The future of disinfection in drinking water & wastewater

IWA
the international water association

WEBINAR

09 November 2022 | 14:00 GMT

iwa-network.org/webinars

WEBINAR INFORMATION

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- This webinar will be **recorded and made available "on-demand"** on the IWA website, with presentation slides, and other information.
- The **speakers** are responsible for **securing copyright permissions** for any work that they will present of which they are not the legal copyright holder.
- The opinions, hypothesis, conclusions or recommendations contained in the presentations and other materials are the **sole responsibility of the speaker(s)** and do not necessarily reflect IWA opinion.

WEBINAR INFORMATION

- **‘Chat’ box**: please use this for general requests and for interactive activities.
- **‘Q&A’ box**: please use this to send questions to the panelists.
  (We will answer these during the discussions)

Please Note: *Attendees’ microphones are muted. We cannot respond to ‘Raise Hand’.*

AGENDA, MODERATORS & SPEAKERS

- Welcome, introduction, housekeeping rules & Poll 1
  Chao Chen
- Recent progress of UV-LED disinfection technology
  Gary L. Hunter
- Risk based water quality management to reduce disinfection and DBPs in the Netherlands
  Patrick Smeets
- Disinfection byproducts in a context of Global Change
  Maria José Farré
- Poll 2 and Q&A discussion moderated by
  Haim Chikurel
- Final remarks and conclusion
  Chao Chen

Chao Chen,
Tsinghua Univ., China

Haim Chikurel,
Consultant, Israel

Gary L. Hunter,
Black & Veatch's Water Technology Group
USA

Patrick Smeets,
KWR Water Research Institute,
Netherlands

Maria José Farré,
Catalan Institute for Water Research ICRA,
Spain

Poll

MODERATOR: CHAO CHEN

Welcome Remarks on Behalf of the Disinfection Specialist Group of IWA

CHAO CHEN, TSINGHUA UNIVERSITY, BEIJING, CHINA

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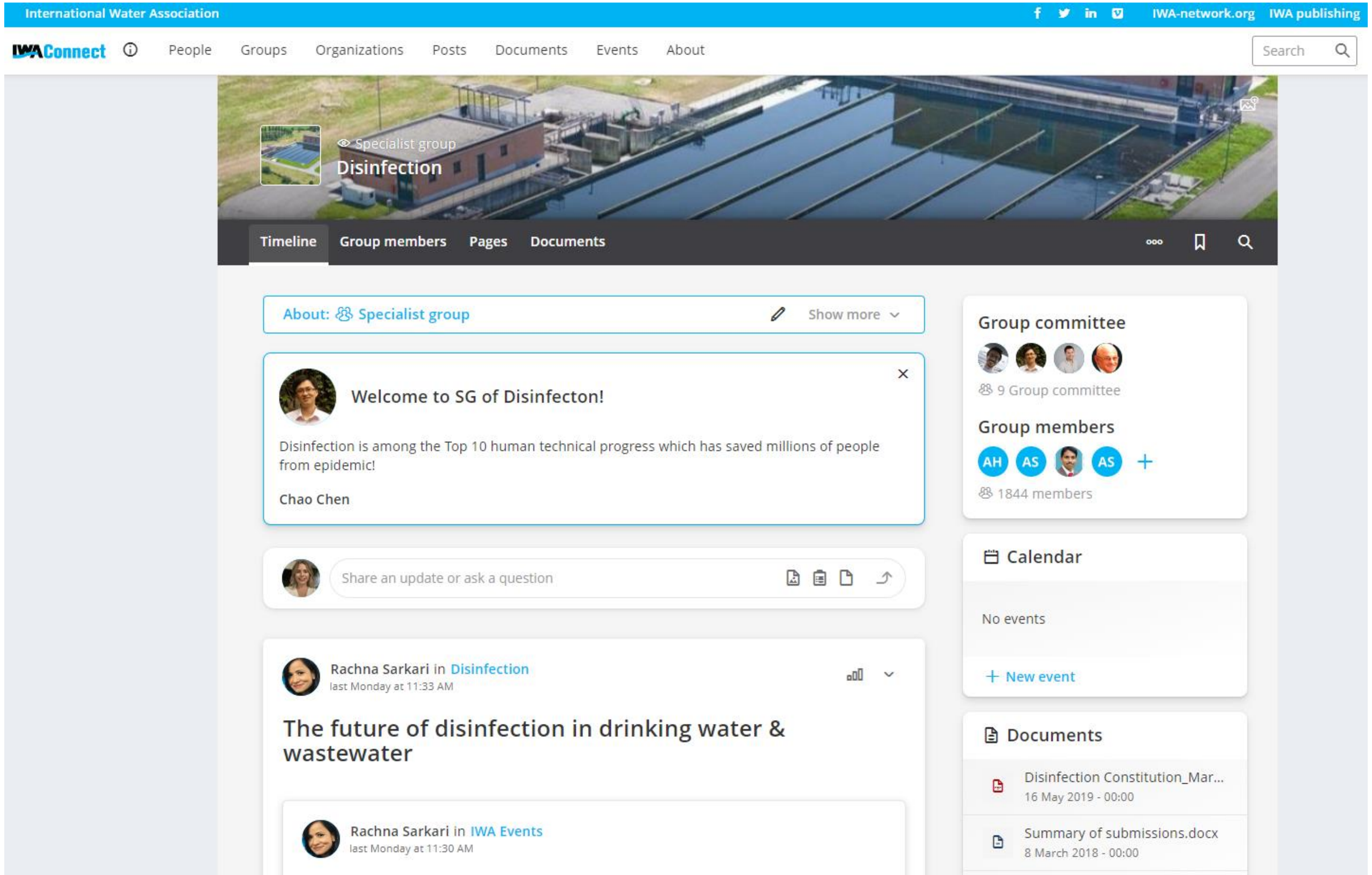
IWA DISINFECTION SG



The Disinfection Specialist group aims to create, exchange and transfer the knowledge and experience of disinfection-related issues in water, wastewater, sludge or excreta.

Join the IWA DISINFECTION SG on IWA Connect!

https://iwa-connect.org/group/health-related-water-microbiology/timeline

DATA OF DISINFECTION SG

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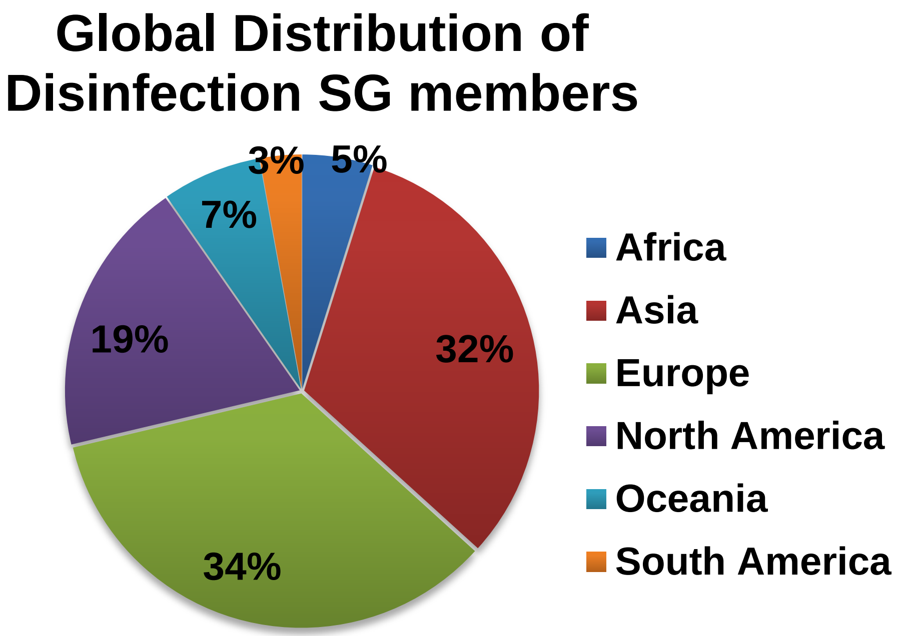
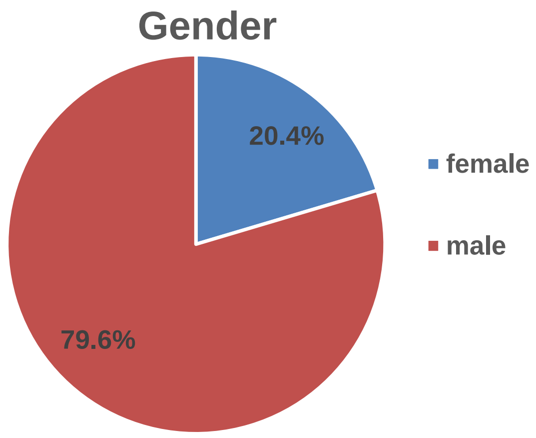
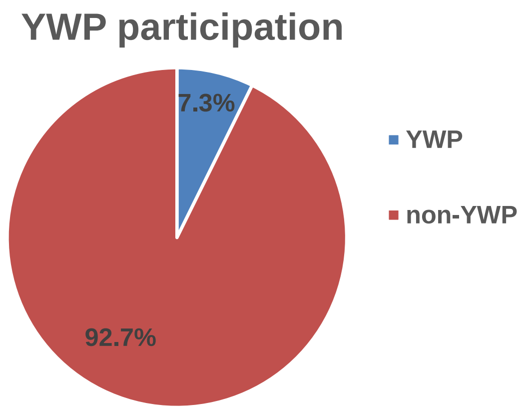
Our SG is one of the largest SG in IWA which have 1845 members from about 140 countries or regions



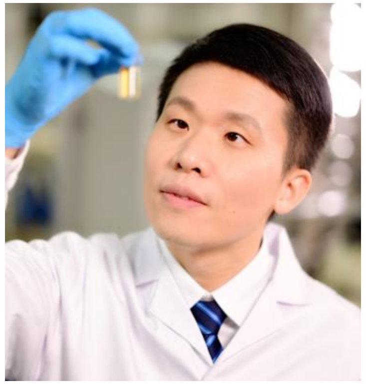




Recent Management Committee members of Disinfection Specialist Group, IWA

Chao Chen, CN

Andrea Turolla, IT



Wenhai Chu, CN

Emmanuel Mousset, FR

Haim Chikurel, IL

J. Paul Chen, SG

Ludwig Dinkloh, GE

Xin Gao, SG

Rhodes Trussell, US

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3rd IWA INTERNATIONAL CONFERENCE ON DISINFECTION AND DBPs
> IWA DDBPs 2022 <

NEXT CONFERENCE: 4TH IWA D&DBPS CONFERENCE

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UNIVERSIDAD DE ALMERÍA

CIESOL
SOLAR ENERGY RESEARCH CENTER
JOINT CENTER UAL - PSA CIEMAT

ALMERÍA CIUDAD

Almeria, Spain, 2024

HOW DOES THE COVID-19 PANDEMIC AFFECT THE WORLD?

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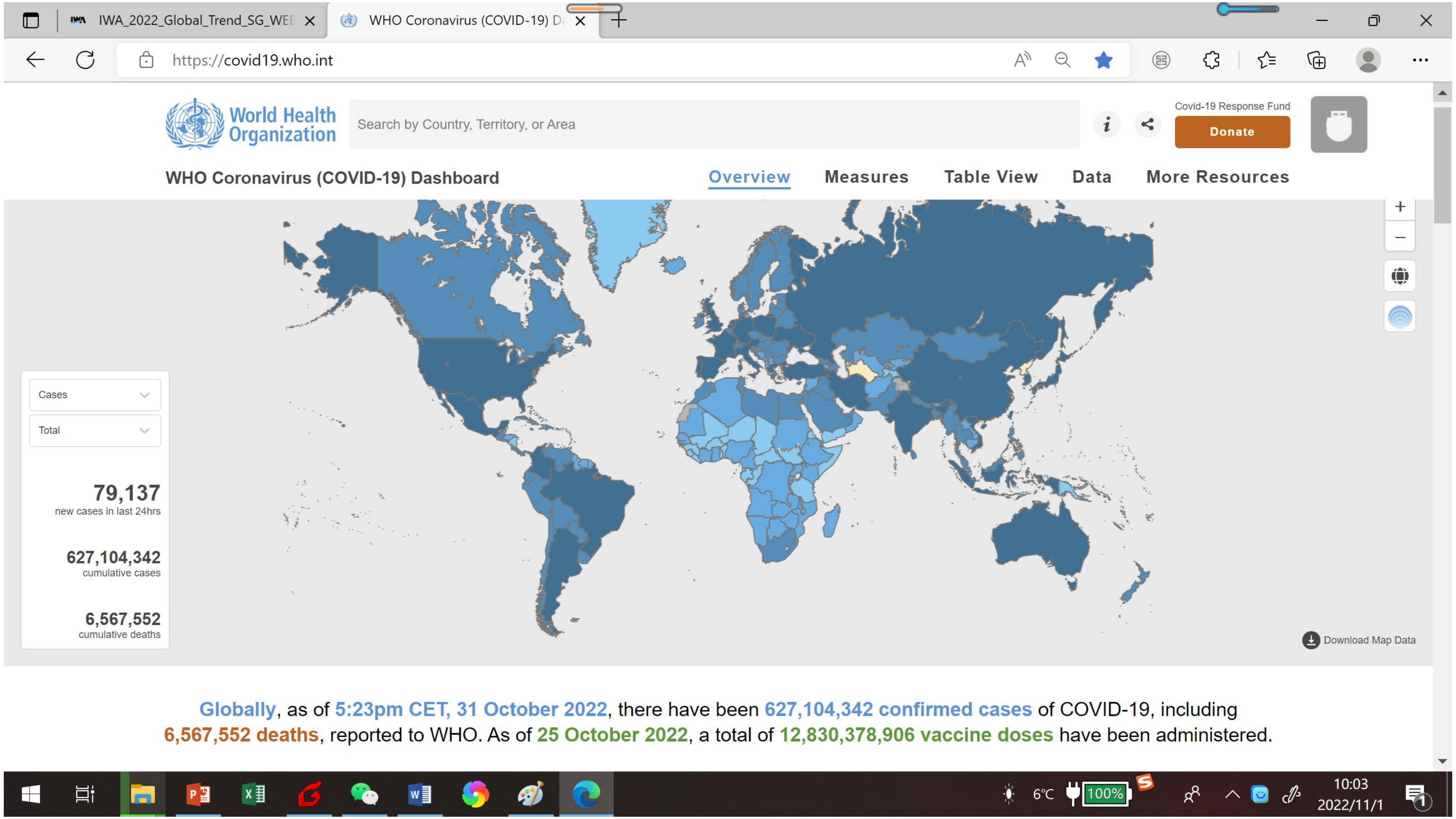
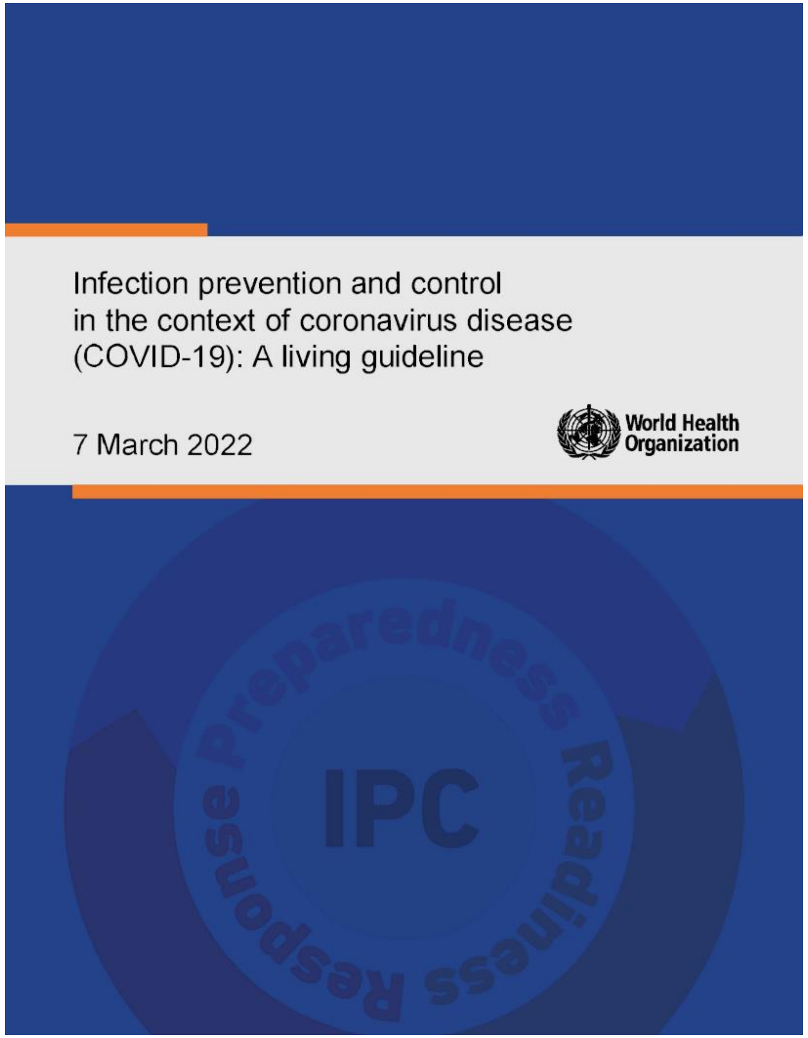


PUBLIC HEALTH AND SOCIAL MEASURES (PHSMS)



(Public Health & Social Measures) include:

- Personal Protective Measures (e.g. physical distancing, avoiding crowded settings, hand hygiene, respiratory etiquette, mask-wearing)
- Environmental Measures (e.g. cleaning, disinfection, ventilation);
- Surveillance And Response Measures (e.g. testing, genetic sequencing, contact tracing, isolation, and quarantine)
- Physical Distancing Measures (e.g. regulating the number and flow of people attending gatherings, maintaining distance in public or workplaces, domestic movement restrictions);
- International Travel-related Measures

COMPREHENSIVE DEMANDS ON DISINFECTION DURING THE COVID-19 PANDEMIC

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- Inactivate the pathogen on each media as much as possible
- Ensure the safety of water, wastewater, air, solid waste and living conditions
- Avoid the unrecoverable impact to ecology and personal health by disinfectants

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| 2.5 |

Disinfection

Part 1 – State of the art and future trends for disinfection technologies

Authors: *Chao Chen, Wenhai Chu, Andrea Turolla, Emmanuel Mousset, Ludwig Dinkloh, Haim Chikurel, J. Paul Chen, Xin Yu, Bin Xu, Xin Yang on behalf of the Disinfection Specialist Group.*

Current disinfection processes

Disinfection is an essential procedure in drinking water and wastewater treatment. Drinking water disinfection is an outstanding contribution for the protection of public health. Especially, chlorination of drinking water represents one of the greatest achievements in public health (Li and Mitch, 2018). In recent years, because of the diverse nature of human pathogens (viruses, parasites, bacteria, etc.), several disinfection technologies are often combined in so-called multi-barrier concepts. Some western European countries, such as the Netherlands, conduct another approach to restrain bacteria regrowth in drinking water distribution system by lowering down assimilable organic carbon (AOC) concentration as much as possible. This approach could avoid the disinfection by-products (DBPs) problem associated with the reaction between disinfectants and organic matter.

Wastewater disinfection is also very important to guarantee public health in relation to the microbiological quality of water body resources, especially for water reuse during the epidemic. Many pathogenic bacteria, viruses (enteric and respiratory) and protozoa can be transmitted and spread by faeces-mouth route. Consequently, free chlorine, chlorine dioxide or UV with higher doses have been applied in wastewater treatment plants (WWTPs) during the previous SARS epidemic and the current COVID-19 pandemic globally (formally called as novel coronavirus).

A global view on water and wastewater disinfection market identified five main disinfection technologies in terms of revenue, including chlorine-related technologies, UV, ozone, advanced oxidation process (AOP) and organic peroxy acids (Frost and Sullivan, 2018). In the following paragraphs, recent advances in consolidated technologies for disinfection are discussed.

Chlorine (Cl_2/NaOCl) and chloramines

Chlorine is still the most popular disinfection process in the water and wastewater industry around the world. In recent decades, more and more water utilities replaced liquid chlorine by stock or on-site generated sodium hypochlorite (NaOCl) in China and the USA because of safety concerns.

In terms of large-scale drinking water treatment plants (DWTPs), chlorine disinfection processes, including free chlorine and chloramines, are currently dominant. For example, the prevalent disinfectants used in the large-scale DWTPs (generally > 10^5 m^3/d) in Taihu Lake basin, Jiangsu province, China, are free chlorine and that used in Shanghai is chloramines. Generally, the selection of chlorine or chloramines mainly depends on source water quality, the water treatment processes, the occurrence of DBPs, including the regulated carbonaceous DBPs (C-DBPs) and unregulated nitrogenous DBPs (N-DBPs), and the requirement for residual disinfectant in distribution systems. The advanced treatment of ozone–biological activated carbon (O_3–BAC) integrated with conventional treatment process has been applied in Chinese DWTPs in recent years with the total capacity of 40 million m^3/d. This updating of DWTPs helps to address the water source pollution and improves the removal of many DBP precursors (Bei et al., 2019). Then, free chlorination or chloramination can be applied safely to avoid the violation of DBP regulation. Meanwhile, chlorine is also frequently added in the water intake, before and after coagulation, before and after filtration as oxidant to enhance coagulation, control algae and odor substances simultaneously in those DWTPs that suffer eutrophication in their water sources. Most recently, chlorination or electro-chlorination is used in the ballast water management systems (BWMSs) with an aim to reduce the biological matters to the extremely low levels

Keywords: Disinfection, disinfectant, chlorine, chlorine dioxide, ultraviolet, ozone, advanced oxidation process

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https://iwa-network.org/wp-content/uploads/2022/09/IWA_2022_Global_Trend_SG_WEB.pdf

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Chapter 2.5 Disinfection

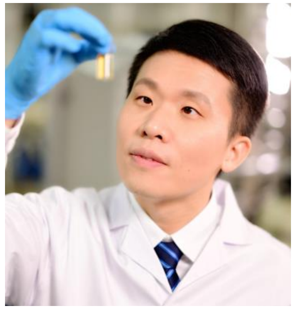
Part 1. State of the art and future trends for disinfection technologies

Part 2. Disinfection-related challenges and opportunities

Part 3. Health concern of disinfection related issues

Written by *Chao Chen, Wenhai Chu, Andrea Turolla, Emmanuel Mousset, Ludwig Dinkloh, Haim Chikurel, J. Paul Chen, Xin Yu, Bin Xu, Xin Yang* on behalf of the Disinfection SG







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WEBINAR SERIES NOV 2022 – JAN 2023

- 1st webinar: November 9th, 2022
  - Topic: The future of disinfection in drinking water and wastewater
- 2nd webinar: December 7th, 2022
  - Topic: Emerging disinfection technologies for water and wastewater treatment
- 3rd webinar: January, 2023
  - Topic: Challenges and opportunities in identification, risk-based prioritization and control of DBPs in drinking water

UVC-LED: The Wave of The Future

GARY L. HUNTER, BLACK & VEATCH'S WATER TECHNOLOGY GROUP, USA

inspiring change

ABOUT THE SPEAKER

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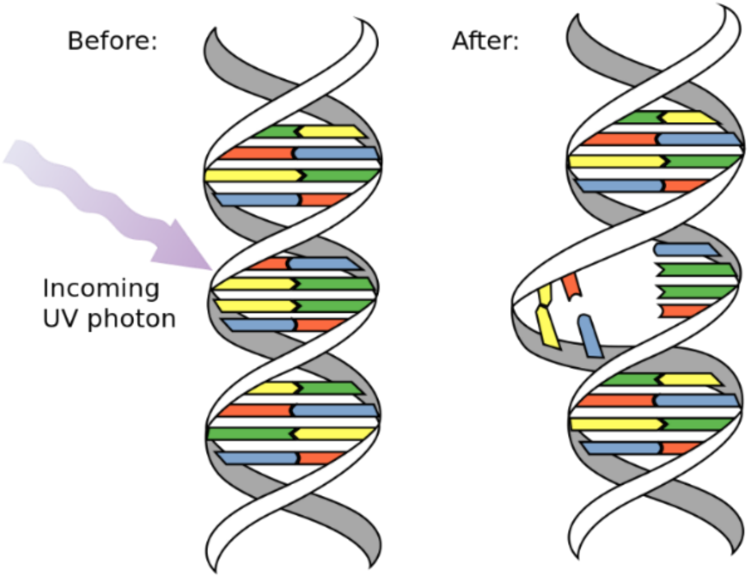
- As a specialist assigned to Black & Veatch's Water Technology Group, Mr. Hunter is responsible for assisting utilities in deployment of disinfection (UV technologies) in both conventional and reuse applications.
- He is responsible for providing process evaluation for UV systems in both domestic and industrial wastewater treatment facilities.
- In this role, he is responsible for conceptual development, detailed design, startup, performance testing, and troubleshooting of UV systems.

