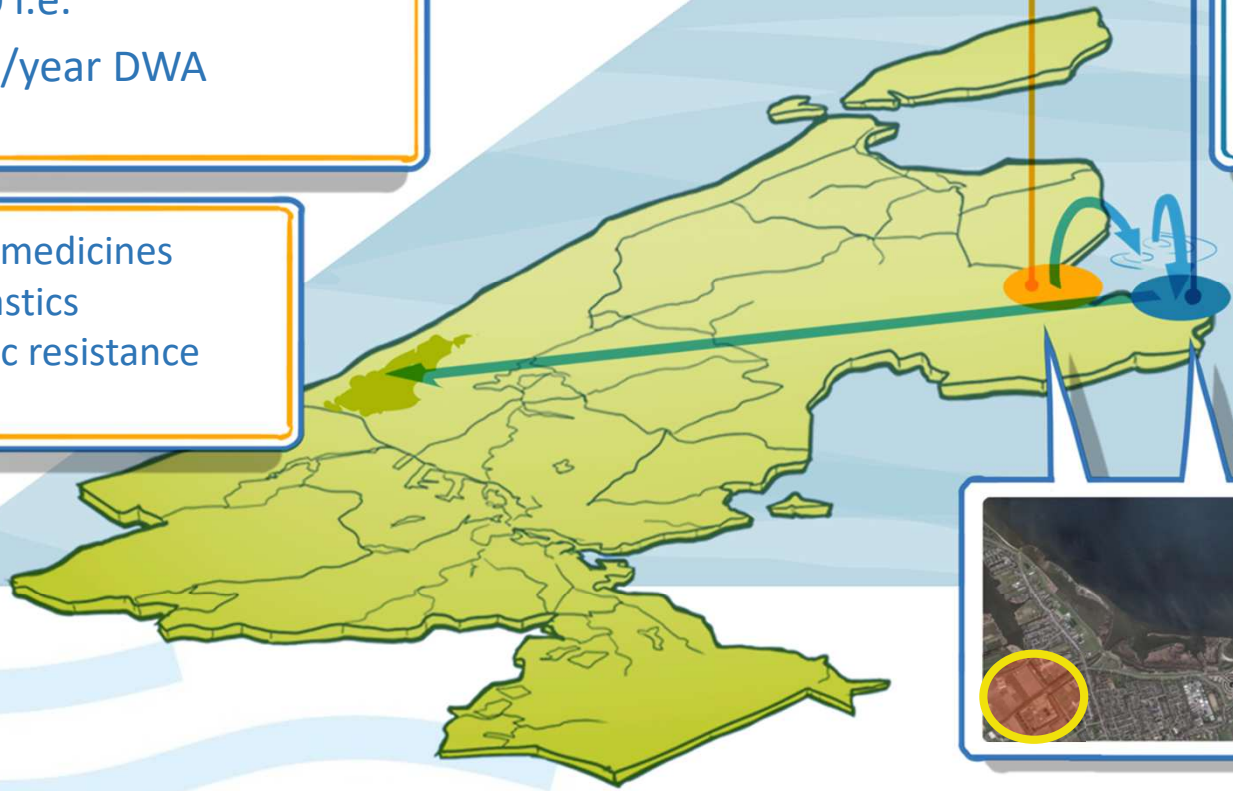
HHNK

WWTP Wervershoof

296.000 i.e.