WHY UV DISINFECTION?

- Ultraviolet radiation causes direct DNA damage
  - Pyrimidine dimerisation inhibits polymerase function in replication
- Inactivation, not removal/destruction
- Photochemical process with immediate effect



RECENT WASTEWATER DISINFECTION ISSUES

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- Changing requirements for basic level disinfection
  - MS-2
  - Virus
- Impacts of Technology Retirement/ Replacement
  - UV 4000
  - Older Technologies
- Reuse
  - Irrigation
  - Indirect
  - Direct

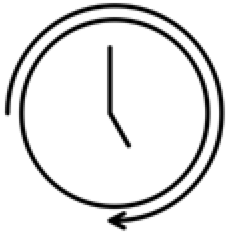
WASTEWATER DISINFECTION ISSUES - CONT

- Extension of Usable Life/Capacity
  - More Capacity
  - Extended Capacity
  - Contol System improvements
- Emerging Contaminants
  - PFAS
  - NDMA/1,4 D
  - PCB
- New Technology
  - UVC-LED
  - Tubular

LIMITATIONS OF CURRENT UV TECHNOLOGY

Materials

- Mercury
- Quartz

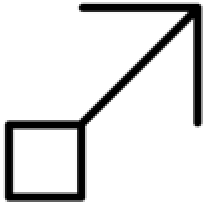


Operation

- Warm-up time
- Limited on/off cycles

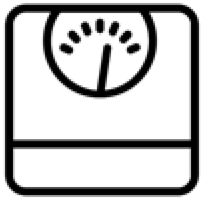
Durability

- Fragile quartz tube



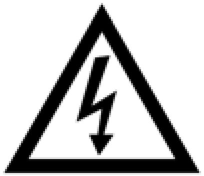
Footprint

- Low power density
- Large ancillaries



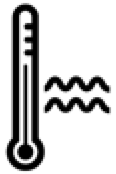
Weight

- Reactor
- Electronics



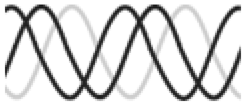
Power

- AC Mains Voltage only



Temperature

- 100-600° C impacts process fluid



Wavelength Compromise

- LP: 254nm
- MP: 200-300nm

IMPROVEMENTS WITH UV LEDS

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Materials
- Mercury-free

Operation
- Instant on/off
- Unlimited on/off cycles

Durability
- Robust design

Footprint
- High power density
- Compact size

Weight
- Light-weight
- Reduced parts list

Power
- Flexible power options

Temperature
- Low heat transfer

Wavelength Selectivity
- Flexible wavelengths based on needs

ADVANTAGES OF UV LED (WEFTEC 2022)

- Solid State LED Technology
  - Instant ON/OFF
  - Unlimited ON/OFF Cycles
  - Real-Time Dose Control
  - *Dynamic Switching of LEDs during operation – increasing turndown capacity and increasing time between LED Change-outs
  - Turndown to <10% of full power
  - Switching from minimum to maximum output in an instant.
  - Highly Reliable

	LED	Hg Lamp
Lifetime (hrs)	10 to 20,000*	8 to 15,000
ON/OFF Cycles	Unlimited	4 per Day
Operating Temp	Ambient	100 to 600°C
Warm-up Time	100mS	Up to 10 min
Mercury Content	None	20-600mg+

POINT OF USE UVC-LED

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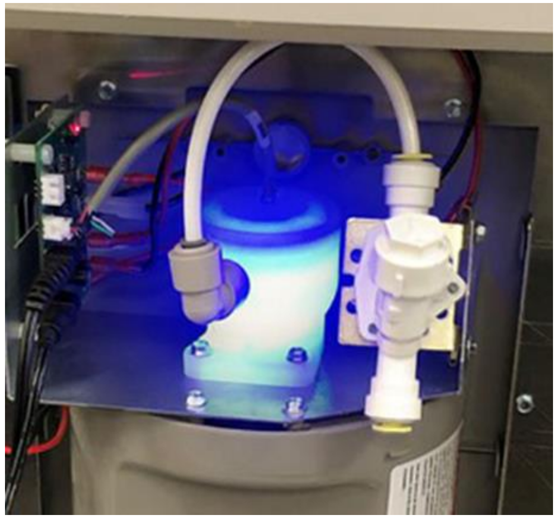
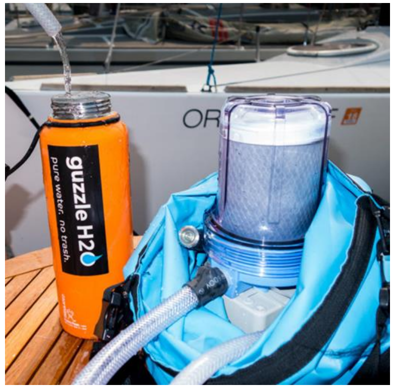
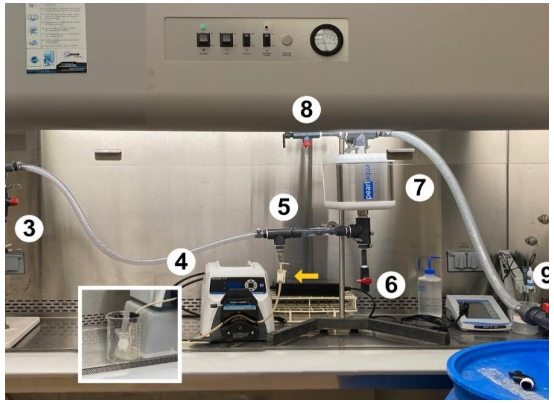
- •Goals: Provide microbial clean water at stations
- •Key Design Parameters:
  - 3 LPM
  - Light weight
  - Compact size
  - Portable/robust design
- Solution: Point of Use System
- Met all design parameters
- Currently in early commercial stage
- Over 200,000 systems in use





UVC-LED: THE WAVE OF THE FUTURE

- 5 Different UVC-LED tests
- 4 Different Configurations
- Bench results comparable removal to traditional UV
- Largest Unit treating 7 MLD on drinking water
- High Quality effluent

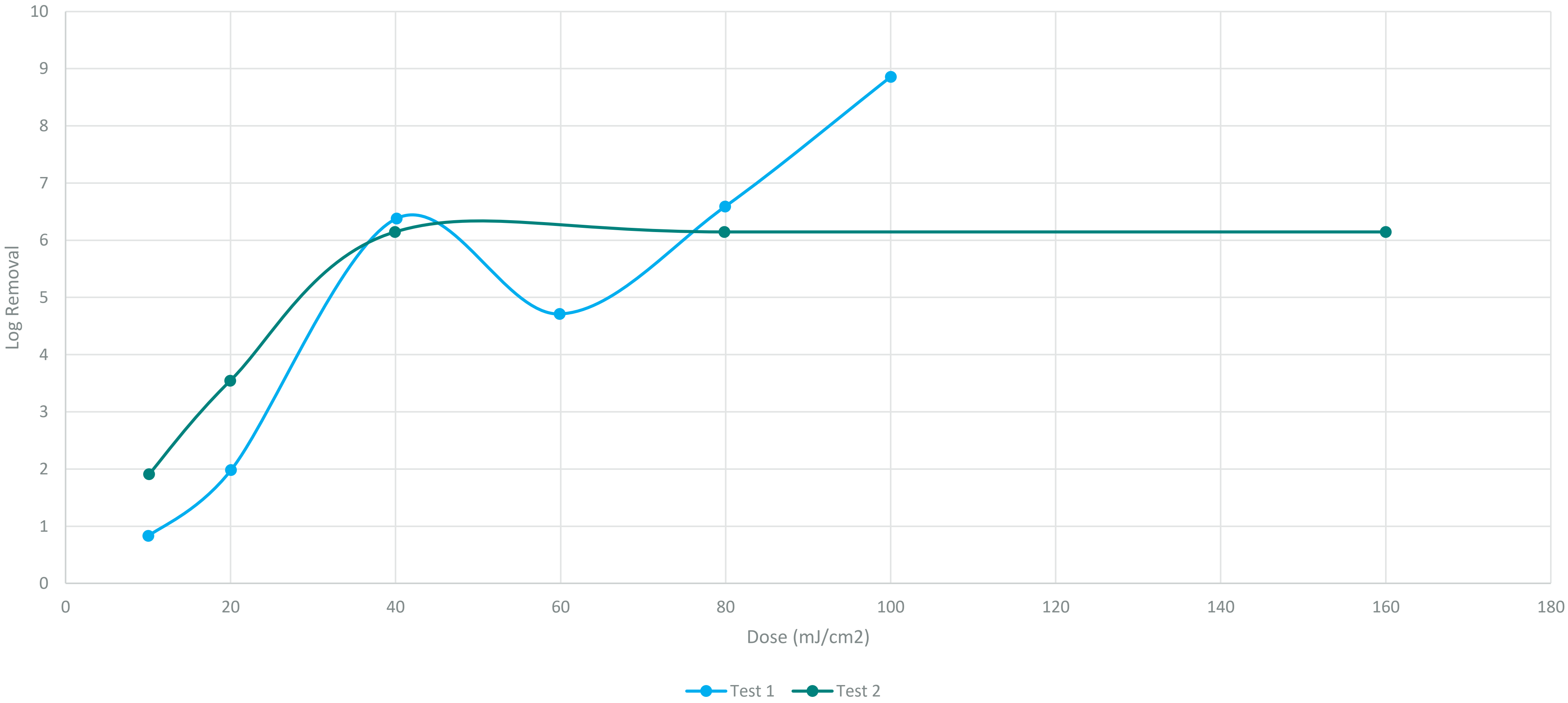


USEPA LED CRADA STUDY (EPRI 2022)

- Partners
  - Washington University
  - AquiSense
  - EPRI
  - USEPA
  - Black & Veatch

- Testing
  - Drinking Water/Wastewater /CSO/Reuse
- Focus is on Bacillus Golibii
  - Additional Micro
    - e Coli
    - MS-2
    - Enterococcus
    - Total Coliform

DOSE RESPONSE FOR BACILLUS GLOBIGII

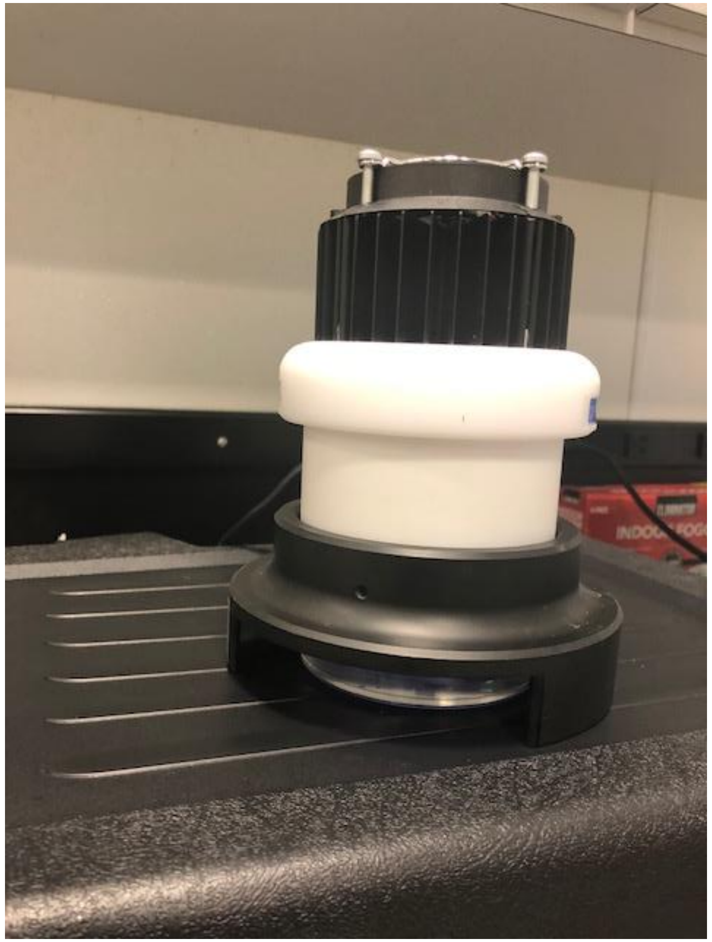


FLOW- THROUGH RESULTS- MS2 (EPRI 2022)

DEMONSTRATION STUDIES

- METAWATER System
  - Units range in size from 200 lpm to 1135 lpm (drinking water)
  - Tested on Wastewater Effluent and Reuse water
  - QBeta used as surrogate (challenge)
  - Tested range for flows from 7.5 to 208 lpm

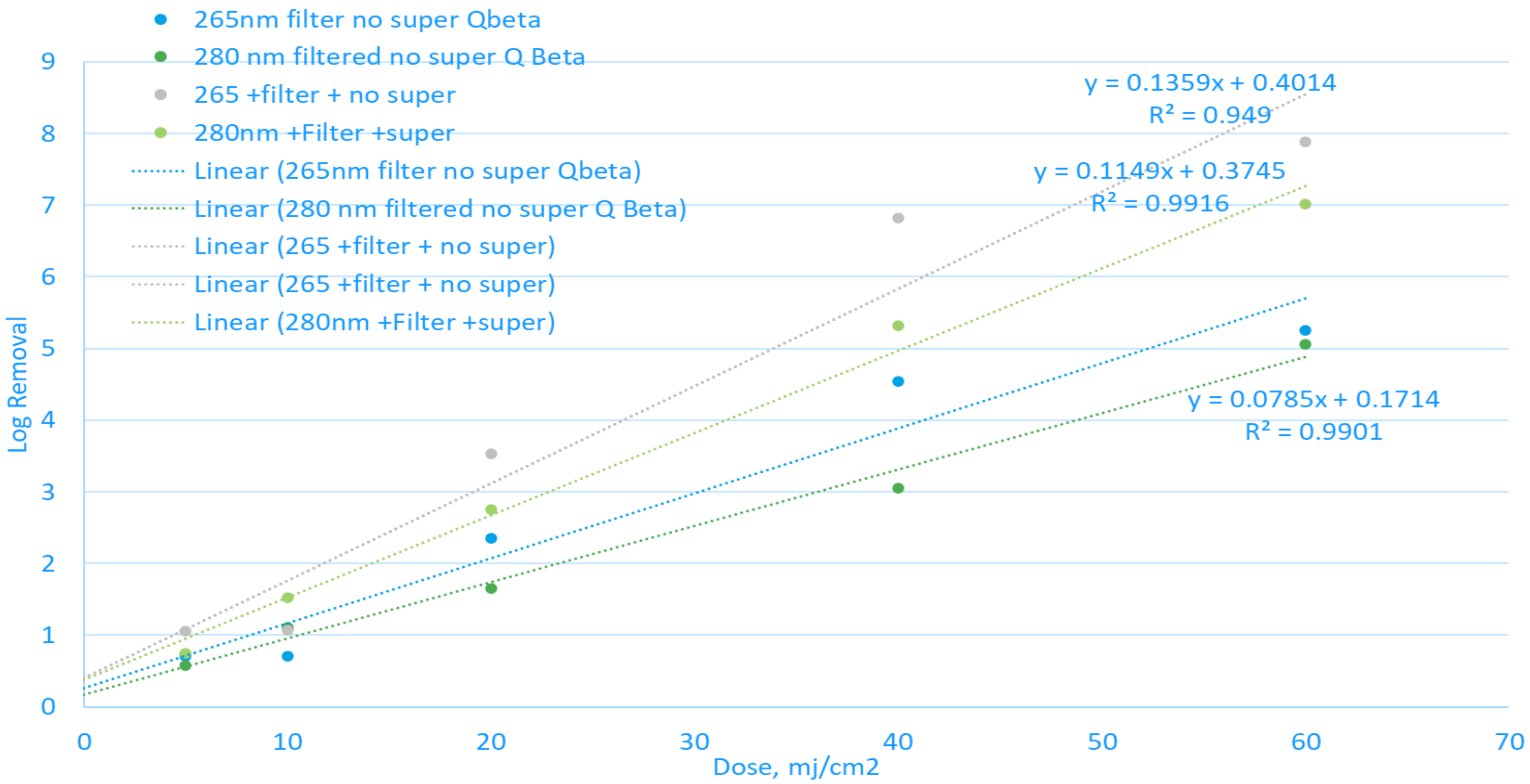
COLLIMATED BEAM



Collimated Beam

Lab Set up for Testing

MODIFIED RESULTS FOR MS2



USEPA LEGIONELLA STUDY (BUSE 2022)

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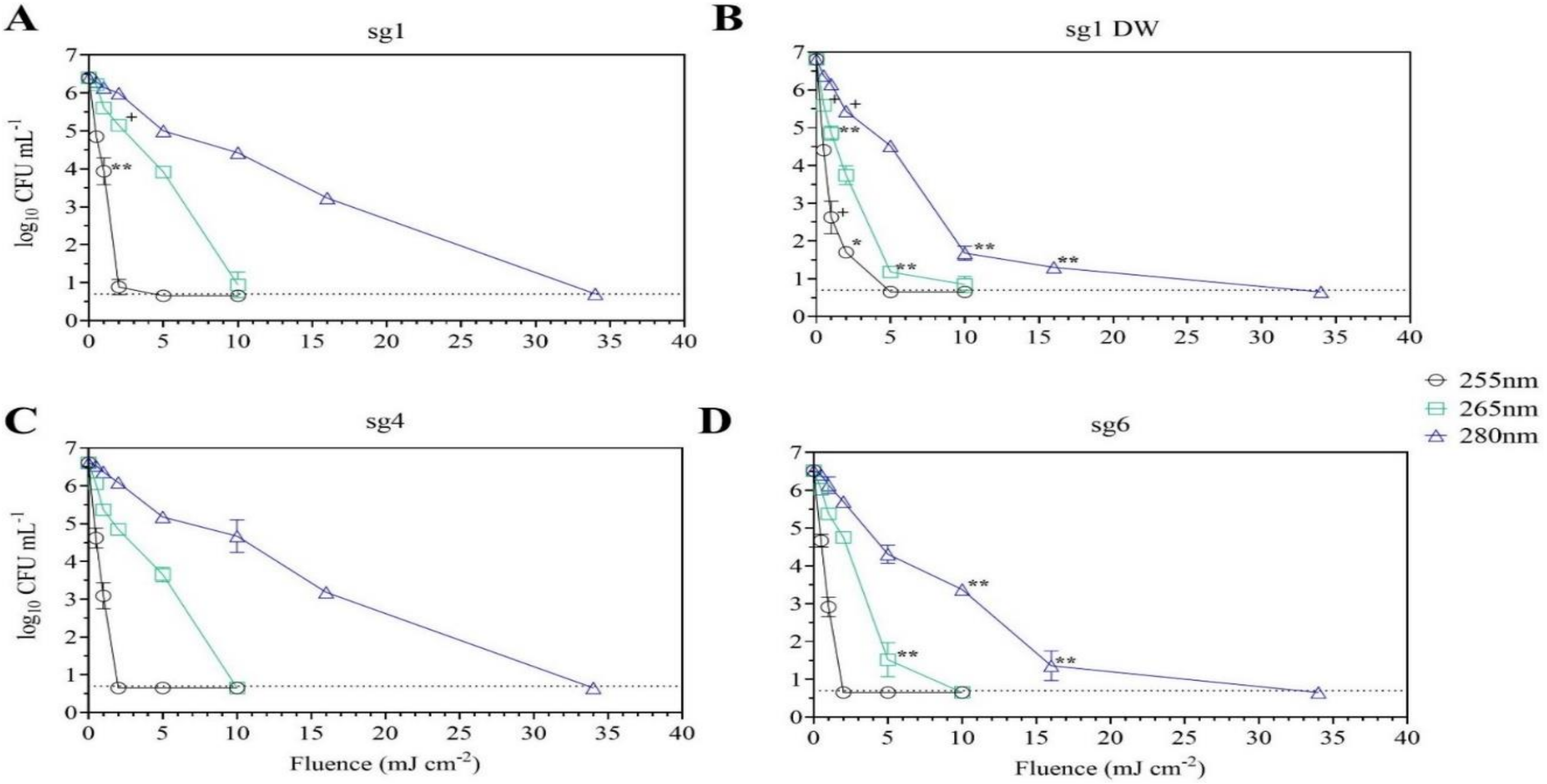
- Legionella pneumphila (Lp) Testing
  - Four different serogroups
  - Three different UV-C LED wave lengths (255, 265, 280).
  - Point-of-entry (POE) treatment set-up (280nm).

COLLIMATED BEAM RESULTS (BUSE 2022)



INNOVATIVE EMERGING UV TECHNOLOGY: LIGHT EMITTING DIODES (LED)

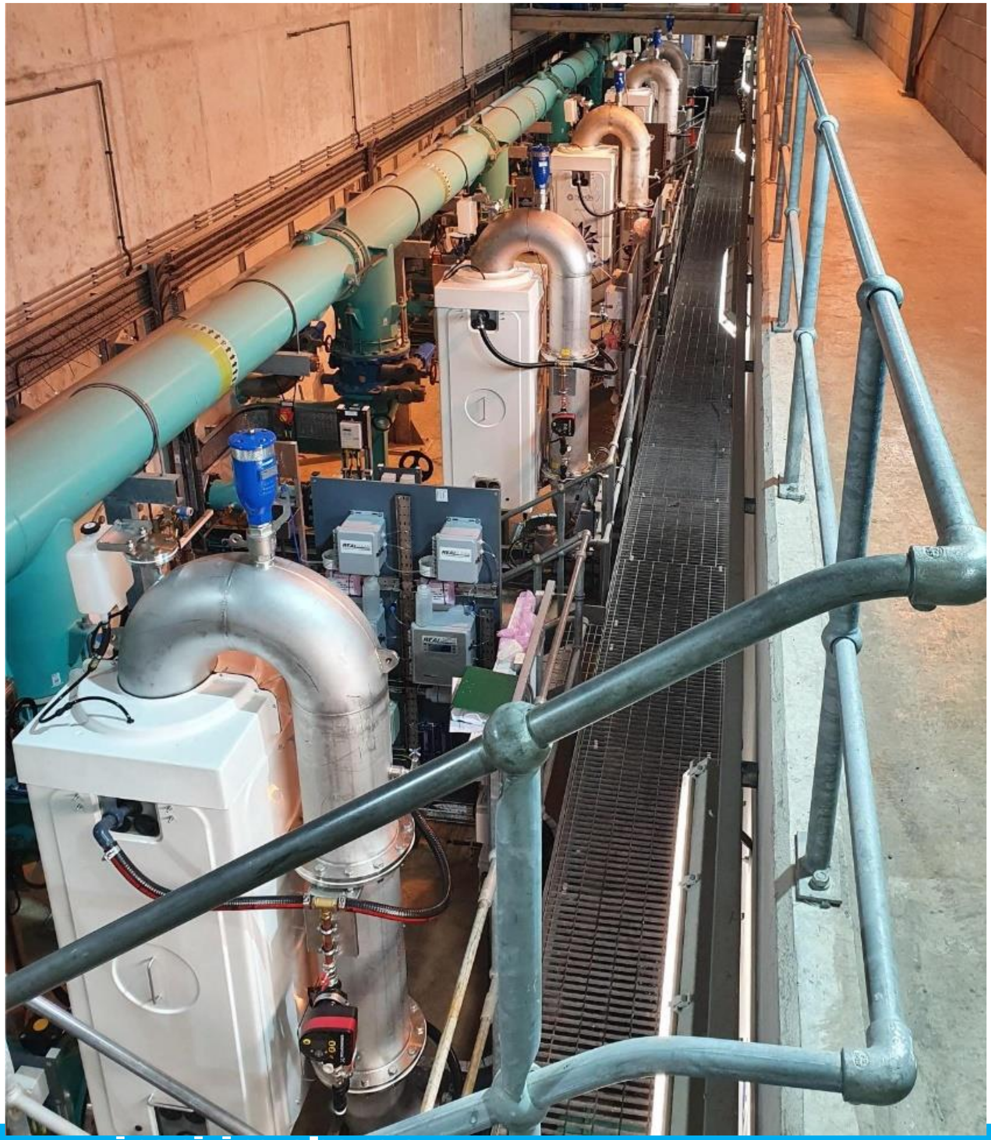
- Numerous benefits
  - Mercury free
  - Unlimited on/off cycles
  - Instantaneous warm up

  Selectable wavelengths (250-300 nm)
- 25,000-hour lifetime
- Projected Savings: 30% CAPEX/50% OPEX (EPRI)
  – Drinking water Capacity – 7 to 11 MLD/unit - (27 MLD)
  – Small capacity UV disinfection vessels
  - Point of use reuse/drinking water treatment
- Ultra high pure water (hospitals, industrial)
- UVT monitors (on-line and handheld devices)

UV-C LED

Sensorex LED
On-line UVT Monitor

MUNICIPAL UV LED (WEFTEC 2021)



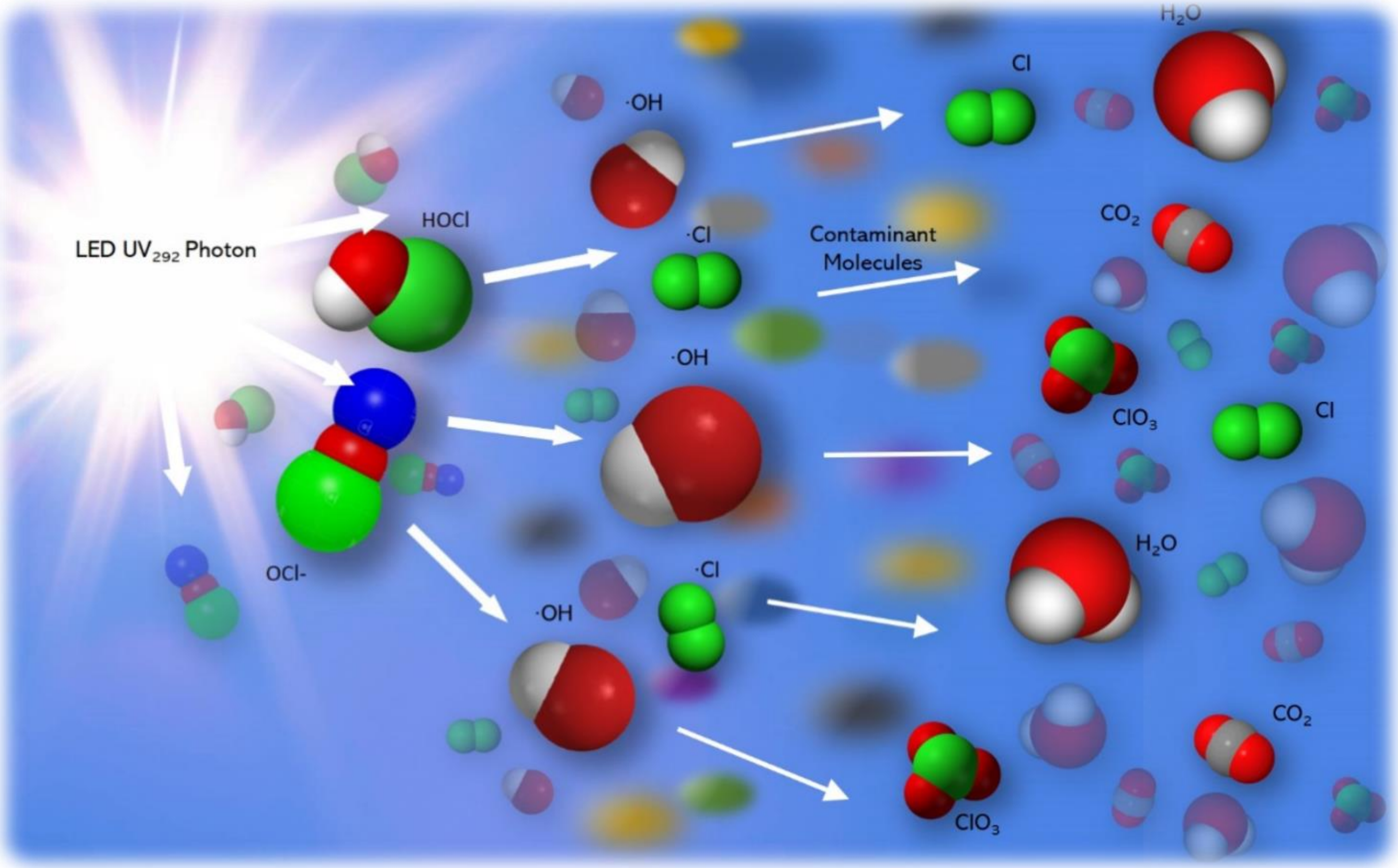
This is the Worlds First Municipal scale UV LED Drinking Water system.

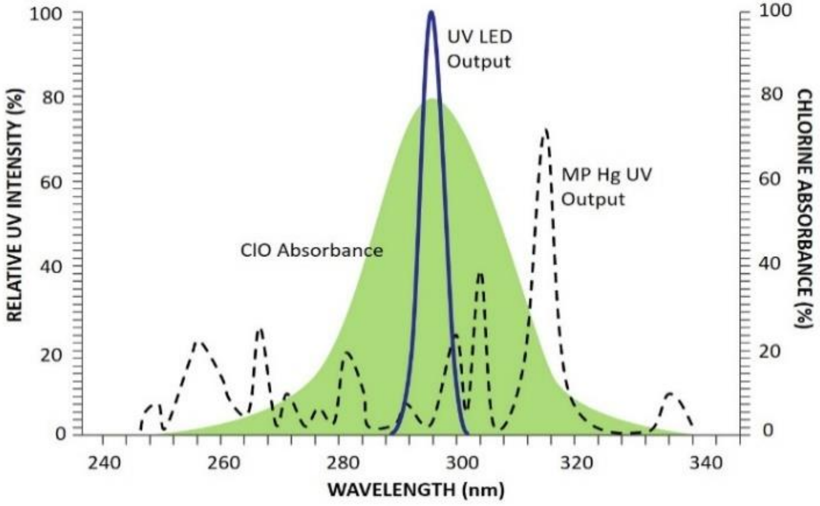
United Utilities
Water for the North West

- Cumbria, UK
- 28 MLD (5,072 USGPM)
- 4 Log Crypto (22mJ/cm^2)
- 6No. BIO-310 Reactors downstream of 6No. RGFs
- Fitting in a 1.5m in-line pipework section.

UV LED AOP (WEFTEC 2021)

Sodium Hypochlorite combined with 292nm UV LED's





- 6-month field trial – removal of Geosmin & 2-MIB
- UV/Chlorine AOP with 30mW LEDs
- Efficient generation of Hydroxyl Radicals
- Effective removal of contaminants with no DBP formation
- Optimisation of pH is key to process efficiency (further studies are ongoing)

More powerful devices needed for UV LED AOP to be commercially viable.

FINAL THOUGHTS

- UVC-LED deployment is growing fast
- Public Health can be impacted by UVC-LED
- Swami looking into his crystal ball sees great future for UVC-LED

- UVC-LED is the Wave..UVC-LED is the Wave …UVC-LED is the Wave

Risk based water quality management to reduce disinfection and DBPs in the Netherlands

PATRICK SMEETS, KWR NETHERLANDS

inspiring change

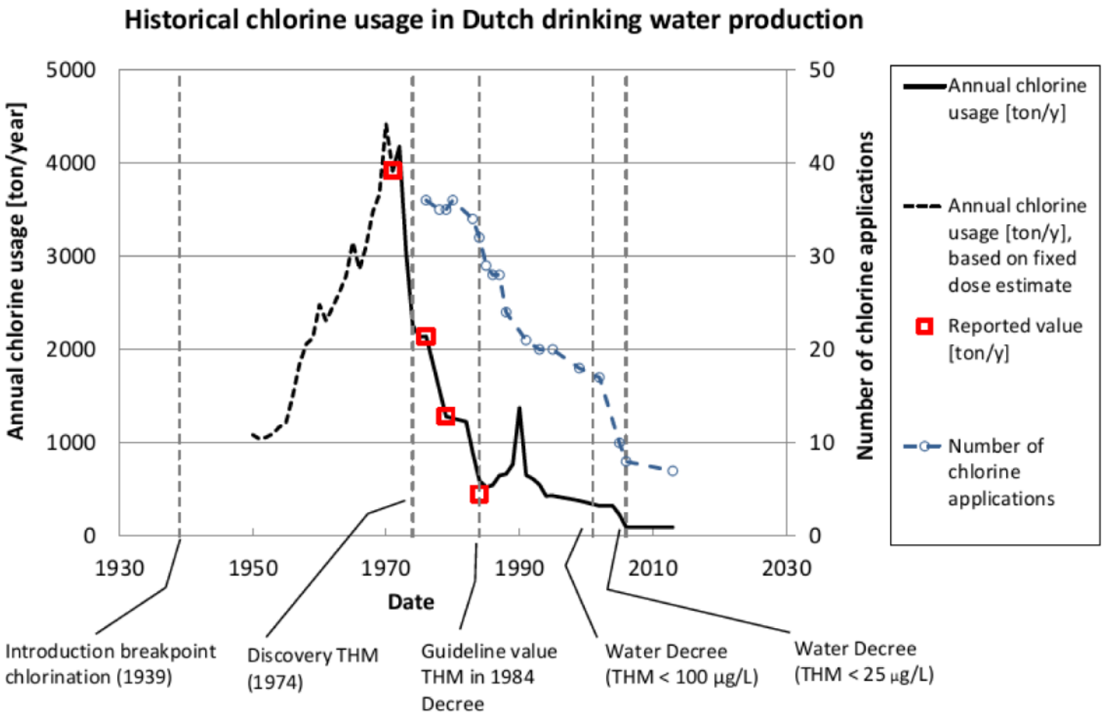
ABOUT THE SPEAKER

the international water association

- Patrick Smeets is an expert in microbial water quality and health with over 20 years of experience in safe water supply.
- WSP and QMRA of drinking water are his main activities in the Netherlands and abroad (India, Egypt, Lebanon, New Zealand).
- He has advised in various legislative scopes related to risk management, QMRA and chlorine free water in the Netherlands, France, Europe, USA, Canada and New Zealand.

BRIEF HISTORY OF CHLORINE IN THE NETHERLANDS

- 1935-1970 Breakpoint chlorination of surface water incl. residual (Groundwater not chlorinated)
- 1974 THM identified as carcinogenic
- 1970-2005 Chlorine in treatment reduced,
- 1983-2006 abandoned chlorine residual
- Currently study for ClO_2 alternatives



WHY IMPLEMENT A CHLORINE FREE SYSTEM?

- Chlorine is unnecessary
- Chlorine may provide false perception of safety, unsafe behavior
- By-products (THM) may cause adverse health effects
- Taste and odor is negatively affected by chlorine
- Chlorine can mask contamination by inactivating *E. coli*

Know your catchment

Know your source water quality

Target your treatment

Protect your distribution

Safe drinking water

Know your catchment

Know your source water quality

Target your treatment

Protect your distribution

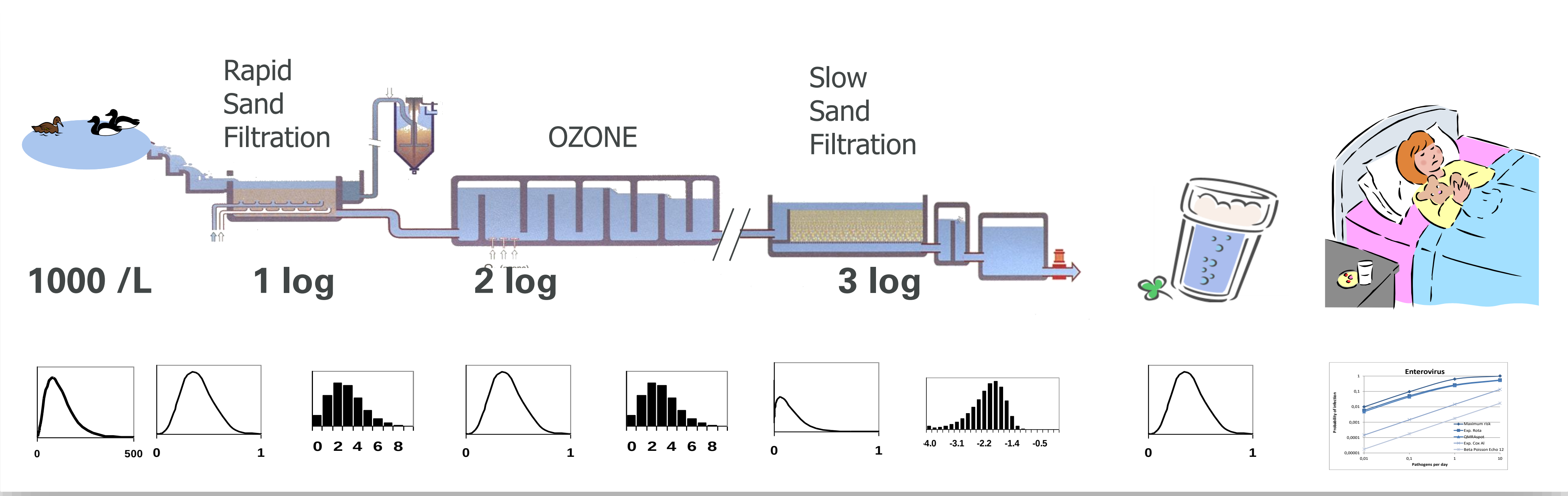
Safe drinking water

Hygiene Codes

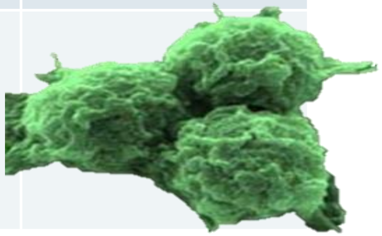
QMRA

CHALLENGE 1 SAFE PRODUCTION

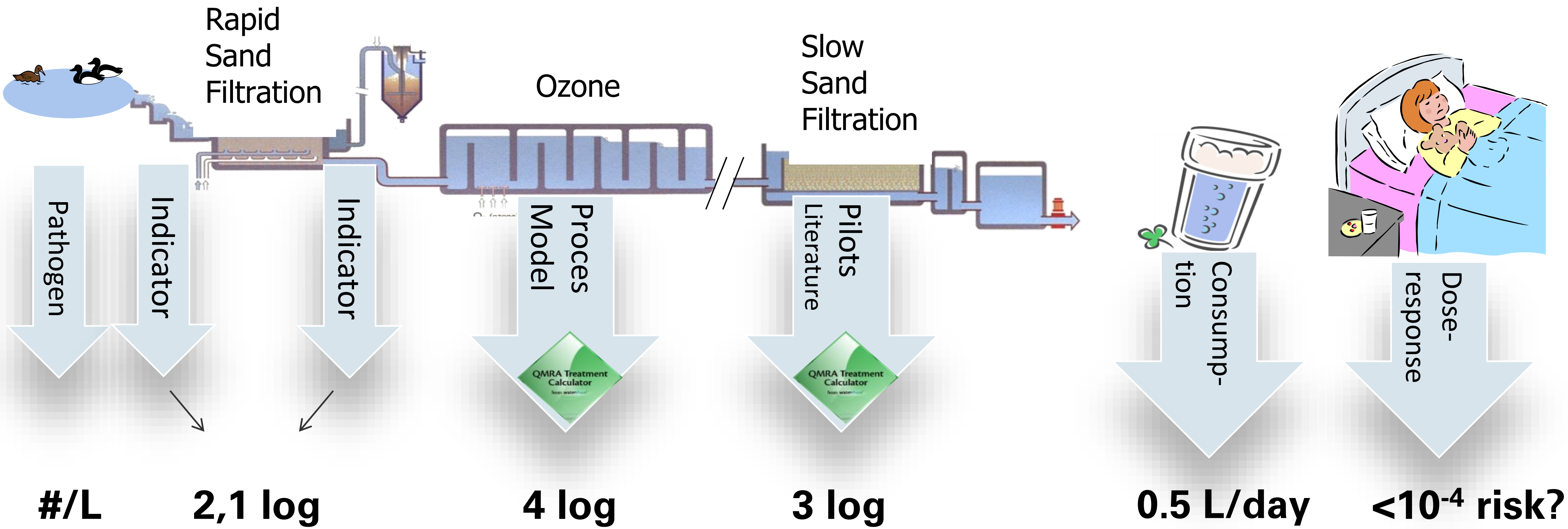
- Netherlands: Legislative Quantitative Microbial Risk Assessment
- Risk of infection < 1/10.000 per persons per year
- (Approximately one pathogen in 1.000.000 liter water)



INDEX PATHOGENS POSE VARIOUS CHALLENGES TO WATER SAFETY

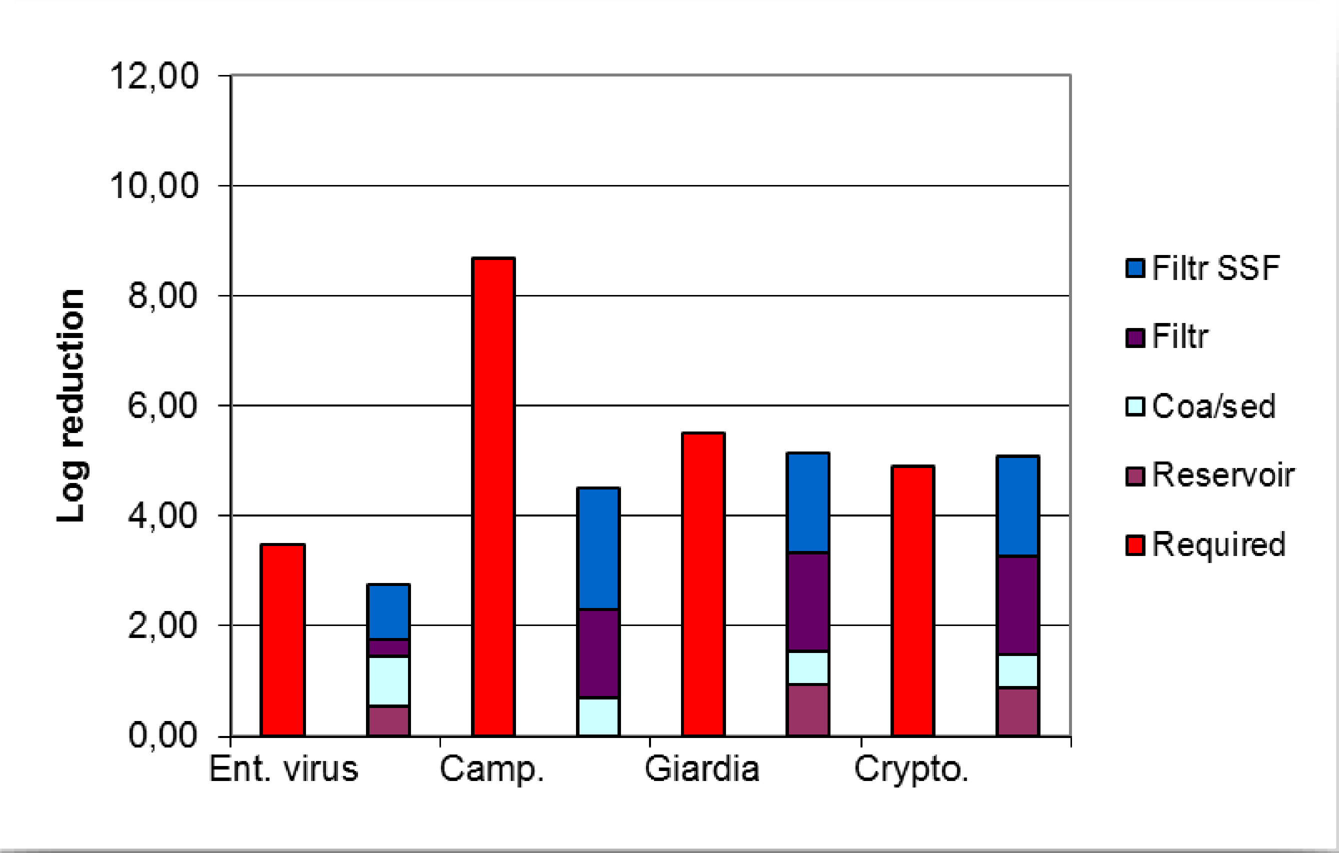
Pathogen type	Source	Characteristics	
Indicators *E. coli, TherTolColi*	Human, Animal	Bacteria, high numbers in feces, Water quality monitoring	
Viruses *enterovirus*	Human	Very small (25 nm), persistent, infectious	
Bacteria *Campylobacter*	Human, Animal	Small (0.2x5 µm), die quickly	
Protozoa *Cryptosporidium* *Giardia*	Human, Animal	Larger (3-6 µm), very persistent, not affected by chlorine	