13 Mm^3/year DWA

Hotspot medicines
Microplastics
Antibiotic resistance



PWN

WTP Andijk, WTP WRK

Drinking- & industry water

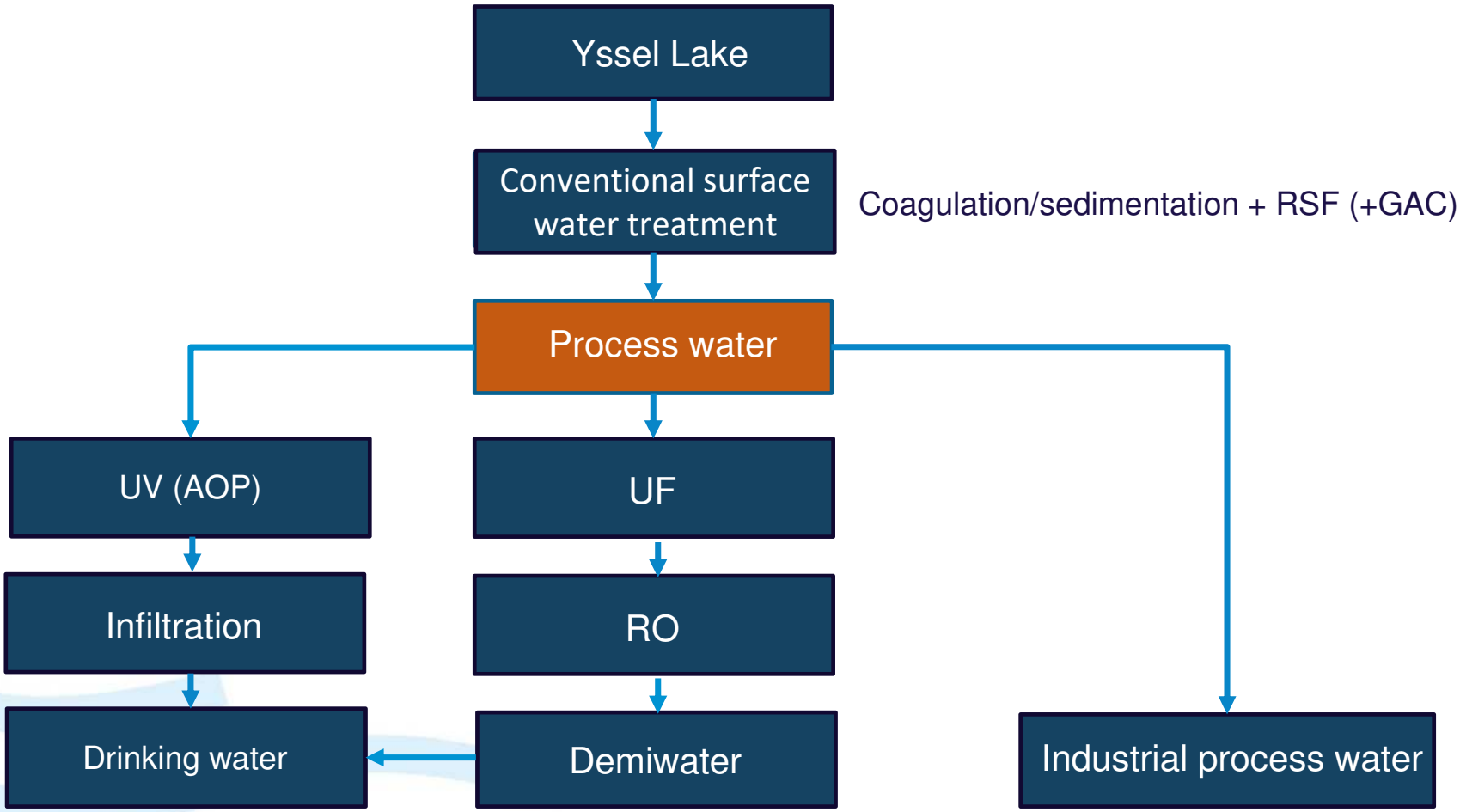
75 Mm^3/year

Source protection
CeC's
Drought -> Chloride

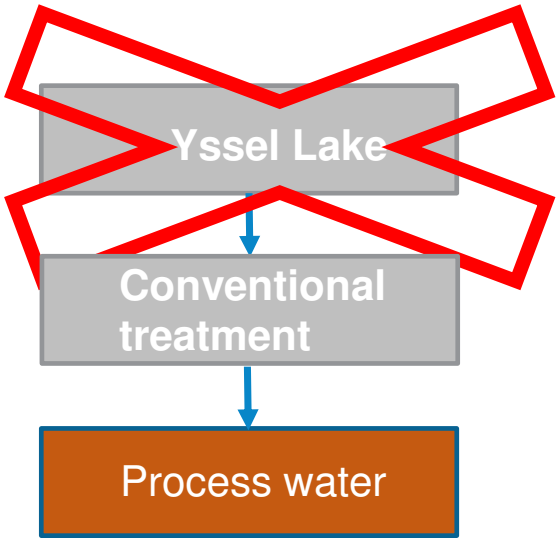
Wastewater reuse in the Netherlands

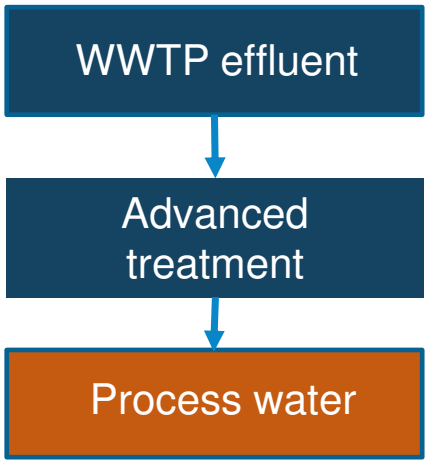
- Dutch ministry infrastructure & water + **EU's urban wastewater treatment directive**: Industry wide approach for pharmaceutical control
- Current Dutch focus wastewater discharge legislation on removal of selected pharmaceuticals: 70% of 7 out of 11 target compounds
- Higher ozone regimes required for pharmaceutical degradation (>90%)
- Additional priority pollutants: other pharmaceuticals, pesticides, microplastics, antibiotic resistance, protozoa/bacteria/viruses
- Additional technologies needed for barrier against micro-organisms
- High quality reuse often requires membranes (CMF/NF/UF, RO)
- Restricted bromate formation required (<1 ug/L)

Water supply system North-Holland



WWTP effluent as alternative source?