HOW TO PERFORM QMRA



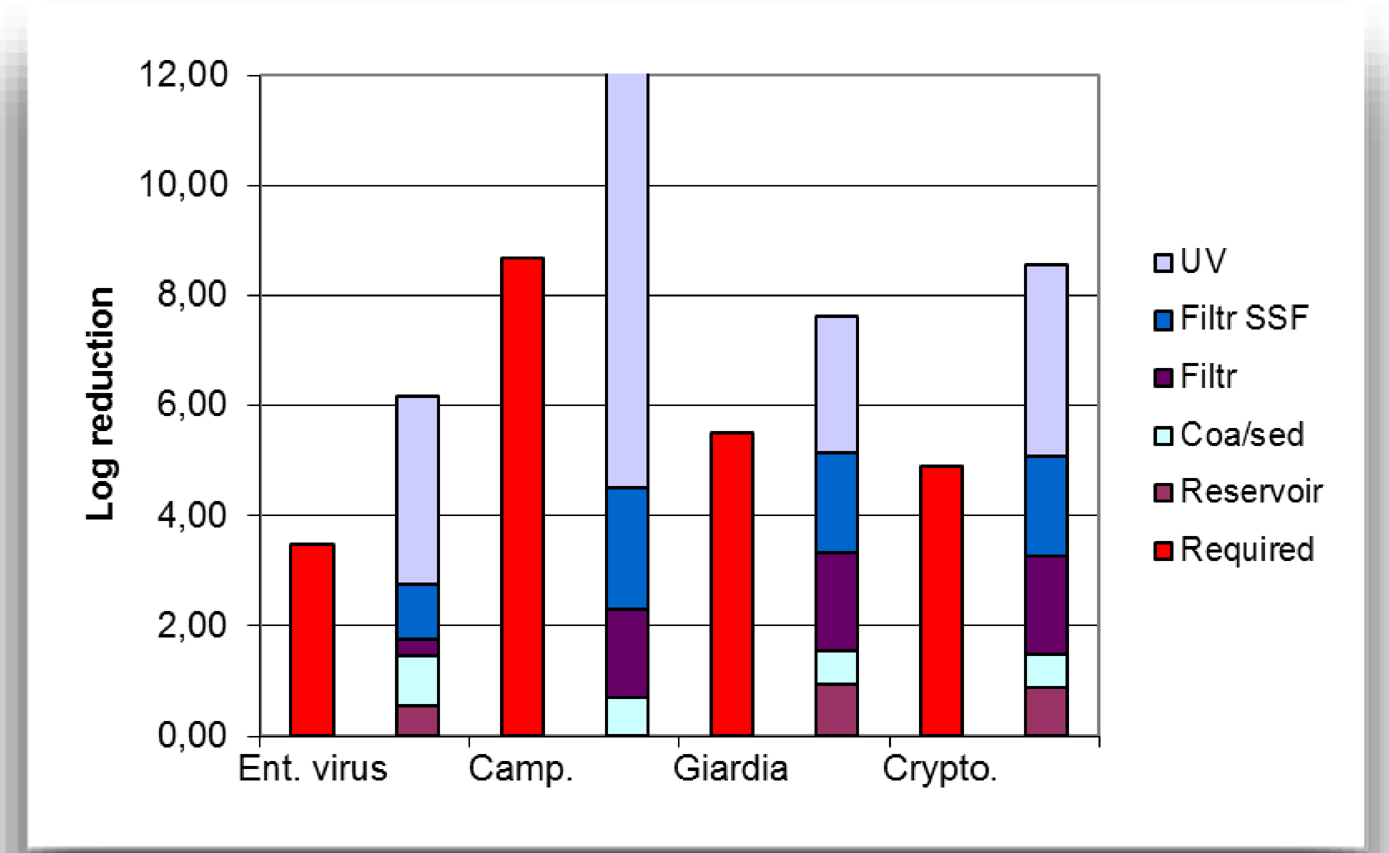
QMRA FOR DECISION SUPPORT: TREATMENT EXTENSION

- Monitor pathogens in raw water
- Required log removal to meet the 10-4 health target
- Assess efficacy of each treatment process
- Non-compliant?

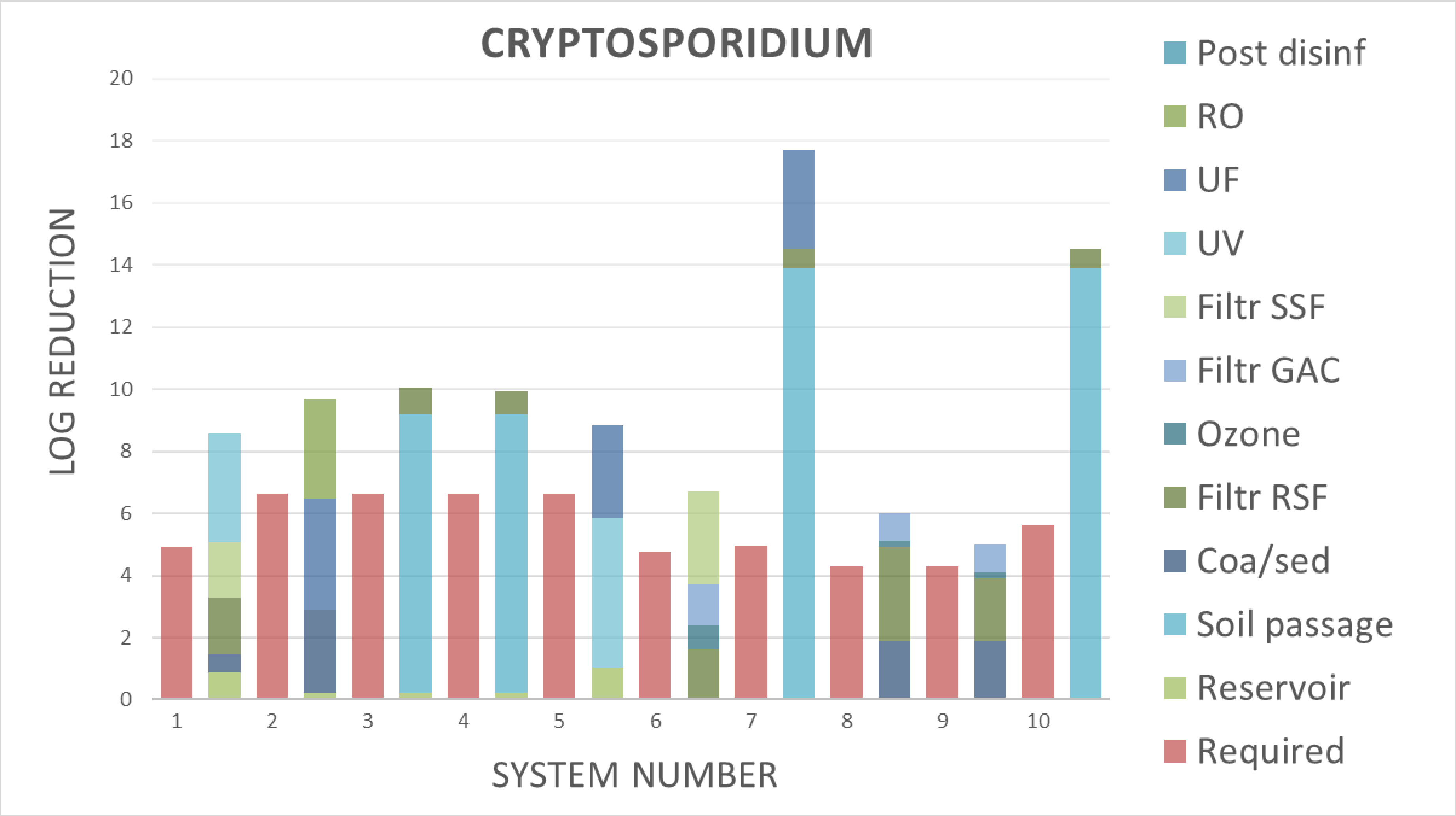


QMRA FOR DECISION SUPPORT: TREATMENT EXTENSION

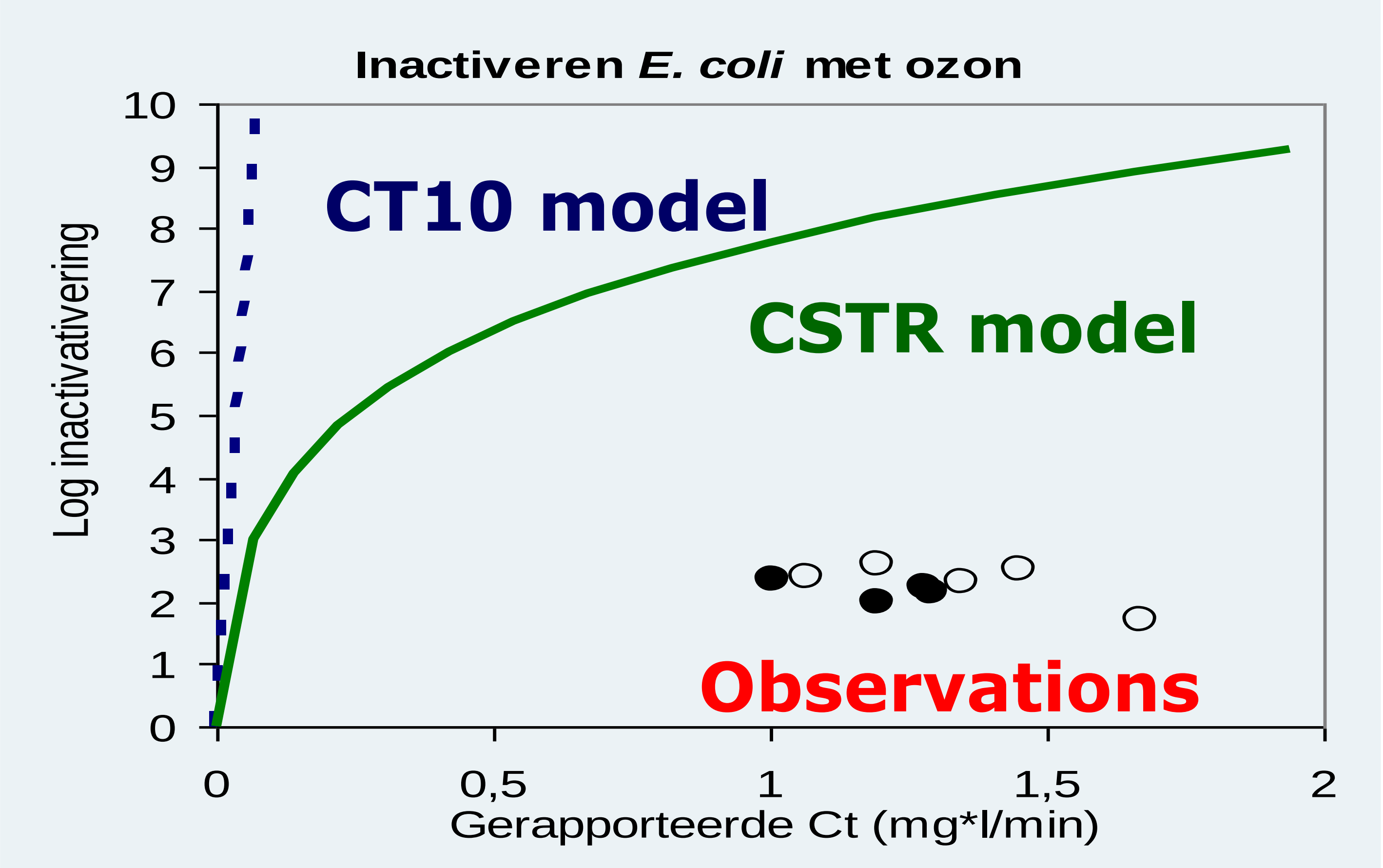
- Monitor pathogens in raw water
- Required log removal to meet the 10-4 health target
- Assess efficacy of each treatment process
- Non-compliant?
- Select a treatment process that addresses all pathogens sufficiently



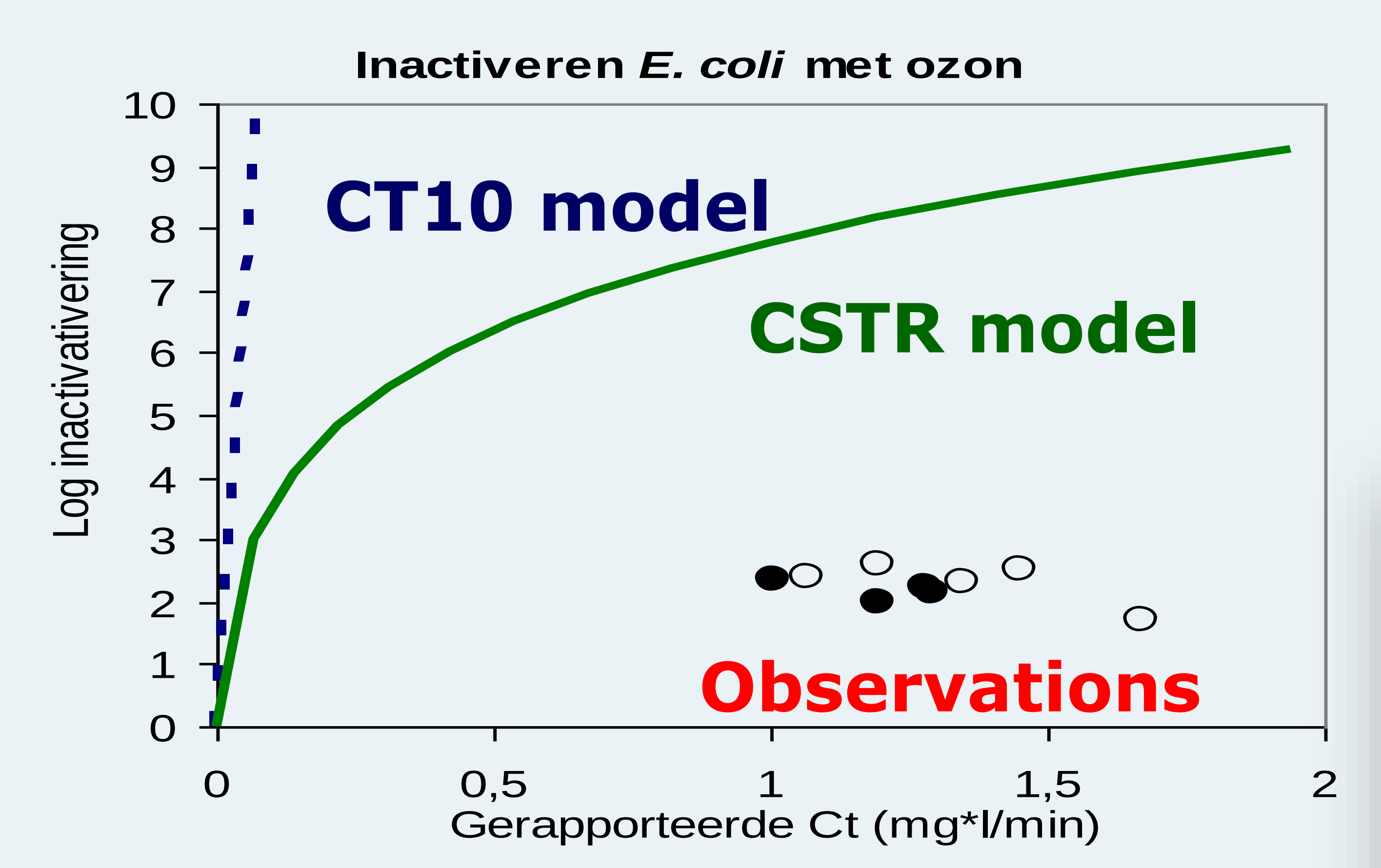
REQUIRED TREATMENT EFFICACY VARIES PER SITE



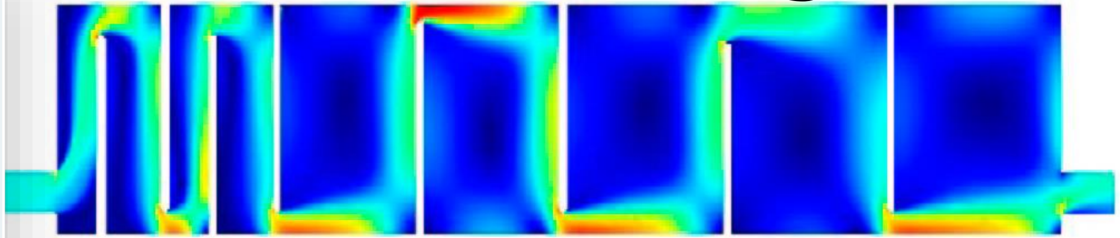
QMRA DECISION SUPPORT:
SMART IMPROVEMENT OF DISINFECTION AT SAME DBP



QMRA DECISION SUPPORT:
SMART IMPROVEMENT OF DISINFECTION AT SAME DBP

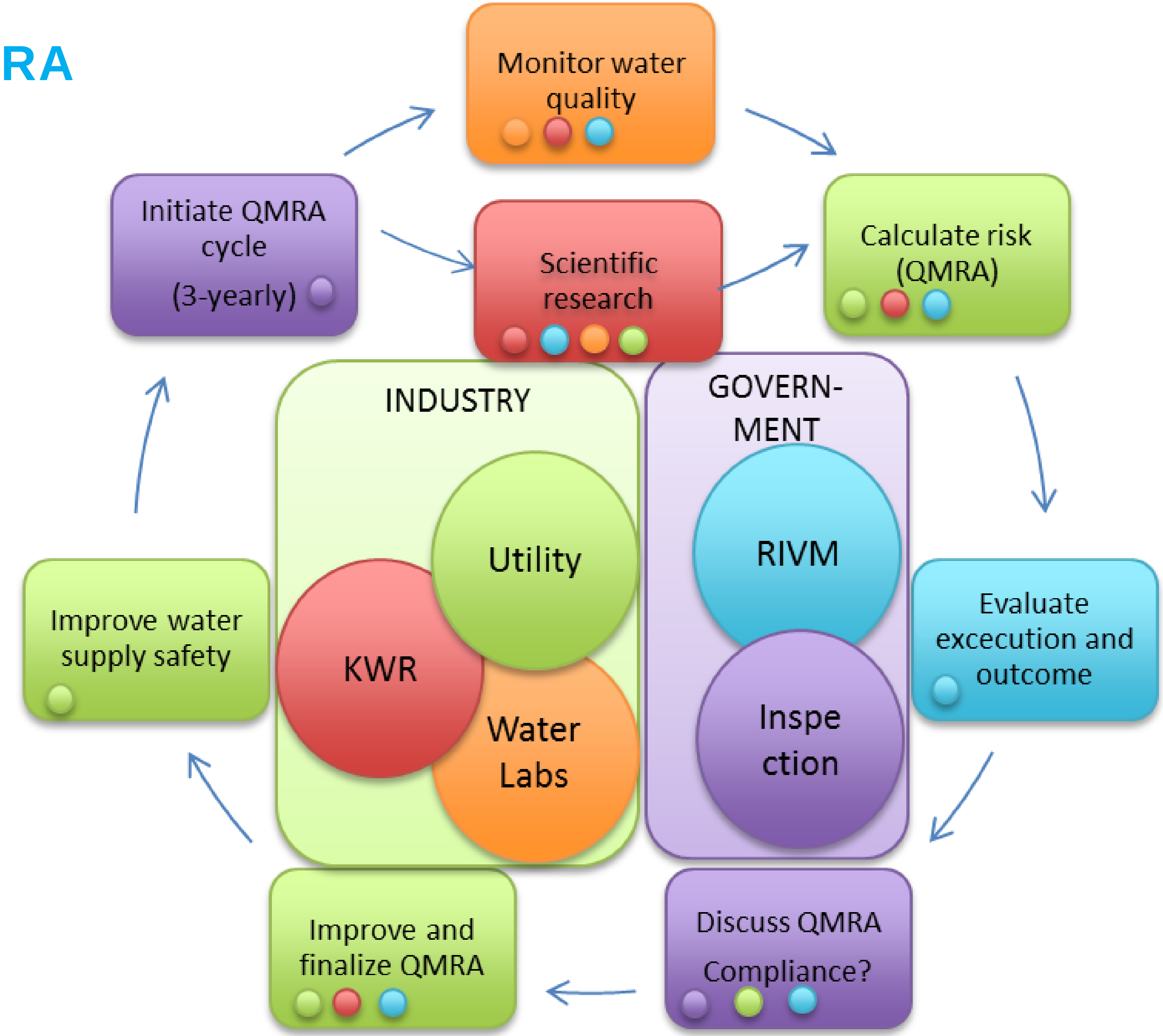


CFD Modelling



Efficient improvements

LEGISLATIVE QMRA CYCLE



BASICS OF SAFE WATER DISTRIBUTION

- Physical integrity of distribution system
- Constant pressurized distribution system
- Prevention of negative transients
- ‘Sealed’ distribution reservoirs
- Backflow and cross-connection prevention
- Safe operations and maintenance

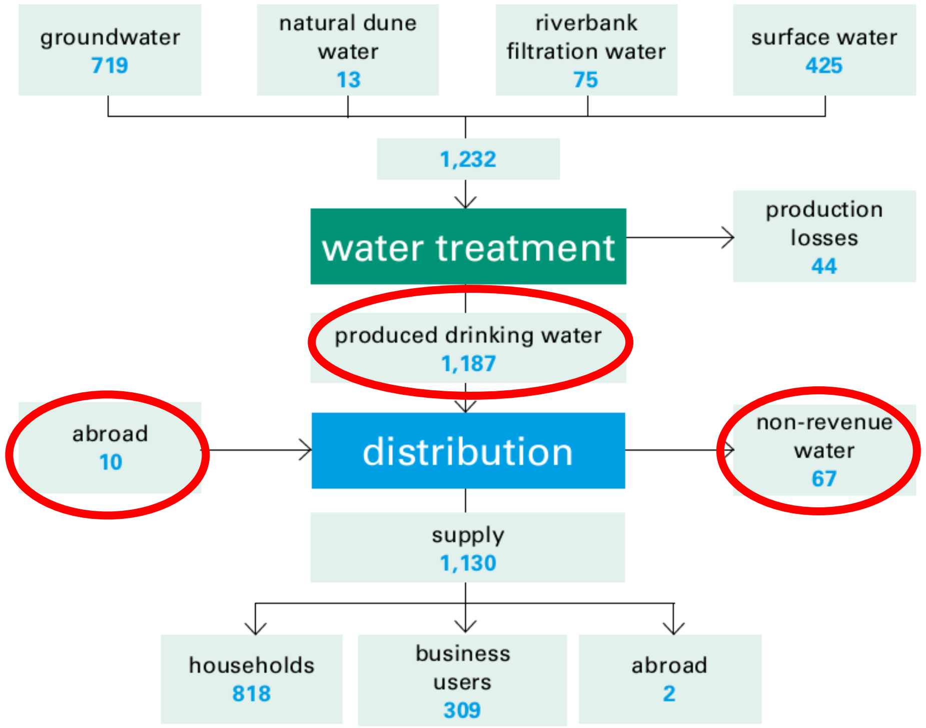
- Biostable water production
- Biostable materials
- Limit temperature (<25°C)

Air filter on distribution reservoir

CHALLENGE 2 PHYSICAL AND OPERATIONAL NETWORK INTEGRITY

- Leakage rate NL ≈5.6%
- Water hammer vessels prevent negative pressure transients
- Automated pumping, backup power
- Pressure monitoring in network
- Backflow prevention at industry, house connection and appliances level
- Regulations at various levels (e.g. building regulations)

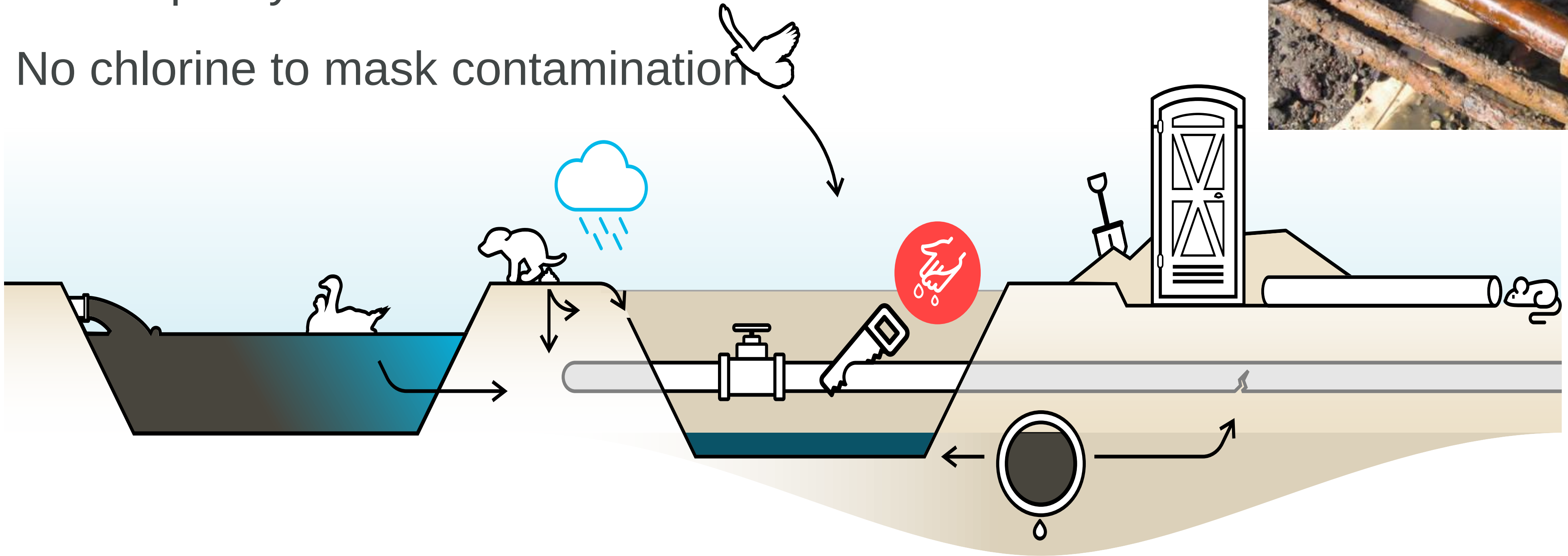
Drinking water balance 2019, in million m^3



CHALLENGE 3 SAFE OPERATIONS AND MAINTENANCE

the international water association

- System is vulnerable during works
- Environment is 'dirty'
- Strickt hygiene codes
- Water quality check
- No chlorine to mask contamination



58

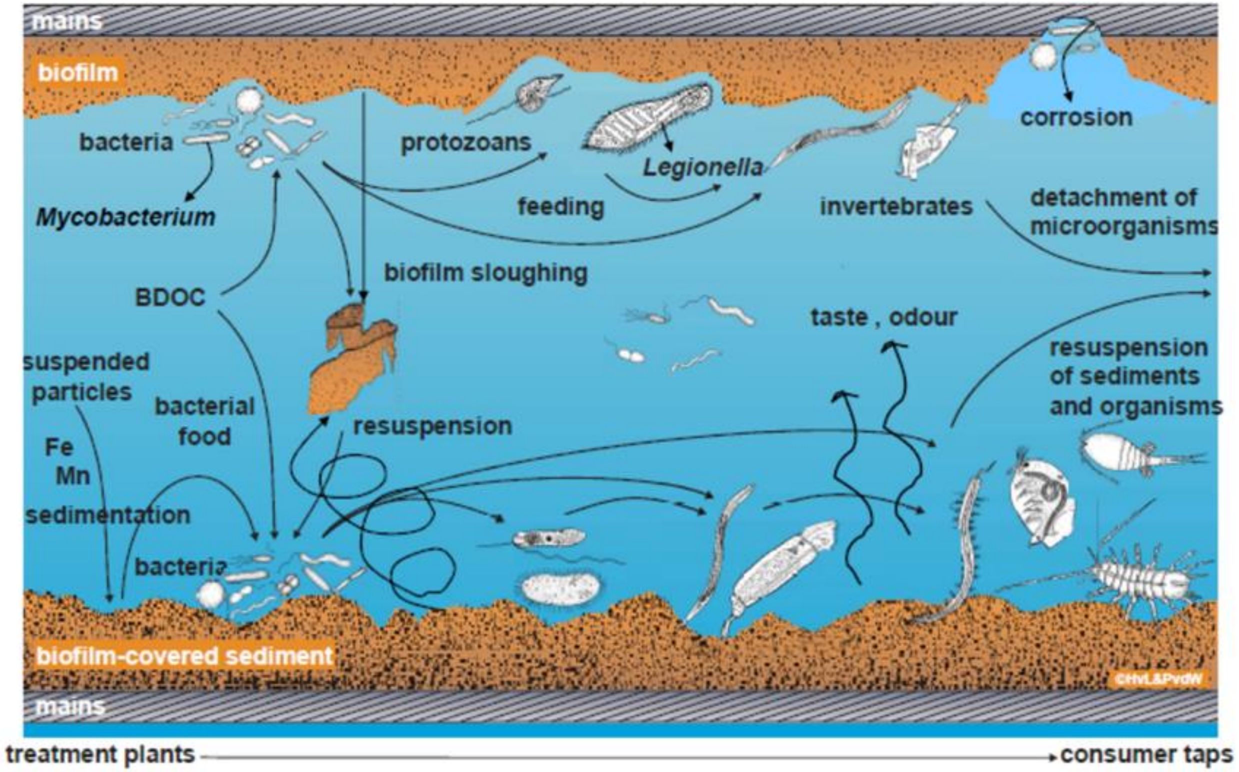
CHALLENGE 4 BIOSTABILITY IN THE NETWORK

Risks

- Opportunistic pathogens (legionella+)
- Taste, odor, visible organisms
- No chlorine to suppress growth
- Distribution + plumbing system

Solutions

- Biostable water (AOC <10 µg/l)
- Temperature <25°C (urban!)
- Clean networks
- Biostable materials



RESUMÉ

- QMRA provides basis to balance disinfection <-> DBPs in treatment
- Safe = safe enough!
- Maximise benefit from DBP producing treatment (e.g. ozone = micropollutant transformation + disinfection + AOC reduction)
- Optimise non-DBP producing treatment barriers for log-reduction
- Holistic risk management: source, design, operation, procedures, protection, improvement
- WSP in NL is covered by existing frameworks (Van den Berg et al. 2019)
- Biological stability enables chlorine free distribution (temperature?)

Van Den Berg, H. H. J. L., Friederichs, L., Versteegh, J. F. M., Smeets, P. W. M. H., & de Roda Husman, A. M. (2019). How current risk assessment and risk management methods for drinking water in The Netherlands cover the WHO water safety plan approach. *International Journal of Hygiene and Environmental Health*, *222*(7), 1030-1037.

THANK YOU FOR YOUR ATTENTION

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the international water association

Disinfection byproducts in a context of Global Change

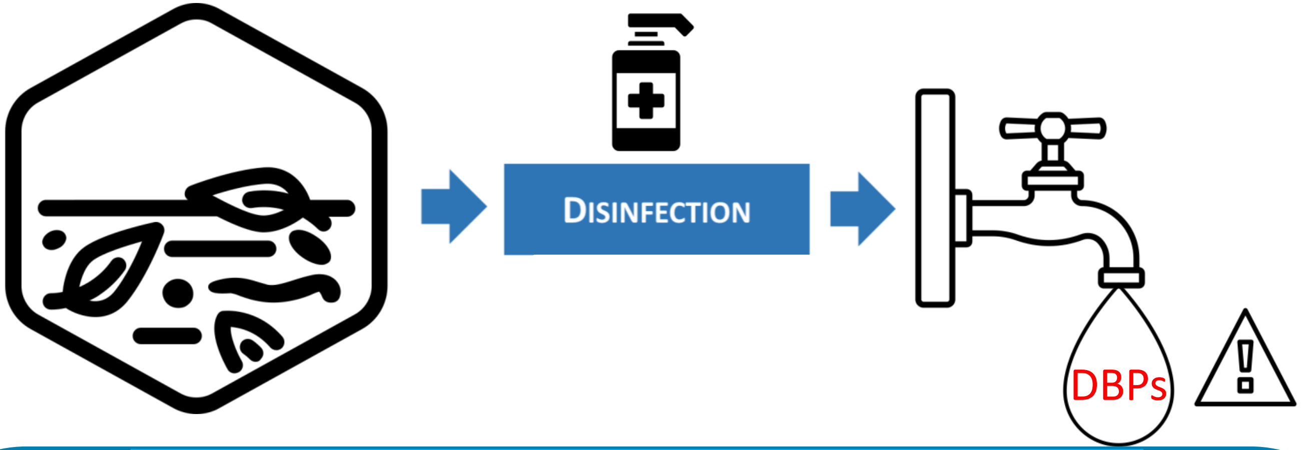
MARIA JOSÉ FARRÉ, CATALAN INSTITUTE FOR WATER RESEARCH ICRA, SPAIN

inspiring change

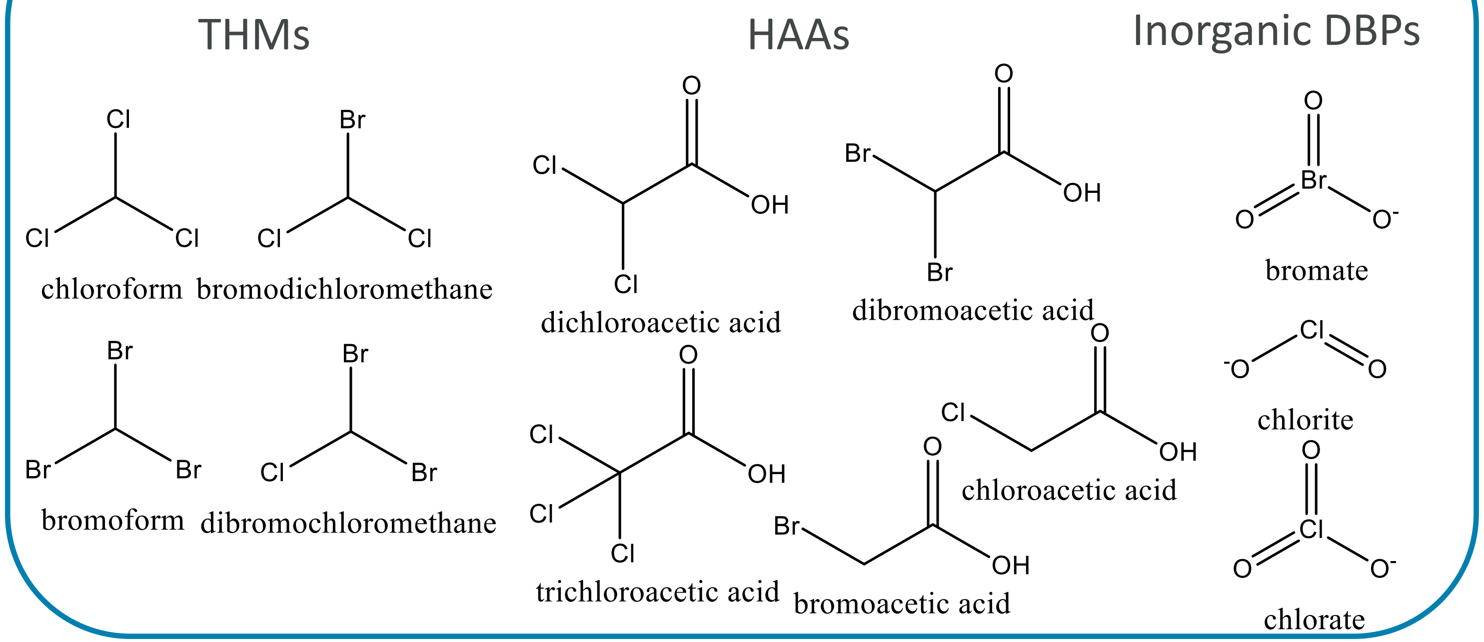
ABOUT THE SPEAKER

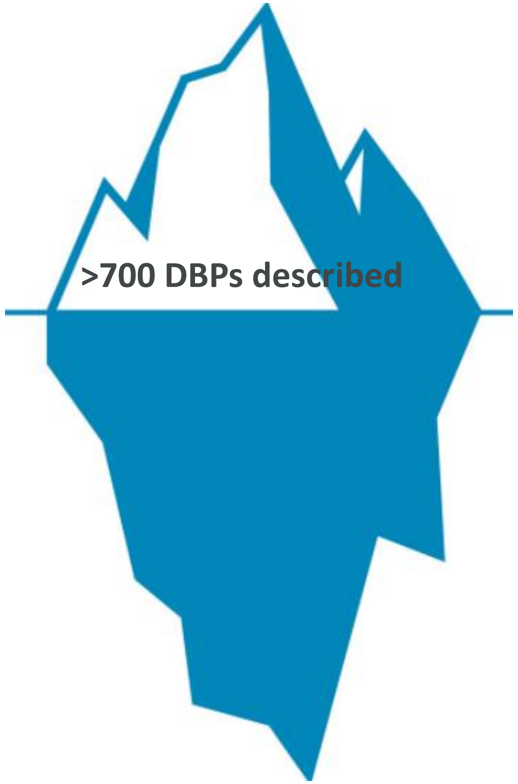
- Maria José has been working on disinfection by-products (DBP) since 2008.
- She is the coordinator of the new Horizon Europe project intoDBP “Innovative tools to control organic matter and DBPs in drinking water”.
- She investigates the following areas: (i) Formation and fate of DBPs in drinking and reclaimed water, (ii) remediation technologies, (ii) environmental forecasting of drinking water quality and (iv) advanced analytical chemistry.

DISINFECTION BYPRODUCTS



Regulated DBPs in drinking water (EU2020/2184)





SOME BASICS TO START…

the international

- Generally present at the µg/L level

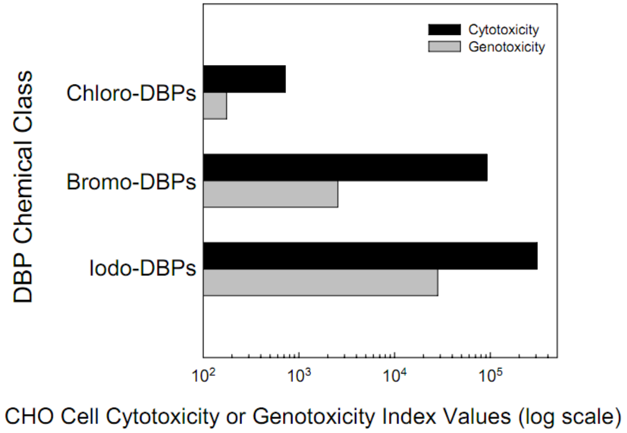
•> 50% of TOX (surrogate for halogenated DBPs) is unknown

•Toxicity:

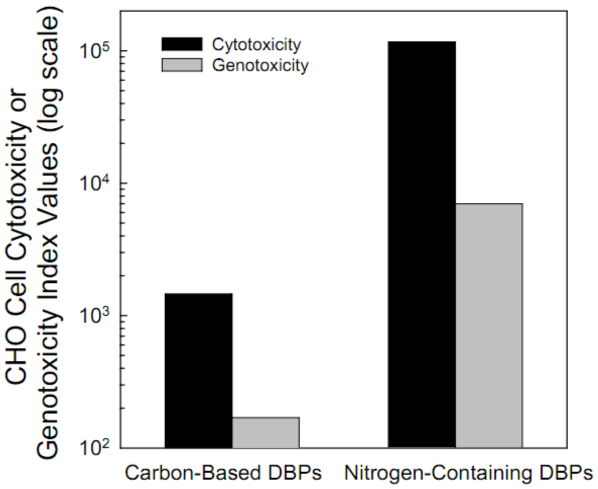
Cl-DBPs<Br-DBPs<I-DBPs

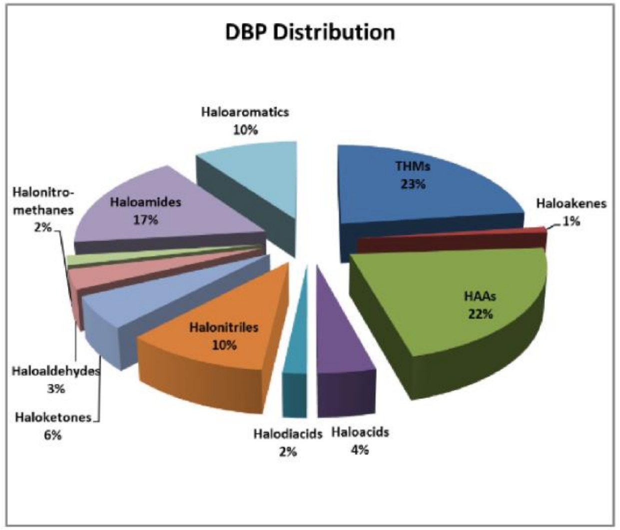
N-DBPs>C-DBPs

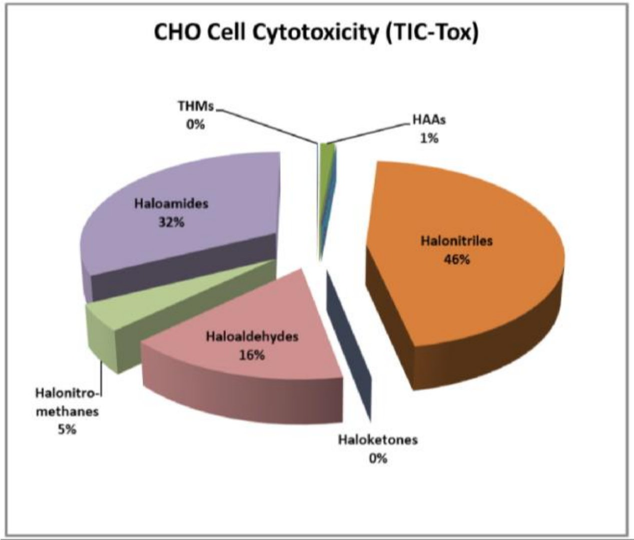
•The most toxic DBPs are not regulated (NDMA, DBAN, IAA..)



Plewa, M. et al. (2008). ACS Symposium Series







Plewa, M.J., Wagner, E.D., Richardson, S.D., 2017.. J. Environ. Sci. 58, 208–216.

DBP EXPOSURE

the international water association

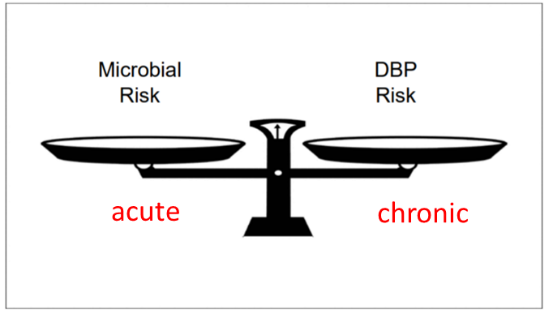
- The DWD 2020/2184 states that Member States shall take all measures necessary to **ensure DBPs are kept as low as possible** without compromising disinfection

- **THMs, HAAs, chlorite, chlorate, bromate** max values **regulated** in the DWD 2020/2184

- Yet, millions of people are daily exposed to DBPs through **ingestion, inhalation, or dermal absorption** when drinking or using municipal tap water

- Minimizing DBP formation is part of an overall public health strategy, as several DBPs have been shown to be **genotoxic and carcinogenic** in in-vitro assays and animal experiments

The Balancing Act

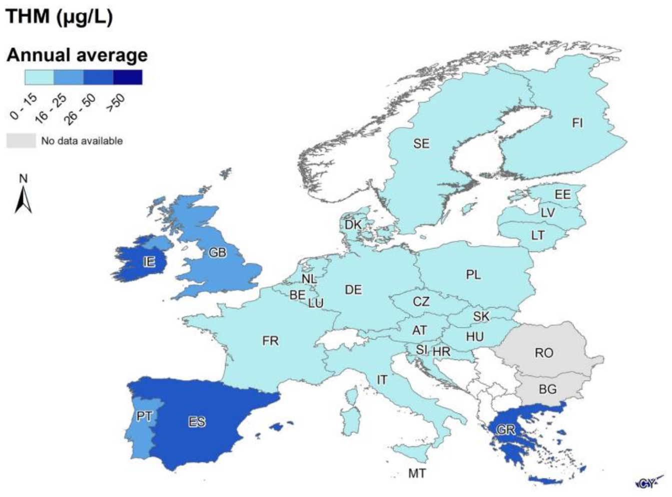


DBP EXPOSURE. CONT.