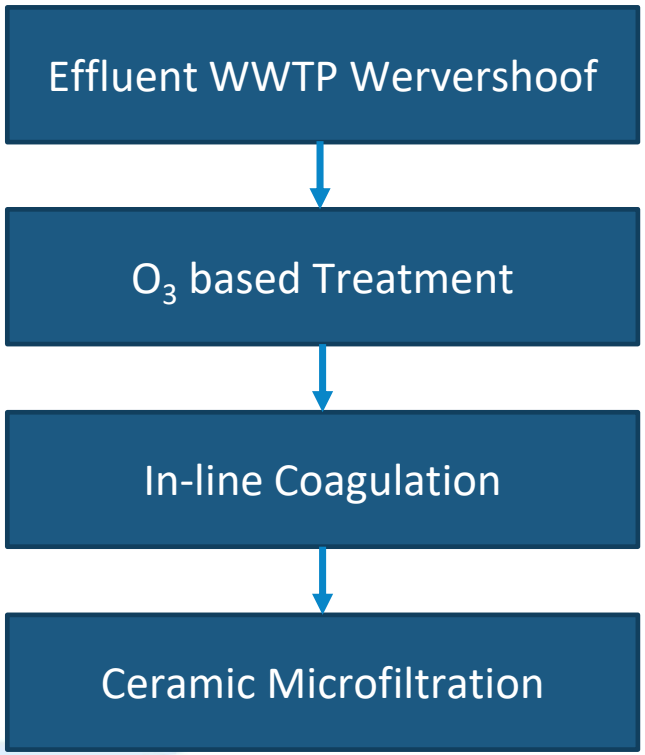




Development reuse scenarios by an integrated multi barrier treatment approach

- Industry process water
- Infiltration water
- Demiwater

Outlook



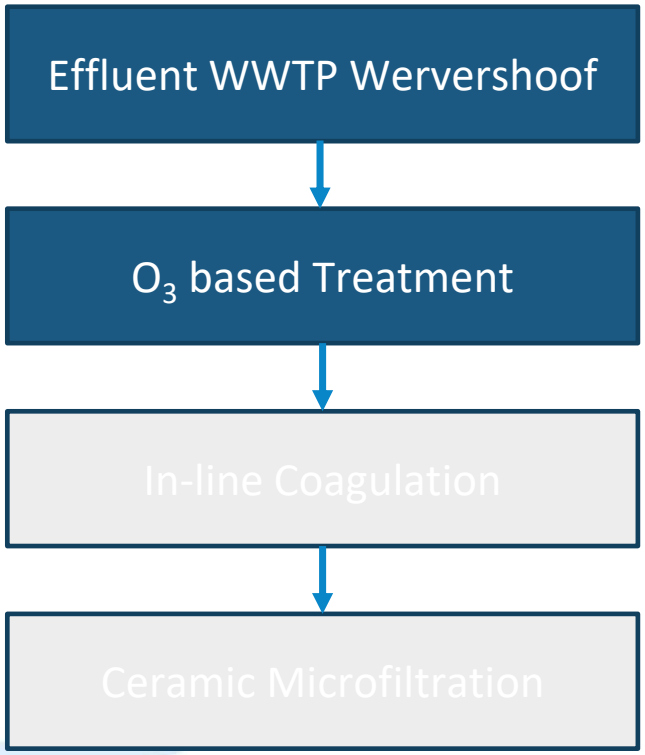
Source for reuse

Degradation micropollutants + flux enhancement

Removal suspended matter and flux enhancement

Removal suspended matter, microplastics and bacteria

Outlook



Source for reuse

Degradation micropollutants + flux enhancement

Removal suspended matter and flux enhancement

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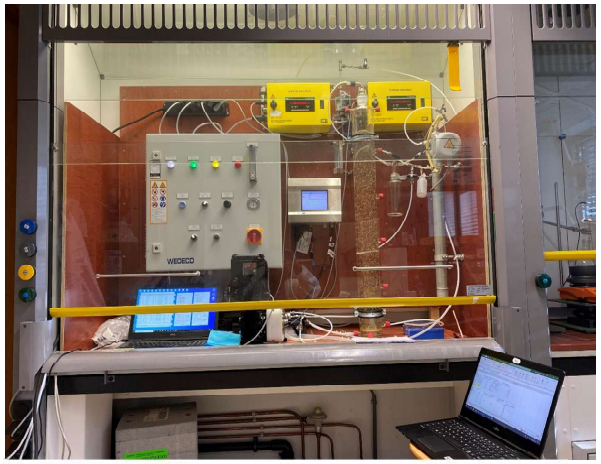
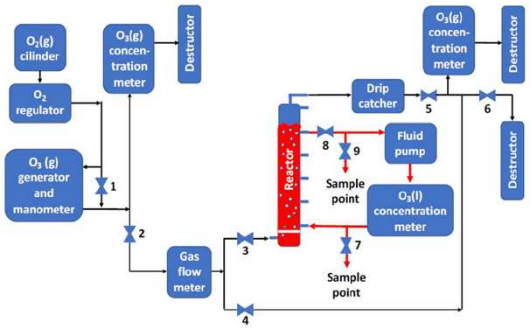
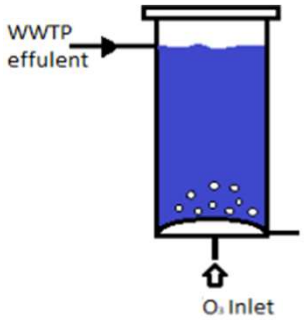
Ozone dispersion systems Wervershoof

Bench scale bubble column (6L)

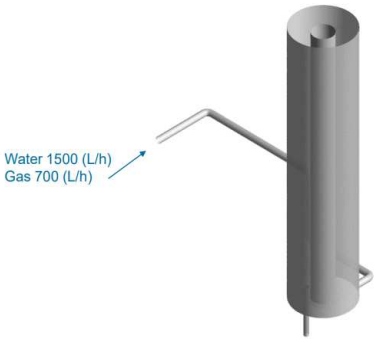




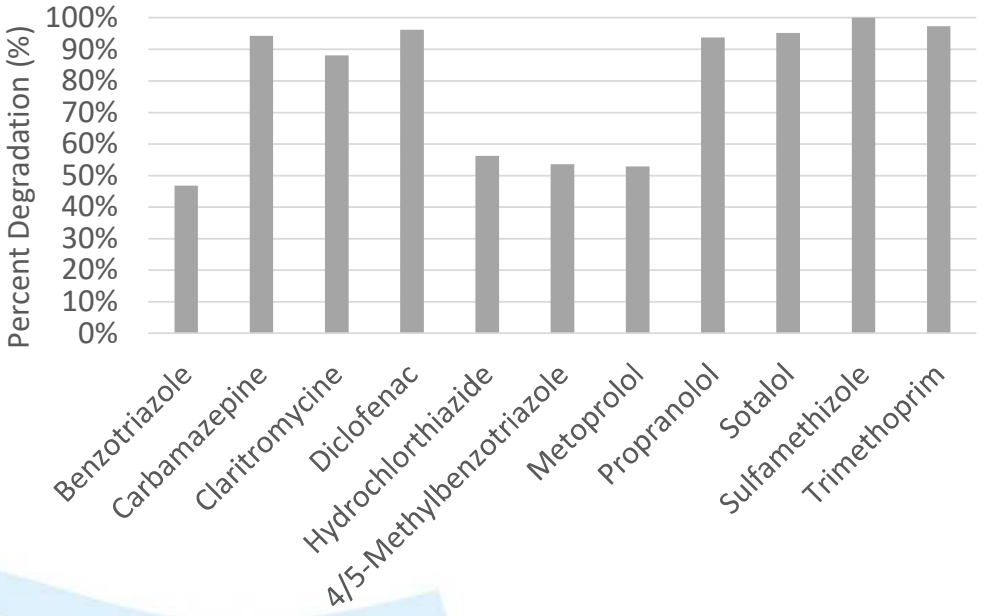
Bubble column (100L/h)

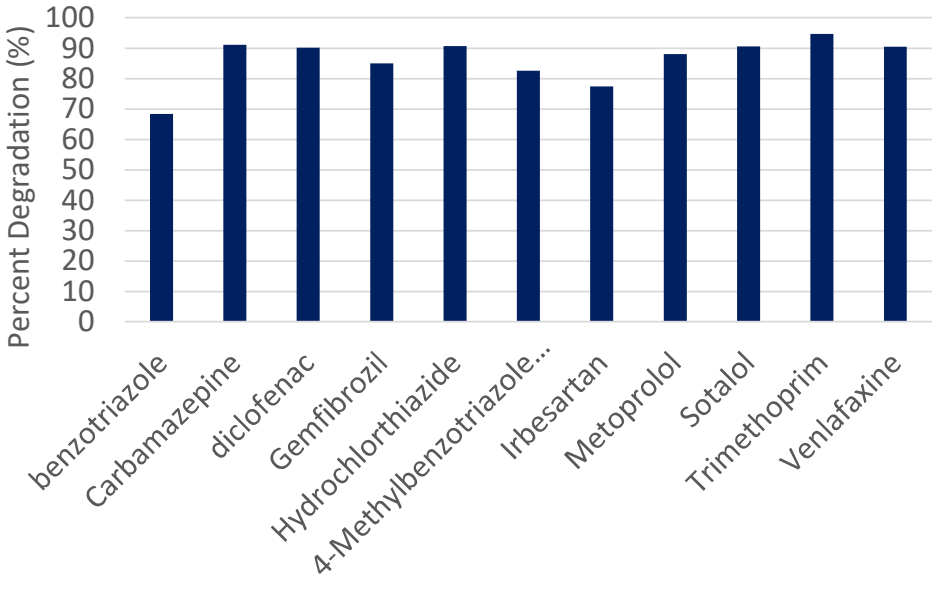


Venturi (1.5 m^3/h)



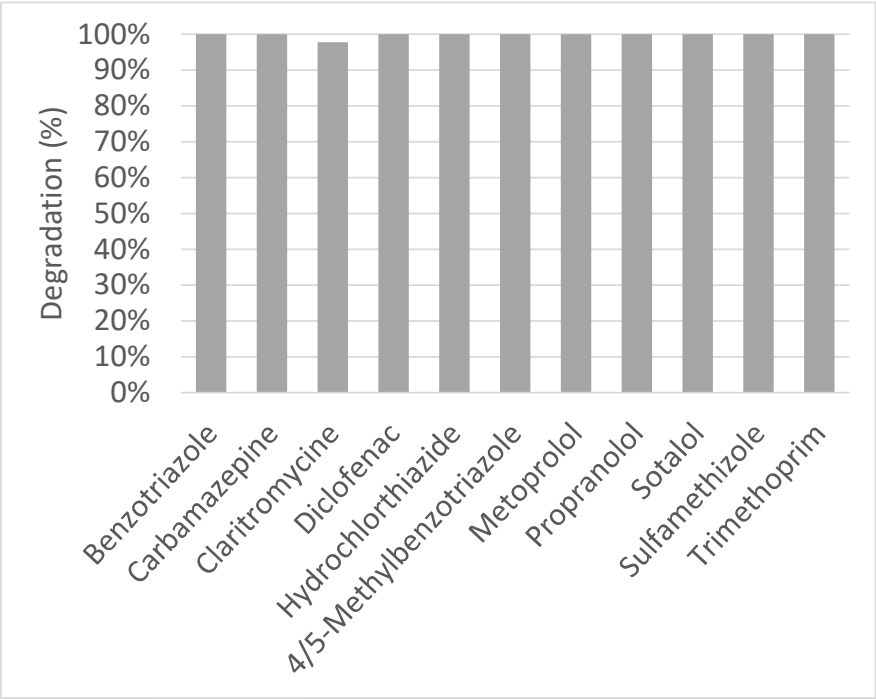
Pharmaceutical degradation bubble column (left) and venturi (right)
(0.75/1 g/g O_3/DOC & 0.6/1 g/g O_3/DOC)