- DBP formation depends mainly on **disinfectant type**, the chemical nature of precursors, pH, temperature, mixing regime and contact time.

Chlorine Cl_2/HOCl
THMs and HAAs
Halogenated acetonitriles, haloketones, trichloroacetaldehyde, halogenated furanones, halonitromethanes

Chloramine NH_2Cl	Ozone O_3	Chlorine dioxide ClO_2	UV disinfection
Cyanogen halides, Nitrosamines Halonitromethanes Dihaloacetonitriles Dihaloacetic acids Dihaloacetaldehydes Iodinated DBPs	Bromate Aldehydes Ketones Carboxylic acids Brominated DBPs	Chlorite Chlorate Aldehydes Carboxylic acids Chlorophenols Quinones	Aldehydes Carboxylic acids Halonitromethanes



Evlampidou, I., et al. 2020. Environ. Health Perspect. 128(1), 1–14.

- **Chlorination** is the most common disinfectant strategy used in Europe; consequently, THMs are the regulated DBPs generated at the highest concentration.
- Most European countries have data on THMs allowing human epidemiologic studies to report current levels related to a **significant burden of bladder cancer.**
- DBP exposure also has been associated with a number of **reproductive and pregnancy outcomes**, although evidence is less consistent.

PUBLIC TRUST IN TAP WATER

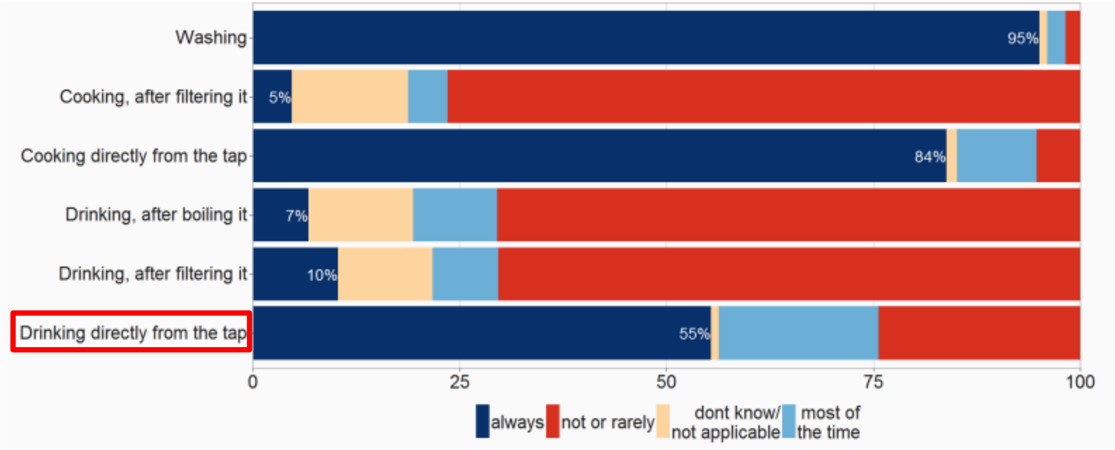


Figure 6: Distribution of responses to the question on the use of drinking water at home

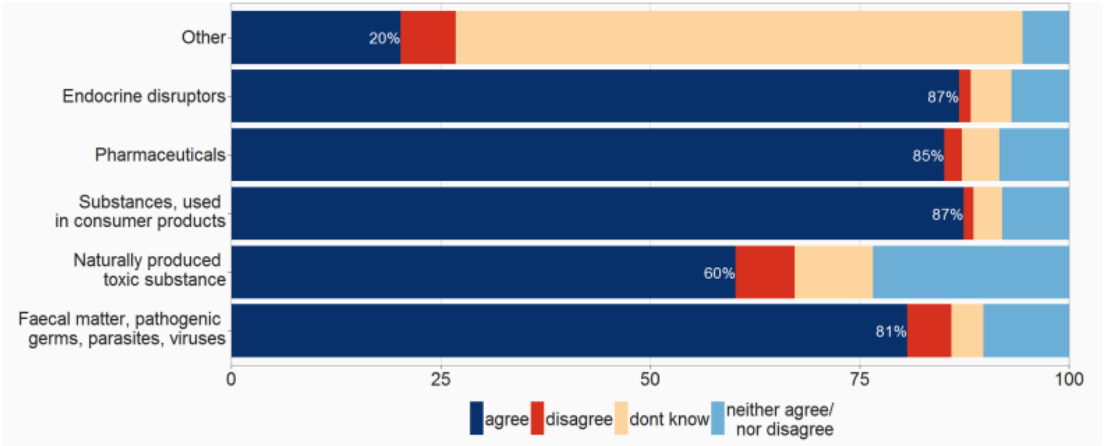


Figure 18: Distribution of responses to the question on other new parameters to be considered

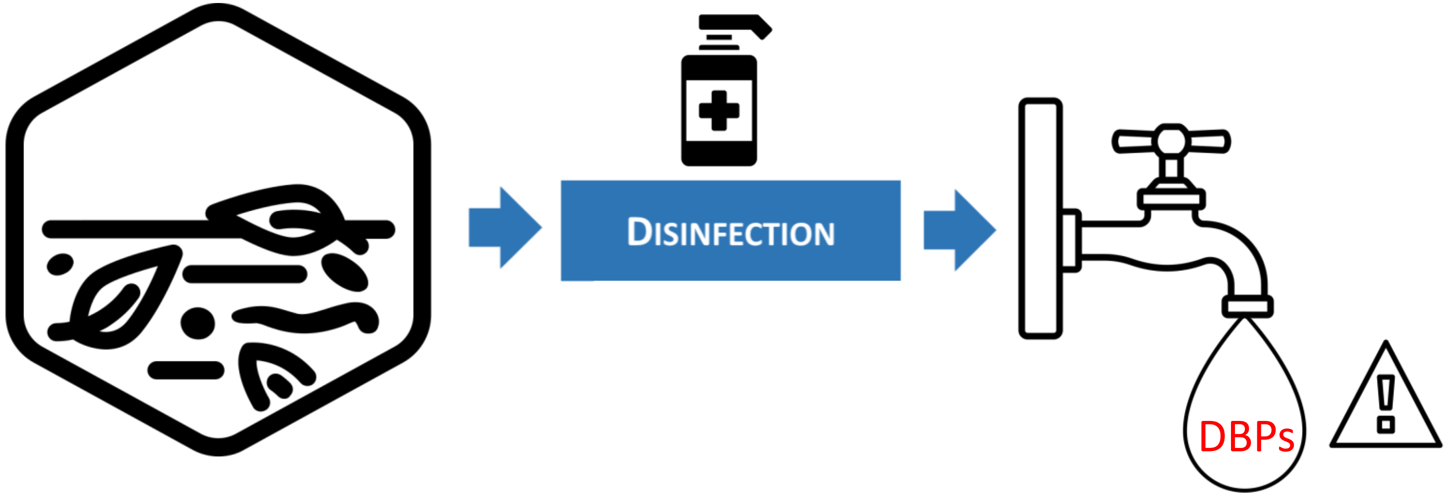
Source: EC -Analysis of the public consultation on the quality of drinking water

Improvements in operational monitoring and treatment optimization to **achieve water quality goals related to microbial protection and DBP reduction**, maximize public health protection for the **full range of water quality conditions**

If TRUST in tap water increases

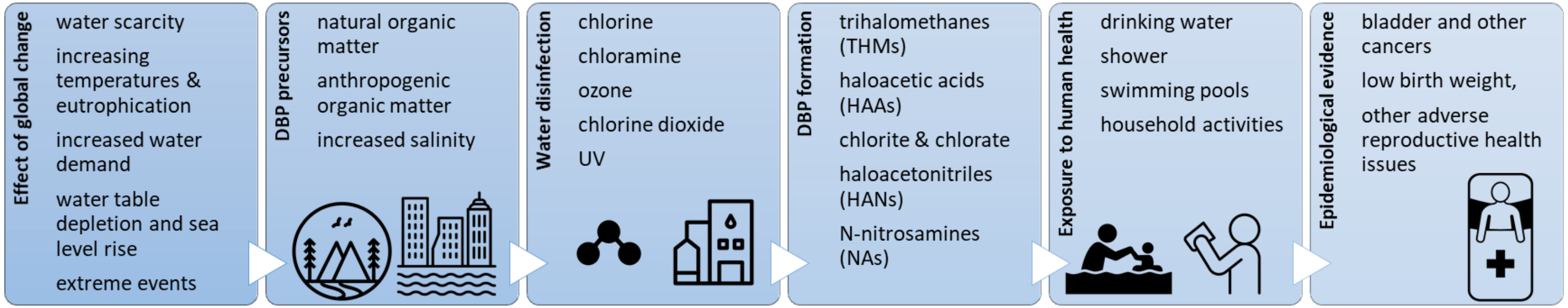
Reduction of bottle water consumption is expected

DISINFECTION BYPRODUCTS (DBPS)



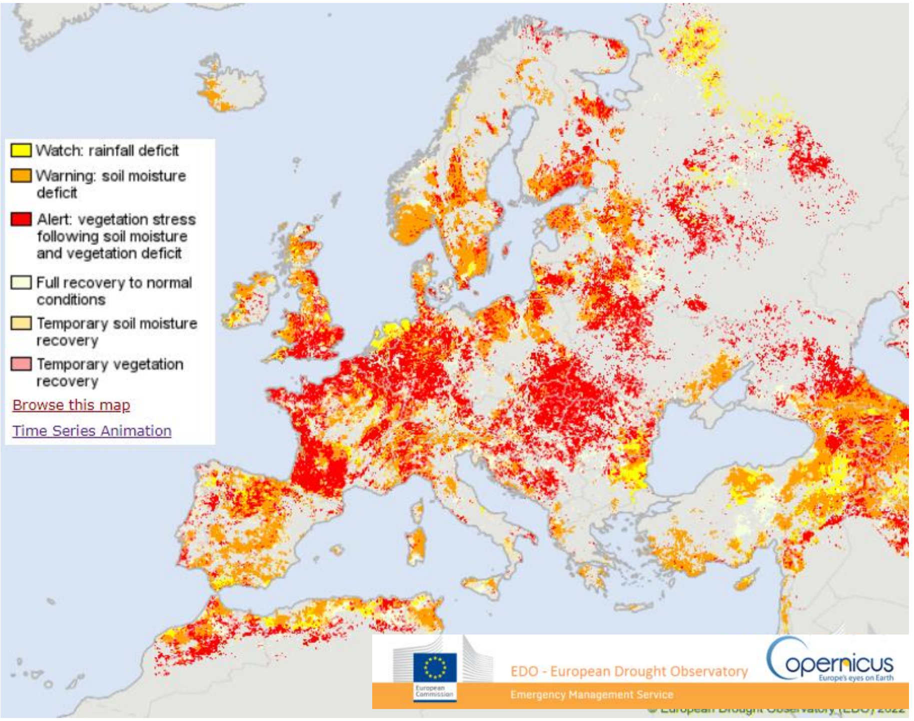
Why DBPs will become even more relevant in the near future?

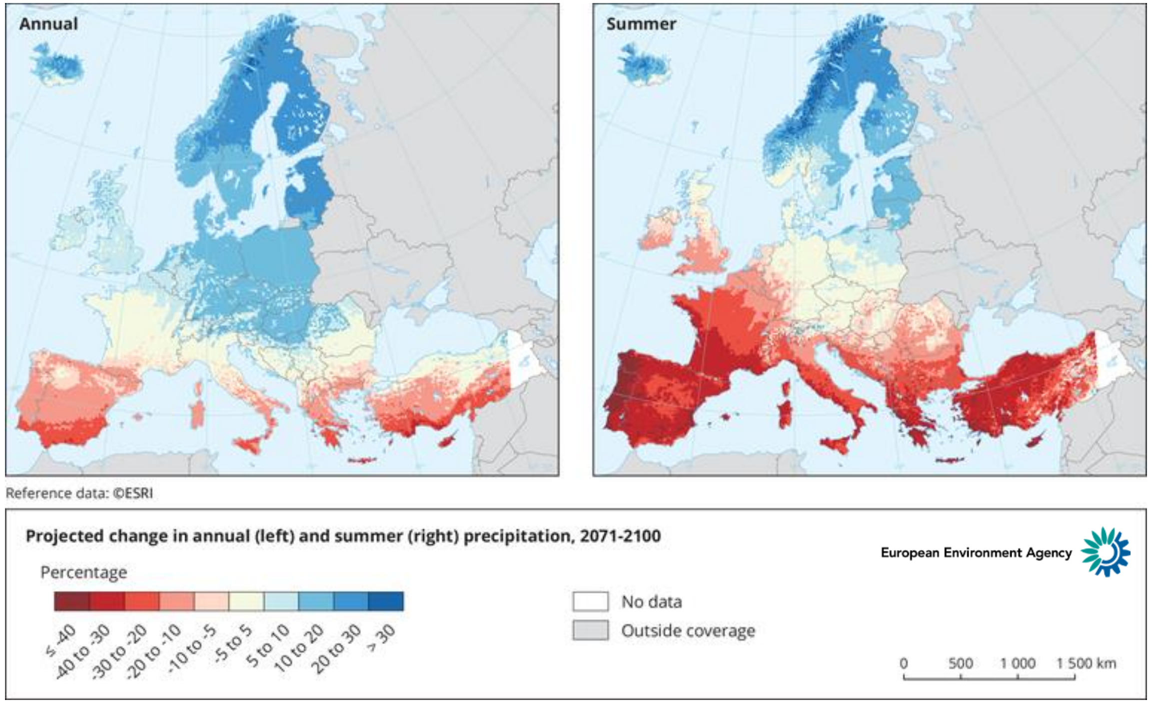
What are the main Research Challenges & Opportunities involved?



WATER SCARCITY AND DBPS

According to the latest map of the **Combined Drought Indicator 22%** of the EU territory is in **Warning** conditions and **27%** is in **Alert** conditions





WATER SCARCITY will:

(1) decrease the ability of surface water bodies to absorb the impact of wastewater emissions

(2) increase the need for water reclamation

→ new pool of DBPs ≠ traditional drinking water DBPs

DISINFECTION BYPRODUCTS (DBPS) - REGULATION

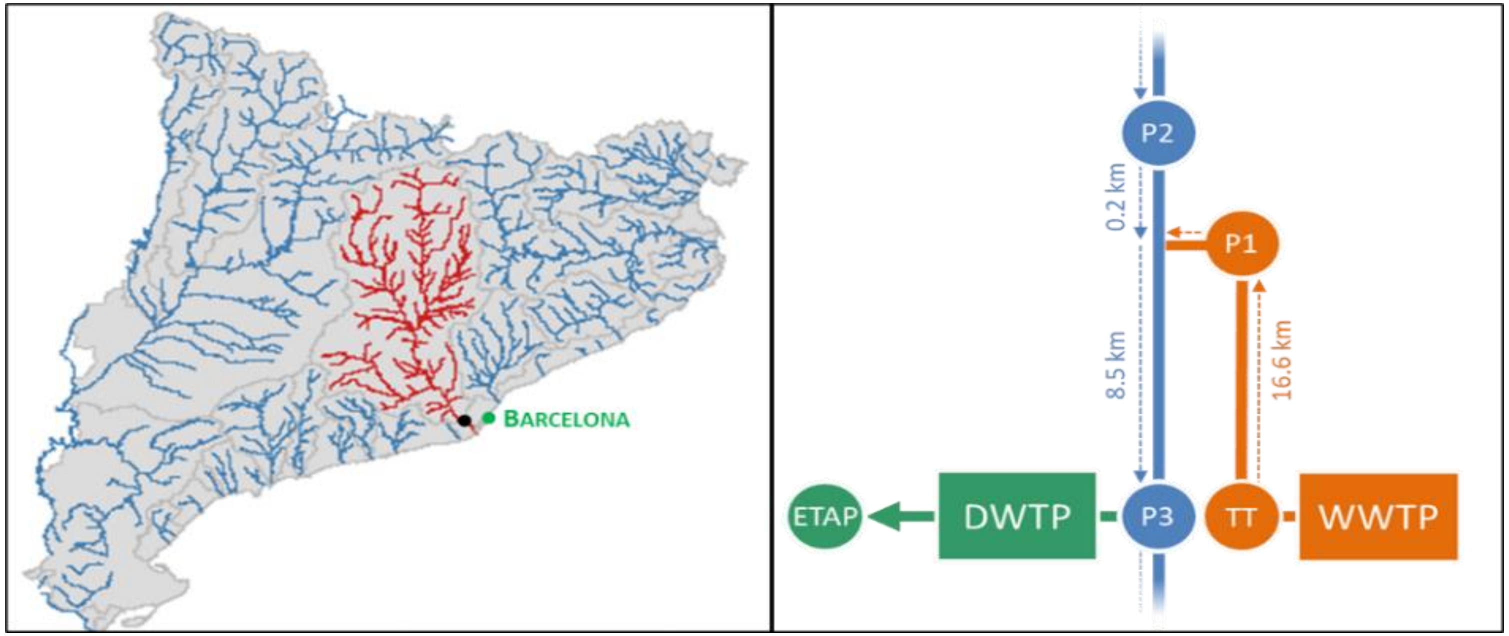
the international water association

DBP	USEPA drinking water (µg/L)	WHO drinking water (µg/L)	2020/2184 EU directive drinking water (µg/L)	AGWR recycled water (µg/L)
Bromate	10	10	10	
BAA	60 as HAA_5		60 as HAA_5	**0.35**
BDCM	80 as THM_4	60	100 as THM_4	**6**
TBM	80 as THM_4	100	100 as THM_4	100
Chlorate		700	250 (700)	
TCM	80 as THM_4	300	100 as THM_4	200
Chlorite	1000	700	250 (700)	
CAA	60 as HAA_5	20	60 as HAA_5	
DBCM	80 as THM_4	100	100 as THM_4	100
DCAA	60 as HAA_5	50	60 as HAA_5	100
TCAA	60 as HAA_5	200	60 as HAA_5	100
DCAN		20		**2**
DBAA	60 as HAA_5		60 as HAA_5	
DBAN		70		
BCAN				**0.7**
NDMA		**0.1**		**0.01**
NDEA				**0.01**

- NDMA is a carcinogenic DBP related to disinfection with **chloramines, ozone and chlorine in the presence of ammonia** and the presence of wastewater
- It is relevant in the low ng/L range unlike most other DBPs (regulated at the µg/L level)

Global Change → Higher concentration of NDMA precursors in drinking water sources

CASE STUDY -DBPS IN WATER REUSE-



TT: tertiary treated wastewater
P1: reclaimed water inflow into the river
P2: river water before TT discharge
P3: intake of the DWTP
ETAP: drinking water

Agència Catalana de l'Aigua

- Dilution: 1:1 – 1:2 (reclaimed water: river water) to simulate the worst-case scenario
- 4 weeks without disinfecting TT
- 3 weeks disinfecting TT with chlorine (10-14 mg/L Cl_2)

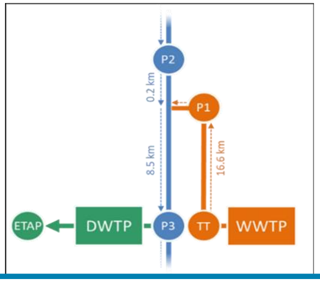
Objective: Evaluate the formation of DBPs and the presence of DBP precursors during wastewater reclamation compared to their usual concentrations in the river downstream of the point of discharge

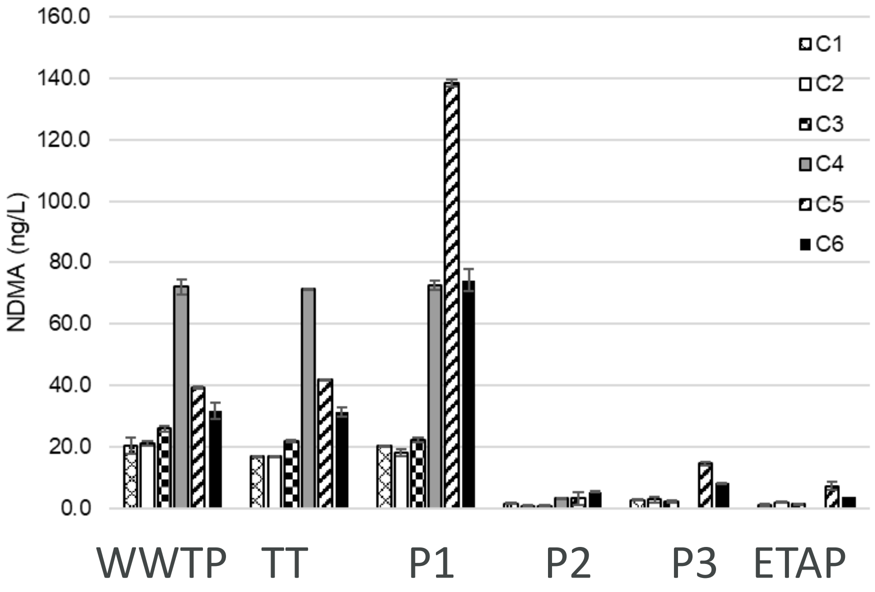
MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

Sanchís, J., (2021) Journal of Hazardous Materials. 407, 124346.

CASE STUDY -DBPS IN WATER REUSE-

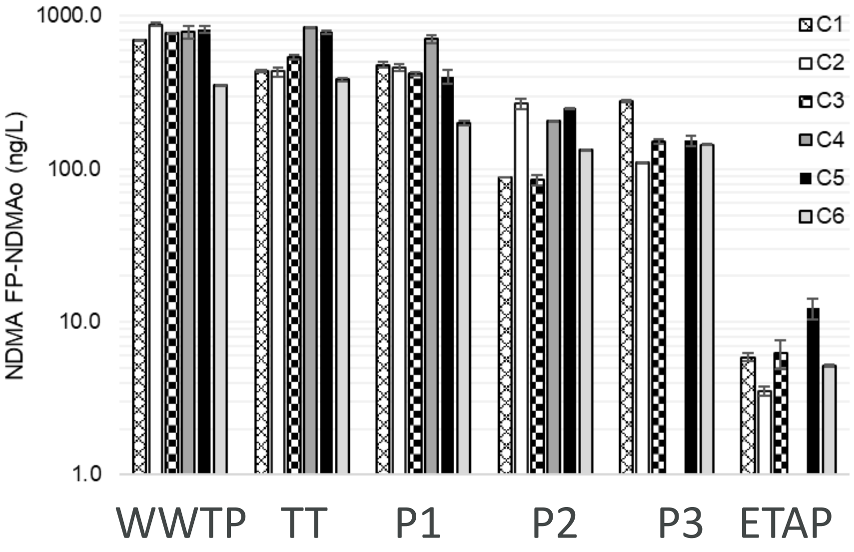




[NDMA] in the river before discharge was low (< 4 ng/L)
[NDMA] increased when chlorine was added to the tertiary treated effluent (containing 0.4-3 mg/L NH_4^+)
[NDMA] was removed in the river due to:

- photolysis
- dilution

[NDMA] maximum concentration in DW samples was 7.3 ng/L



[NDMA precursors] in the river before discharge was 90-270 ng/L (de-facto reuse)
[NDMA precursors] in tertiary treated water was 200-700 ng/L
Natural attenuation of NDMA precursors:

- hydrolysis
- photodegradation
- sorption
- redox reactions

[NDMA precursors] maximum concentration in DW samples was 12.5 ng/L

INCREASED TEMPERATURE AND DBPS

An algal bloom in Stuart, Florida, in June led to a state of emergency.

Study role of climate change in extreme threats to water quality

Record-breaking harmful algal blooms and other severe impacts are becoming more frequent. We need to understand why, says **Anna M. Michalak**.

Michalak, A.M. 2016. Nature 535:349–350.

INCREASING TEMPERATURES will:

(1) modify the hydrology of catchments and the biogeochemistry of soils, with increasing trends of DOM concentration in runoff
(2) change thermal structure and mixing regimes in lakes
(3) increase in the magnitude and frequency of extreme events that imply source water with high (and different) content of DOM from catchment soils or phytoplankton blooms

→Need to adopt source protection strategies and adapt treatment technology to overcome these new challenges

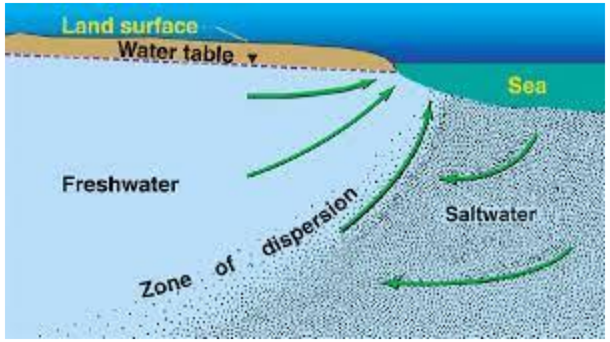
WATER TABLE DEPLETION, SEA LEVEL RISE AND DBPS

the international water association

Sea water intrusion may :

(1) Increase the concentration of bromide and iodide in drinking water sources.

→Need to develop treatment strategies to increase I^- and Br^- removal



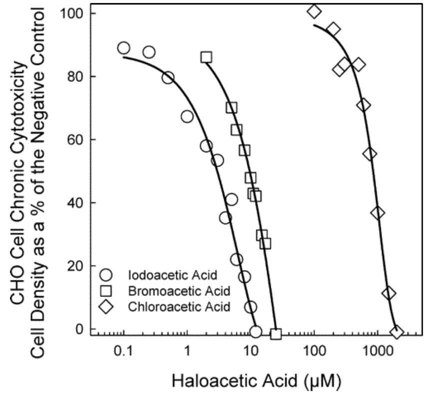
- Bromine reacts faster than chlorine to form Br-DBPs (toxic)
- BrO_3^- (toxic) formation undesired

HOCl -> HOBr $k=1.5\ 10^3\ M^{-1}\ s^{-1}$

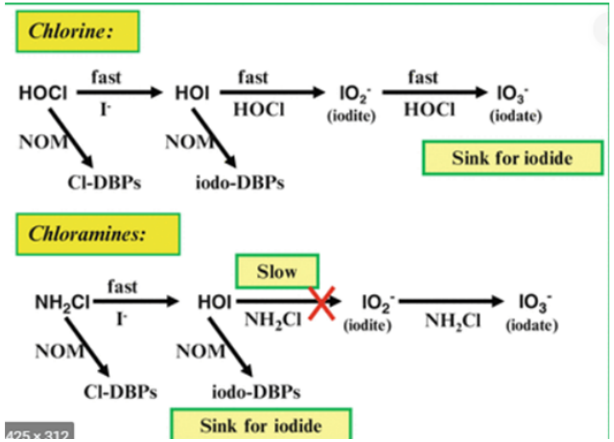
(Kumar and Margerum, 1987)

THMs formation $k=0.01 - 0.03\ M^{-1}\ s^{-1}$

(Gallard and Von Gunten, 2002).

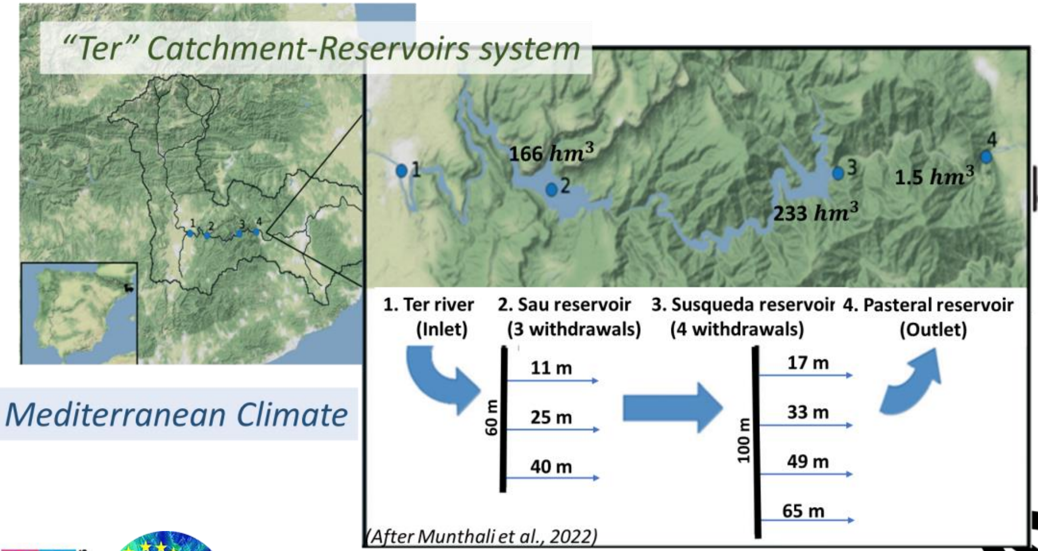


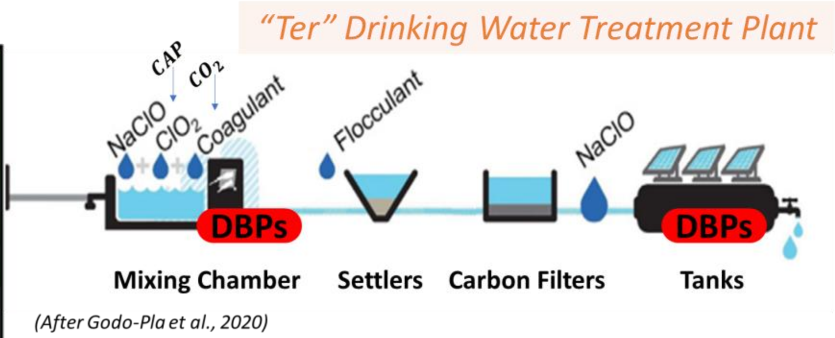
- Iodine will form I-DBPs (toxic) if not oxidized to IO_3^- (non toxic)

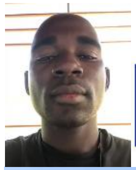


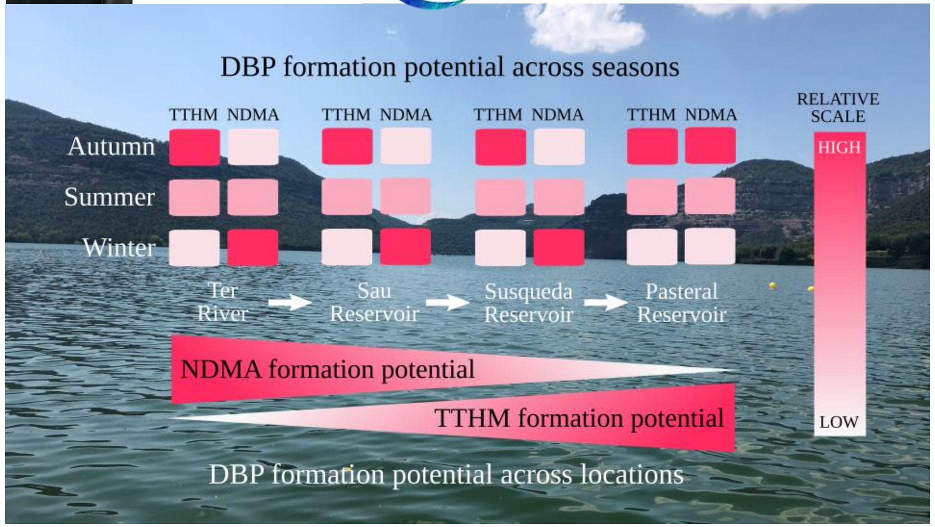
Iodoacetic acid is still the most genotoxic DBP identified to-date.

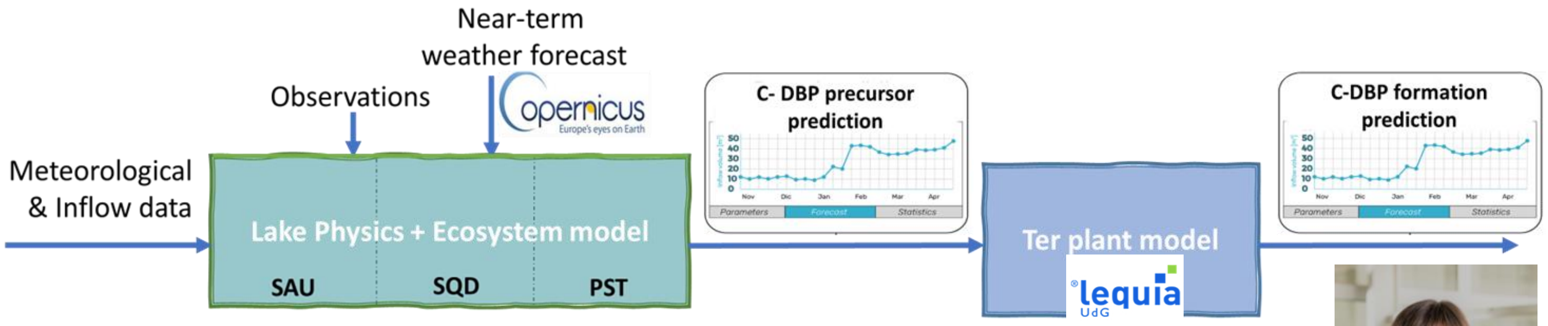
CASE STUDY – FORECASTING-







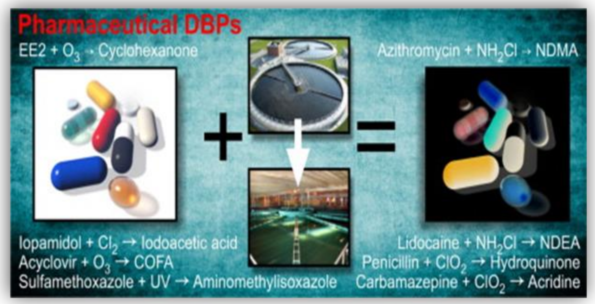




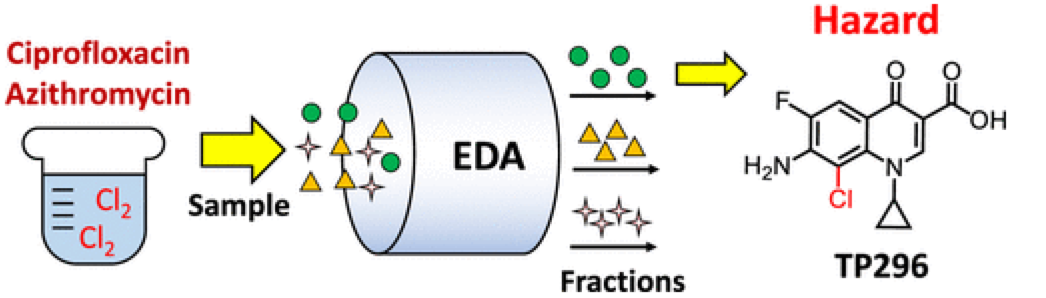
Munthali, E., et al. (2022) ESWRT. 8, 968.

DBP PRECURSORS

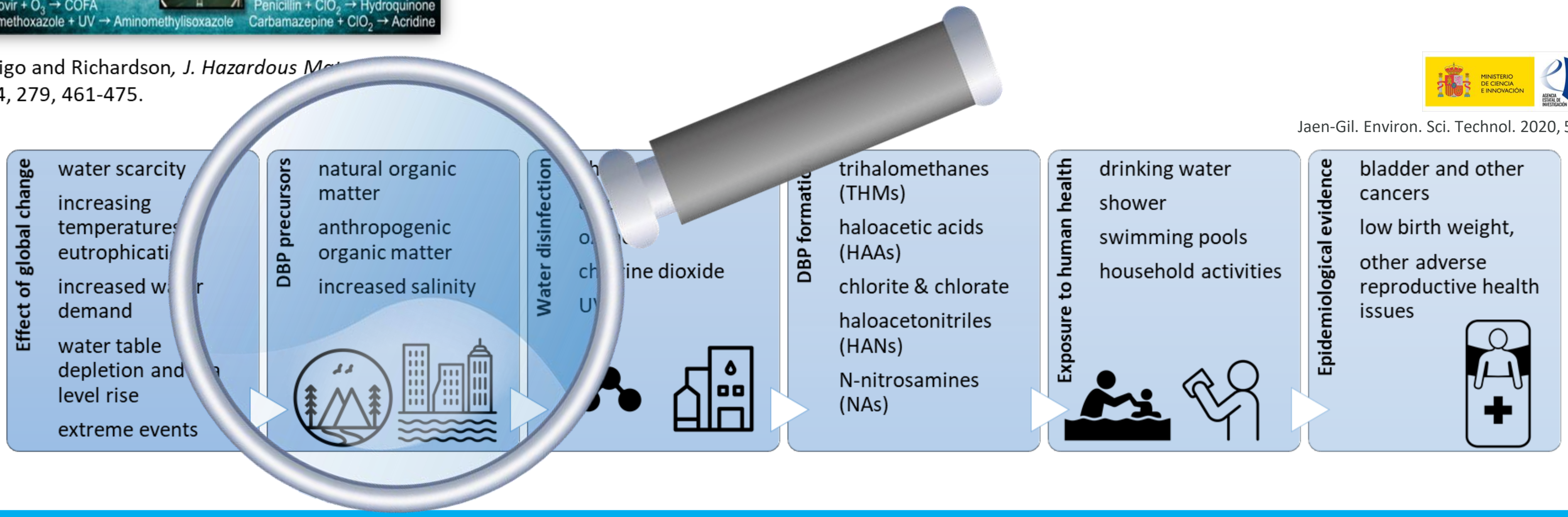
- Dissolved organic matter → formation of DBPs
- Bromide and iodide → speciation of DBPs
- Effluent organic matter → halogenated TPs
- Ammonia → changes in the disinfectant species



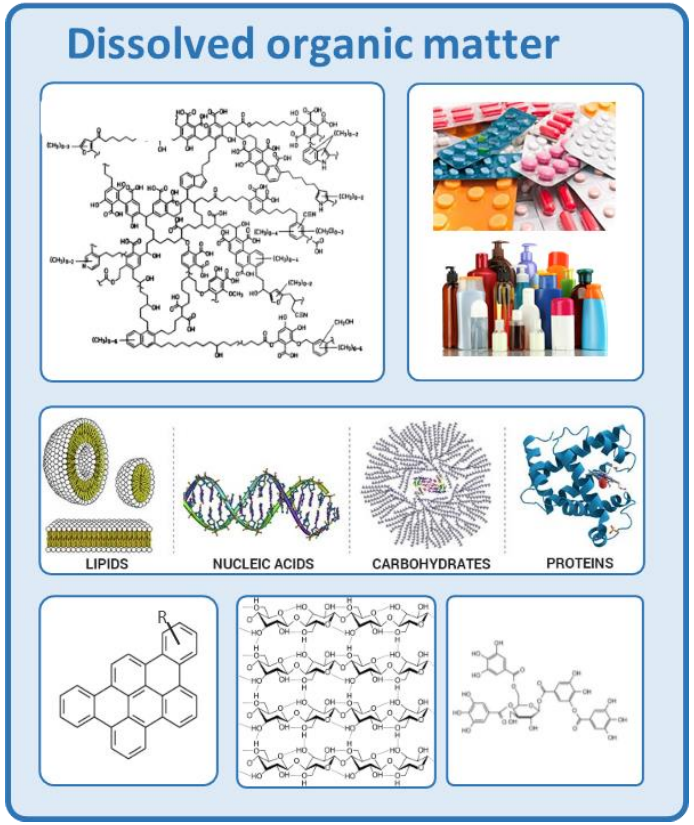
Postigo and Richardson, *J. Hazardous Mat.* 2014, 279, 461-475.



Jaen-Gil. Environ. Sci. Technol. 2020, 54, 14, 9062–9073



DISSOLVED ORGANIC MATTER (DOM)

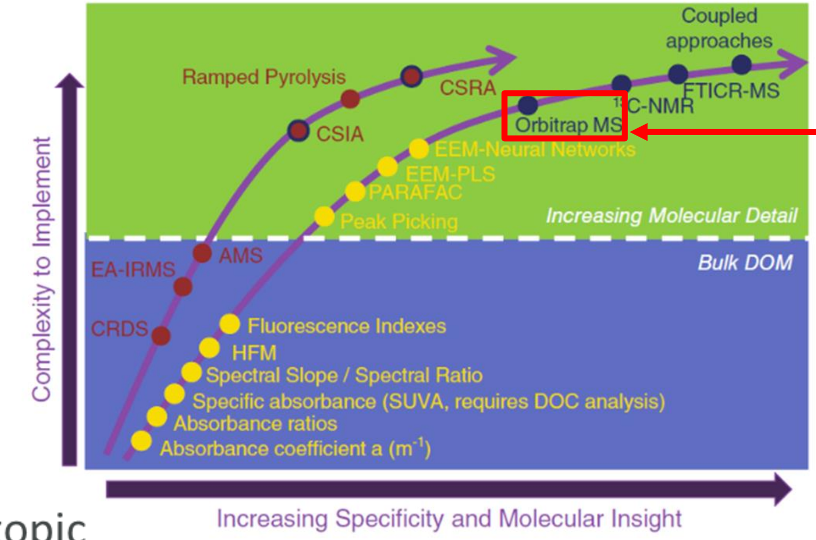


Past limitations for DOM characterization :

- limited analytical capabilities
- large sample volume requirements
- low sample throughput
- time constraints
- data handling
- low resolution instrumentation

The present...

- isotopic
- optical
- molecular
- molecular & isotopic



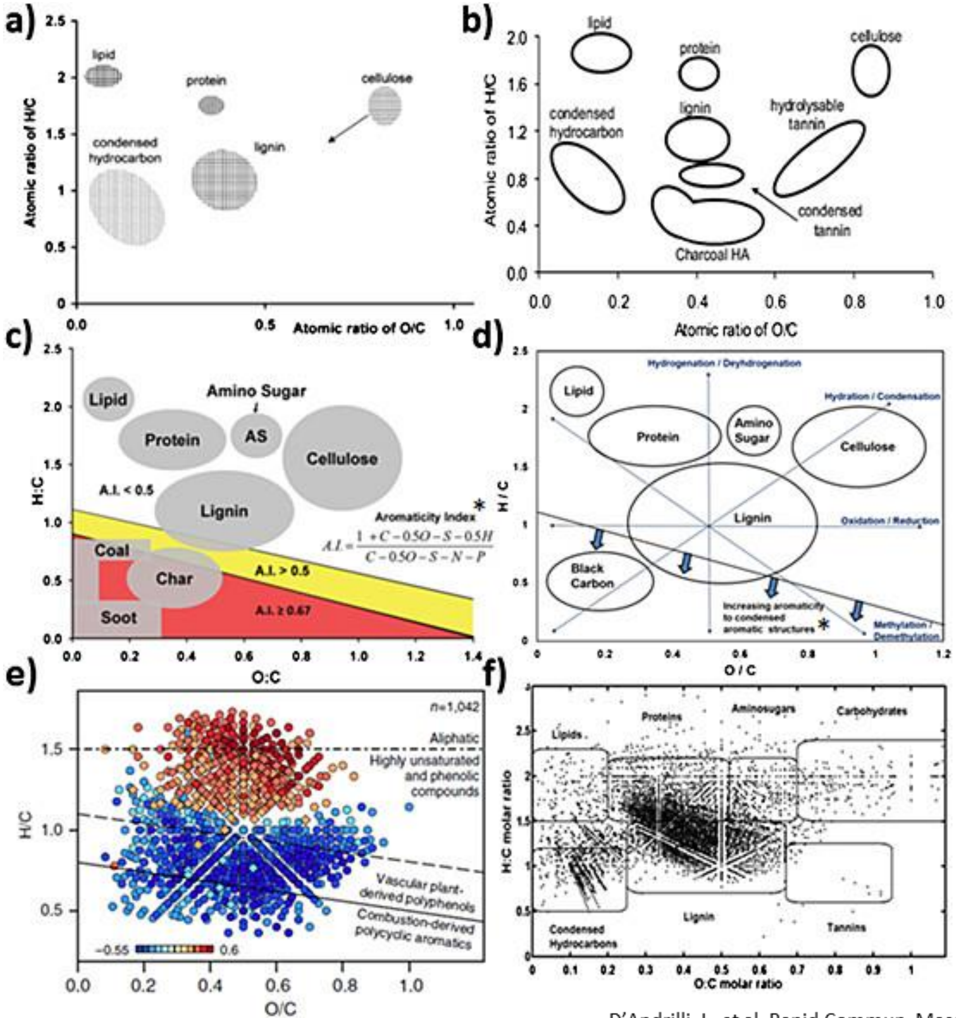
Orbitrap MS

McCallister, S.L. et all. 2018. Limnnology and Oceanography letters, 3, 444-457

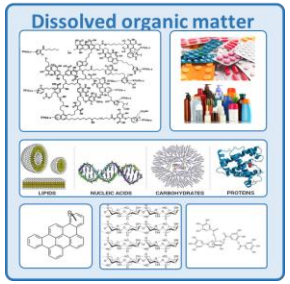
ADVANCED ANALYTICAL TECHNIQUES FOR DOM CHARACTERIZATION AND FORMATION OF DBPS

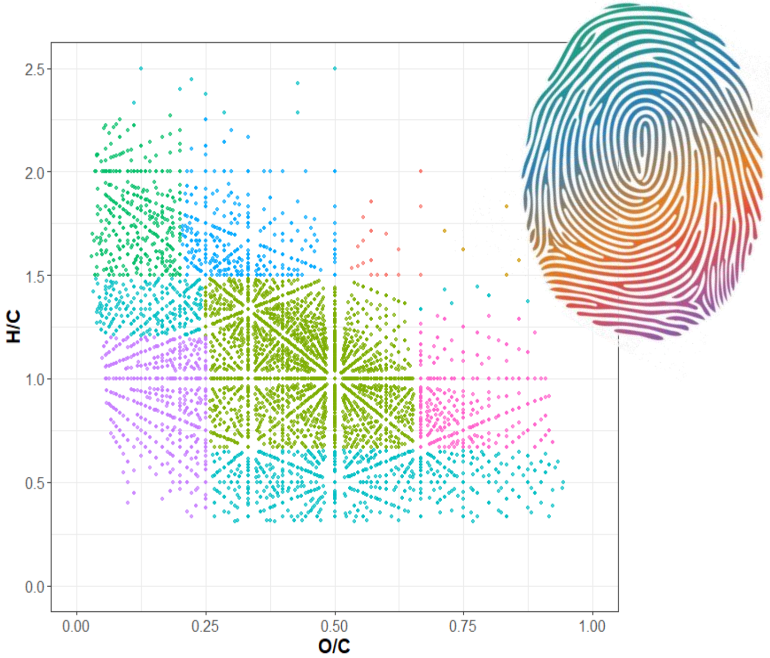
the international water association

HRMS FINGERPRINT VAN KREVELEN DIAGRAM



D'Andrilli, J., et al. Rapid Commun. Mass Spectrom. 2015, 29, 2385–2401





LIMNOLOGY and OCEANOGRAPHY: METHODS

ASLO

Limnol. Oceanogr.: Methods 18, 2020, 235–258

doi: 10.1002/lom3.10364

An international laboratory comparison of dissolved organic matter composition by high resolution mass spectrometry: Are we getting the same answer?[a]

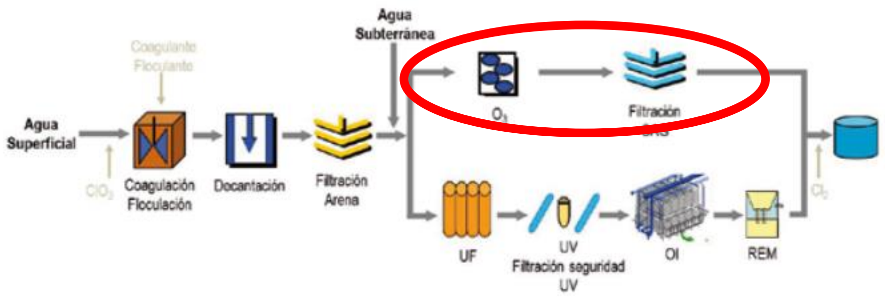
CASE STUDY – DOM IN REUSE -

Hawkes, J.A., et al. (2020) Limnol. Oceanogr.: Methods 18 (6), 235-258.