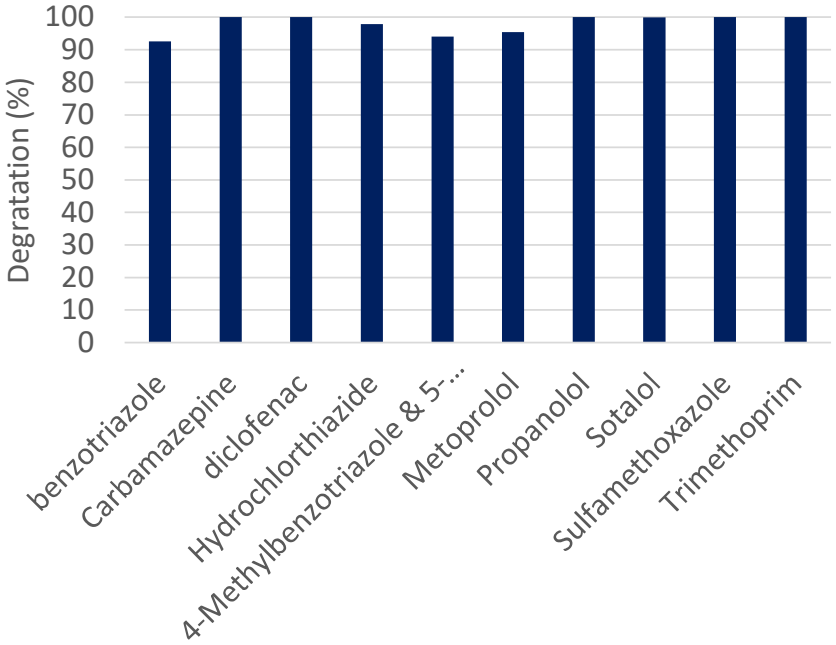




>70% degradation 7 out of 11 target compounds

Pharmaceutical degradation bubble column (left) and venturi (right)
(1.9/1 g/g O_3/DOC)

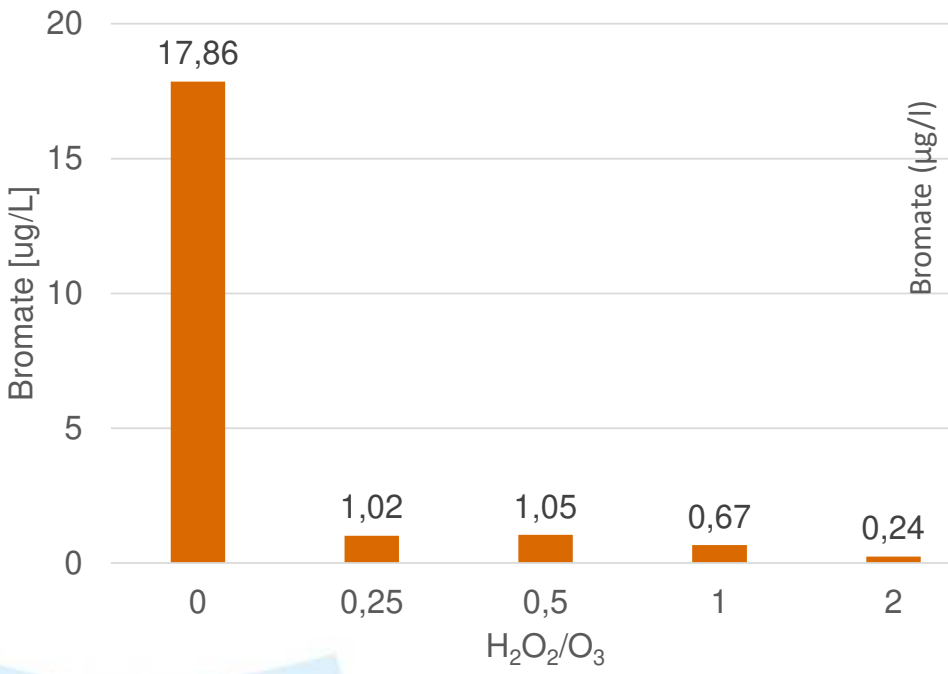


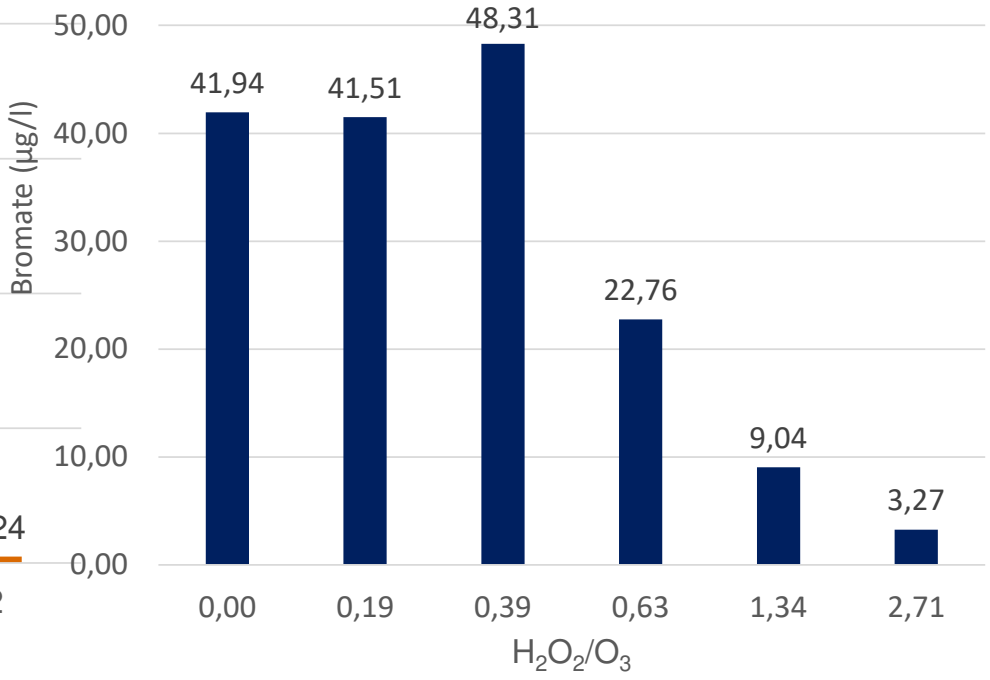


Reuse requirements in terms of pharmaceutical control can be met

Ozone based AOP (O_3/H_2O_2): Bubble column (left) and venturi (right)

Bromate formation as function of peroxide dosage





Ozone based advanced oxidation (O_3/H_2O_2) can effectively limit bromate formation at high ozone dosages

Ozonation & advanced (wastewater) treatment

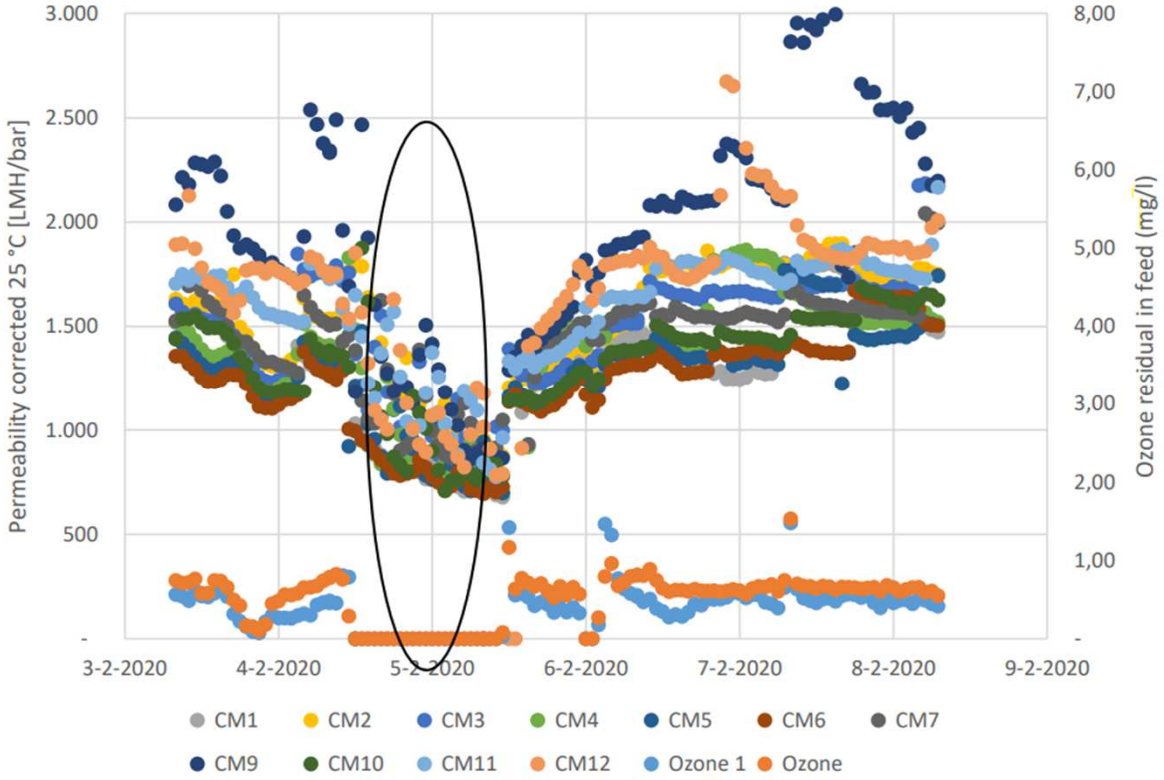
Pharmaceutical control (Oxidation)

Ceramic Membrane performance enhancement by pre-ozonation

Full scale example ozone and ceramic membrane filtration: CCKWW drinking water treatment (Singapore)

- 180 MLD drinking water plant
- Into service May 2019
- Ozonation pretreatment
- Ceramic microfiltration (C-90 Ceramac©)
- O_3 on membrane: typically 0.5 – 0.7 mg/L

Full scale example ozone and ceramic membrane filtration: CCKWW drinking water treatment (Singapore)



- Residual ozone normally between 0.5 – 0.7 mg/L
- ‘No-ozone test’ carried out for 2 days
- Permeability decreased during ‘no-ozone test’
- Permeability recovered when ozone dosing resumed

Lam, V., Shorney-Darby, H., Welling, M., Linzi, Z., Yinjie, W. (2020) Upgrading of Choa Chu Kang Waterworks with Ozonated Ceramic Microfiltration. WC2020

Ozone & WWTP effluent: oxidation and flux enhancement?

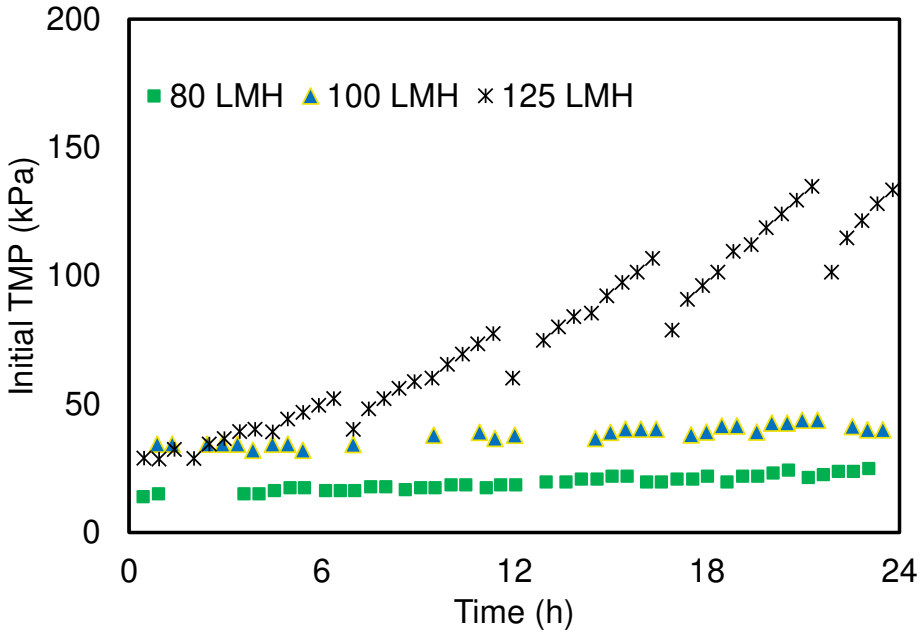
- Ozone: pharmaceutical control

- Ozone: membrane flux enhancement

Pilot circular Wervershoof

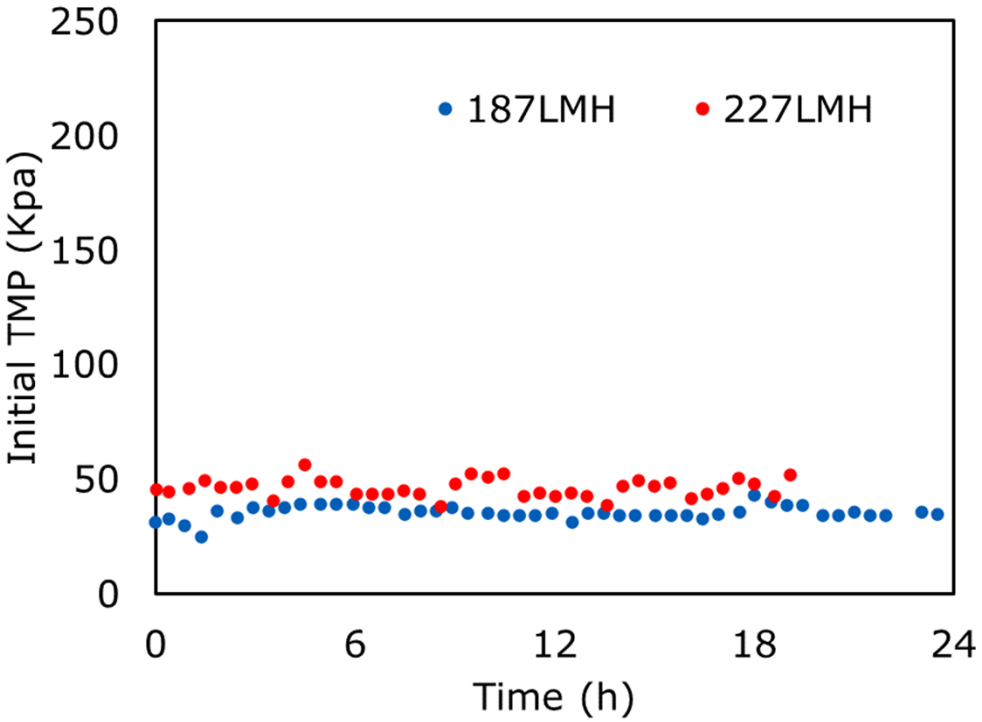
- Membrane module
  - Poriegrootte = 0.1 µm
  - Oppervlakte = 0.4 m^2
  - Max TMP = 200 kPa
- Ozone pretreatment
- Coagulation + ozonation pretreatment

CMF: no pretreatment



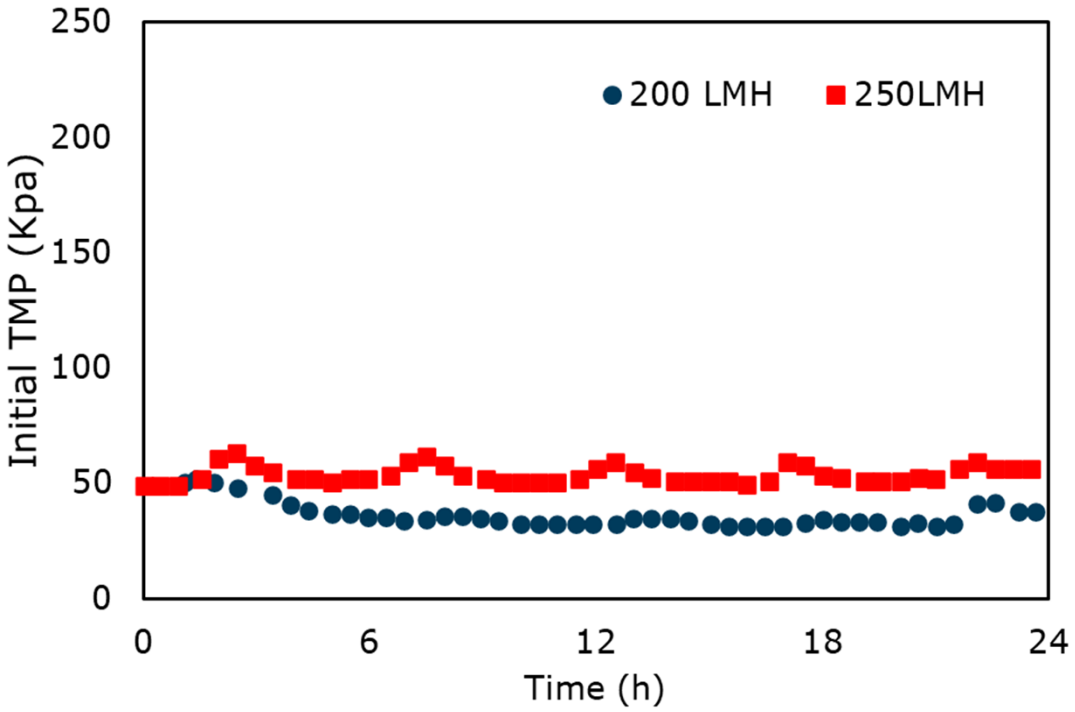
- 24h flux test
- WWTP effluent
- No pretreatment
- Sustainable flux 80 Lmh

CMF: O_3 pretreatment



- 24h flux test
- WWTP effluent
- O_3 pretreatment (1/9/1 O_3/DOC)
- O_3 on membrane: 0.6 mg/L
- Sustainable flux 227 Lmh

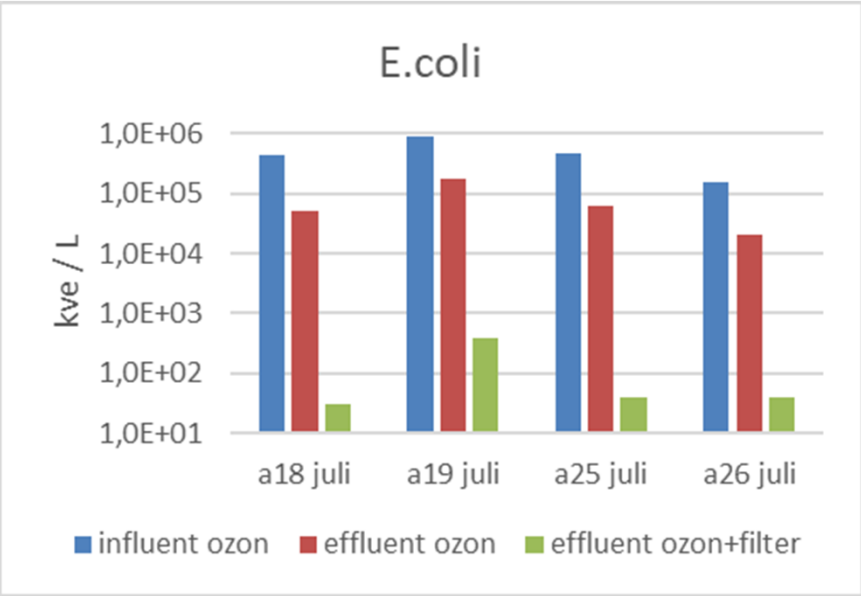
CMF: Ozone + Coagulation pretreatment

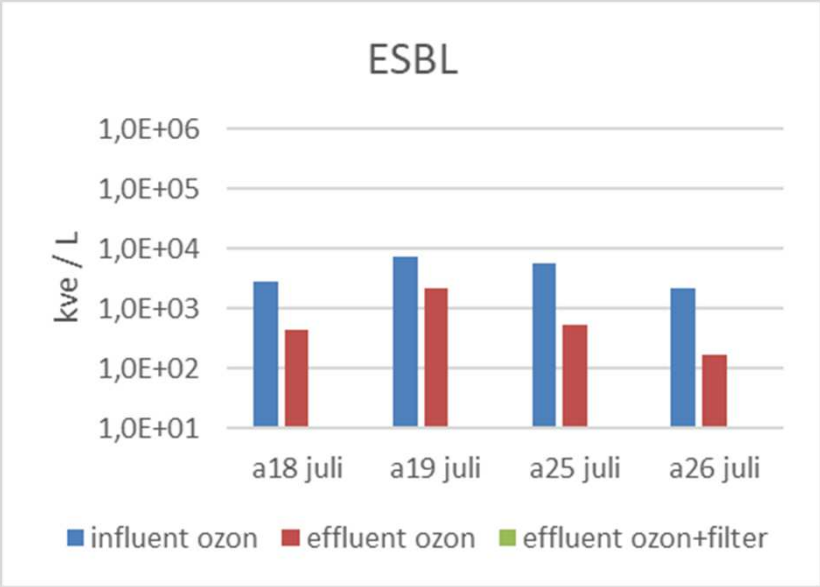


- 24h flux test
- WWTP effluent
- O_3 pretreatment (1.9/1 O_3/DOC)
- Coagulation: 10 mg/L Fe^{3+} at pH 6.8
- No residual O_3 on membrane
- Sustainable flux 250 Lmh

Water quality O_3-Coagulation-CMF

Microbiology (antibiotic resistant) bacteria





Removal (antibiotic resistent) bacteria partly removed by ozone

Ceramic microfiltration needed for further removal

Summary performance

- Ozone+SF (reference technology): objective pharmaceutical degradation
- Ge(O)zond (reuse): in context of reuse requirements, additional efforts needed

		Ozone + Sand Filtration	Ge(O)zond (reuse)
CO_2-footprint [1]	g CO_2/m^3	128	349
Costs [1]	€/m^3	0,17	0,67
Removal Efficiency Dutch guide substances[2]	%	80-85%	85-90 (86% bypass)

[1] 1 Per treated m3 wastewater: peak dry weather flow must be treated. ***Please note: standardized cost and CO2 levels for 2018****; recalibration of all CO2- and cost levels will take place during the evaluation of the Innovation Program in 2024*

[2] Overall Removal Efficiency of effluent wwtp to influent wwtp (including bypass post treatment) for 7 of 11 guide substances: benzotriazool, carbamazepine, diclofenac, irbesartan, gabapentine, metropolol, hydrochloorthiazide, mixture of 4- en 5-methylbenzotriazool, sotalol, trimethoprim en venlaflaxine in every 24h or 48h flow or time proportional sample. The sampling has to take the hydraulic retention time of the wwtp into account.

Conclusion

- Degradation target compounds: For all ozone dispersion systems >70% degradation
- Bromate formation: For guidline (70%) target compounds, bromate formation <1 ug/L. For higher degradation targets, substantial bromate formation >20 ug/L
- Minimization bromate formation: ozone AOP (O_3/H_2O_2) effective
- Reuse:
  - Microbiological parameters comparable or better than process water North-Holland
  - Treated WWTP effluent potentially suitable for UF-RO application
  - Concentration ions point of attention (mainly chloride and sulphate)
- Ozone dispersion systems: Contact time and type of ozone dispersion affect bromate formation (part of research HHNK Wervershoof demonstration plant)

Acknowledgements

- Drinking water company PWN
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Ministry of Infrastructure and Water Management

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Results of the Dutch Innovation and Implementation Program

November 8 and 9 2023
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