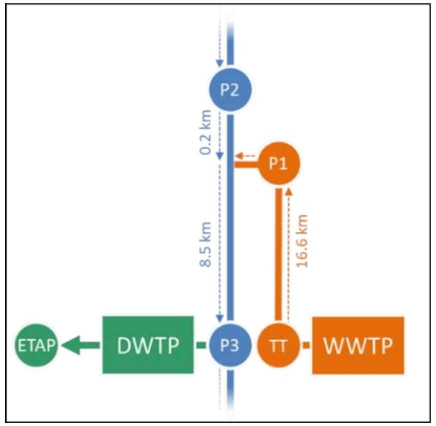
REGIONS SELECTED:

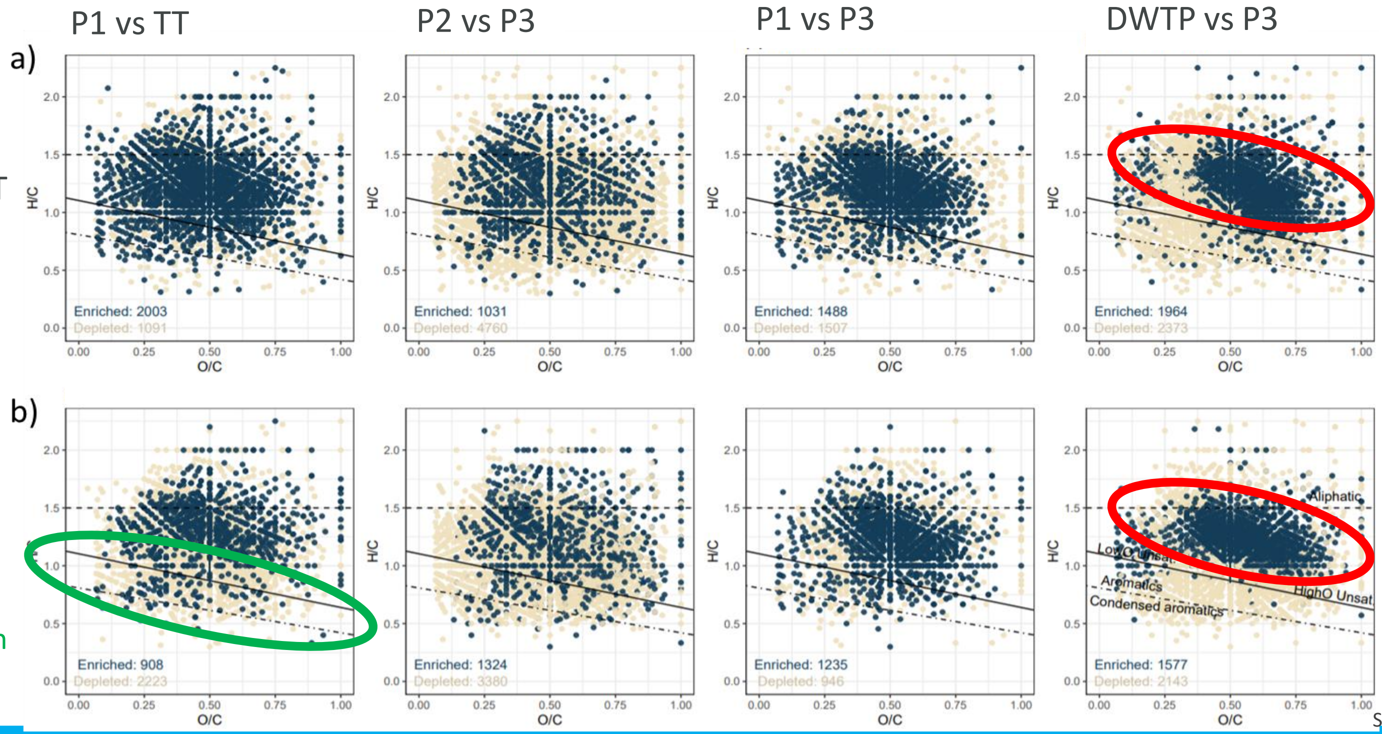
- Aliphatic (H/C ≥ 1.5),
- Low O unsaturated (H/C < 1.5, AImod < 0.5, O/C < 0.5),
- High O unsaturated (H/C < 1.5, AImod ≥ 0.5, O/C ≥ 0.5),
- Aromatics (0.5 < AImod < 0.67)
- Condensed aromatics (AImod ≥ 0.67)

$AI_{mod} = (1 + C - 0.5O - S - 0.5 (N + P + H) / (C - 0.5O - S - N - P)$



DWTP St Joan Despí





No disinfection of TT

Disinfection of TT

Reaction of chlorine with aromatic compounds

Removal of aliphatic and aromatic compounds, but also the production of more oxidized molecules due to ozonation

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Sanchís, J., (2021) Journal of Hazardous Materials, 407, 124346

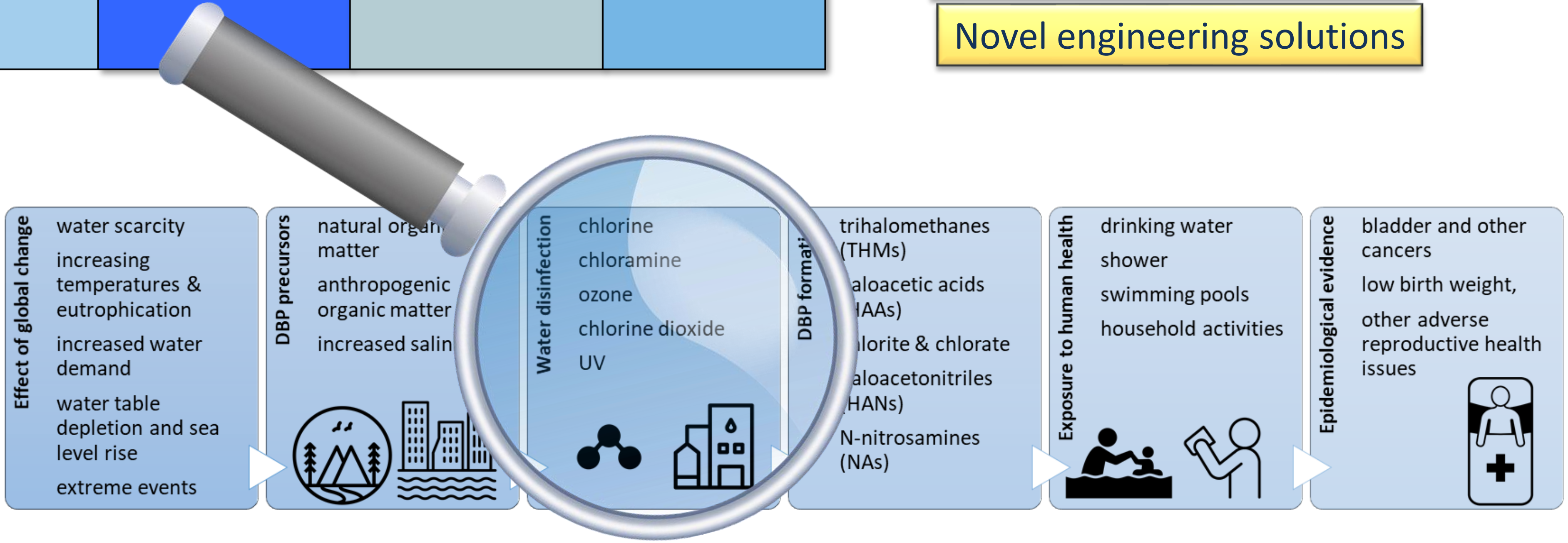
DISINFECTION STRATEGIES

Chlorine Cl_2/HOCl				
THMs and HAAs Halogenated acetonitriles, haloketones, trichloroacetaldehyde, halogenated furanones, halonitromethanes				
Chloramine NH_2Cl	Ozone O_3	Chlorine dioxide ClO_2	UV disinfection	
Cyanogen halides, Nitrosamines Halonitromethanes Dihaloacetonitriles Dihaloacetic acids Dihaloacetaldehydes Iodinated DBPs	Bromate Aldehydes Ketones Carboxylic acids Brominated DBPs	Chlorite Chlorate Aldehydes Carboxylic acids Chlorophenols Quinones	Aldehydes Carboxylic acids Halonitromethanes	

Novel disinfectants:

- UV/chlorine-based systems
- Other AOPs
- Organic acids (WW)
- Electrochemical systems
- etc

Novel engineering solutions



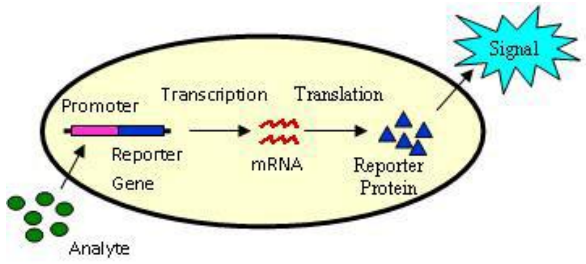
MONITORING → SENSORS

Real-time source to supply information

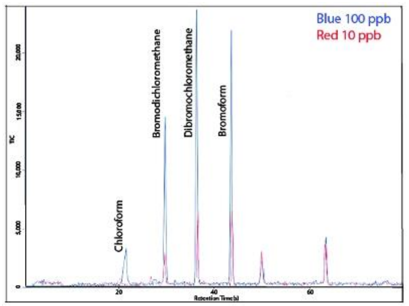
Optical sensors
UV, EEM

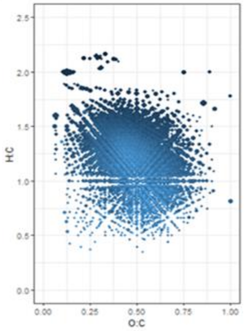
Chemical sensors
THMs

Biosensors/bioreporters



Spectrometric
sensors





-how many?
-where to place them?
-prediction capabilities?

A combination of strategies will mostly be necessary

Effect of global change
- water scarcity
- increasing temperatures & eutrophication
- increased water demand
- water table depletion and sea level rise
- extreme events

DBP precursors
- natural organic matter
- anthropogenic organic matter
- increased salinity

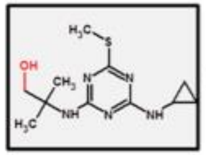
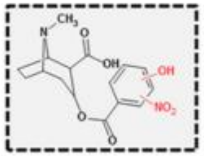
Water disinfection
- chlorine
- chloramine
- ozone
- chlorine dioxide
- UV

DBP formation
- trihalomethanes (THMs)
- haloacetic acids (HAAs)
- chlorite & chlorate
- haloacetonitriles (HANs)
- N-nitrosamines (NAs)

Exposure to human health
- drinking water
- shower
- swimming pools
- household activities

Epidemiological evidence
- bladder and other cancers
- low birth weight,
- other adverse reproductive health issues

NON-TARGET SCREENING OF DBPS

Example	*Identification confidence*	*Minimum data requirements*
	***Level 1: Confirmed structure*** by reference standard	MS, MS², RT, Reference Std.
	Level 2: Probable structure a) by library spectrum match b) by diagnostic evidence	MS, MS², Library MS² MS, MS², Exp. data
	***Level 3: Tentative candidate(s)*** structure, substituent, class	MS, MS², Exp. data
$C_6H_5N_3O_4$	***Level 4: Unequivocal molecular formula***	MS isotope/adduct
192.0757	***Level 5: Exact mass*** of interest	MS

Schymanski. E., et al. Environ. Sci. Technol. 2014, 48, 4, 2097–2098

Reference Standard for DBPs are no easy to obtain

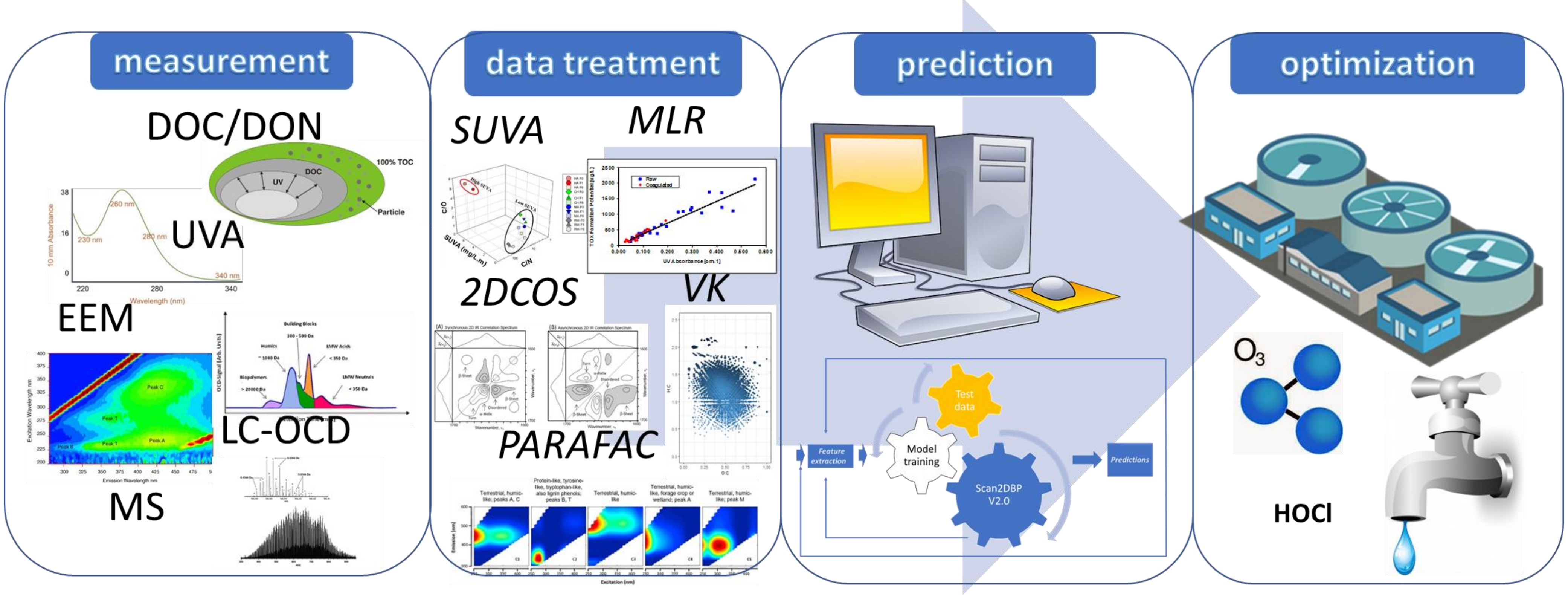
S87	CHLORINETPS	**List of chlorination byproducts of 137 CECs and small disinfection byproducts**	CHLORINETPS in XLSX, CSV (09/12/2021) CompTox CHLORINETPS List

A list of chlorination byproducts of 137 contaminants of emerging concern (CECs) and small molecular weight disinfection byproducts from the CHLORINE_TPs database, described in Postigo et al DOI: 10.1016/j.teac.2021.e00148. 91% are amenable to LC-ESI-HRMS.

Dataset DOI: 10.5281/zenodo.5767356

Postigo C., et al. Trends in Environmental Analytical Chemistry. 32, 2021, e00148

OUR VISION



waterPRINT

SCAN2DBP

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Plan de Recuperación, Transformación y Resiliencia

AGENCIA ESTATAL DE INVESTIGACIÓN

INNOVATIVE TOOLS TO CONTROL ORGANIC MATTER AND DISINFECTION BYPRODUCTS IN DRINKING WATER

IntoDBP

Coordinator: ICRA

ICRA Institut Català de Recerca de l'Aigua

University of Cyprus

nireas International Water Research Center

KOIOS Research and Innovation Center of Excellence

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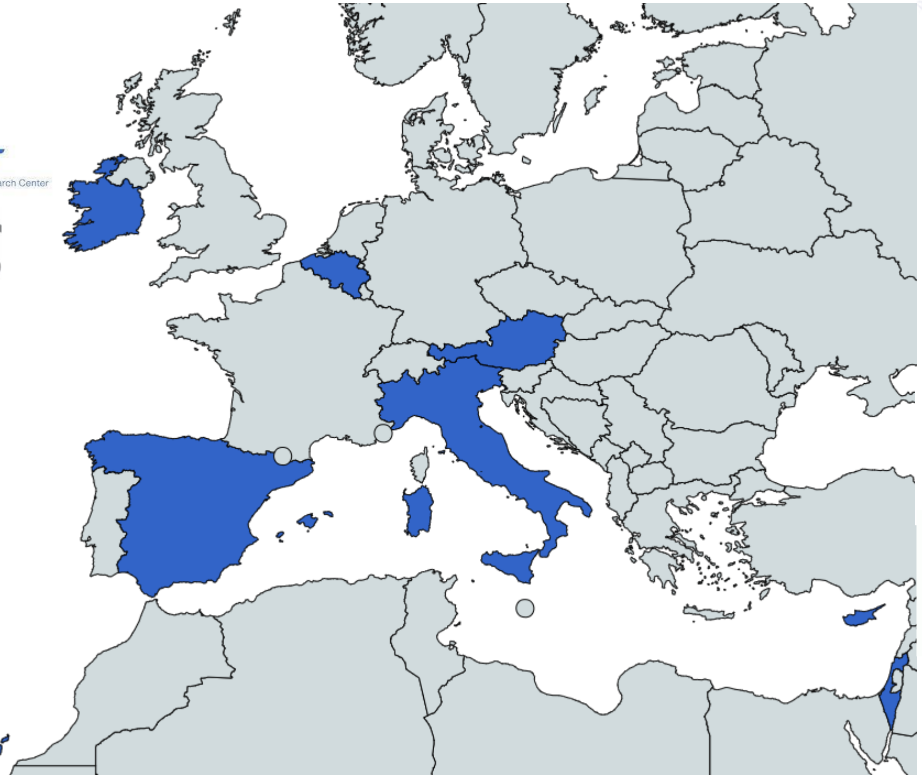
DUNDALK INSTITUTE OF TECHNOLOGY



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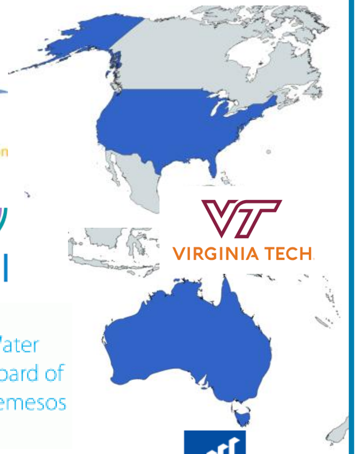

VIRGINIA TECH

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CALL: No-101081728 HORIZON-CL6-2022-ZEROPOLLUTION-01 Duration: 1/12/2022-30/11/2026

European Commission

TAKE-HOME MESSAGES

the international water association

- ✓ Millions of people are daily exposed to DBPs through ingestion, inhalation, or dermal absorption when drinking or using municipal tap water

- ✓ Reduction of DBPs should not compromise acute microbiological risks

- ✓ Improvements in operational monitoring and treatment optimization to achieve water quality goals related to DBP reduction will maximize public health protection for the full range of water quality conditions → increase public trust → reduce bottle water consumption

- ✓ Global Change will bring new challenges (and opportunities) for DBP control
  - -water scarcity/ increased water demand → water reuse → new precursors
  - -increase in temperatures → need for forecasting water quality
  - -sea water intrusion → control of brominated and iodinated species (more toxic)
  - -extreme events → More frequent events = less time to react; More intense events = greater impacts

- ✓ New tools to predict DBP formation can be useful for treatment optimization in a context of Global Change

THANK YOU FOR YOUR ATTENTION
MJFARRE@ICRA.CAT

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Project PDC2021-121045-I00 (**Scan2DBP** funded by MCIN/AEI/10.13039/501100011033 and the European Union NextGenerationEU/ PRTR)
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ICRA Catalan Institute for Water Research

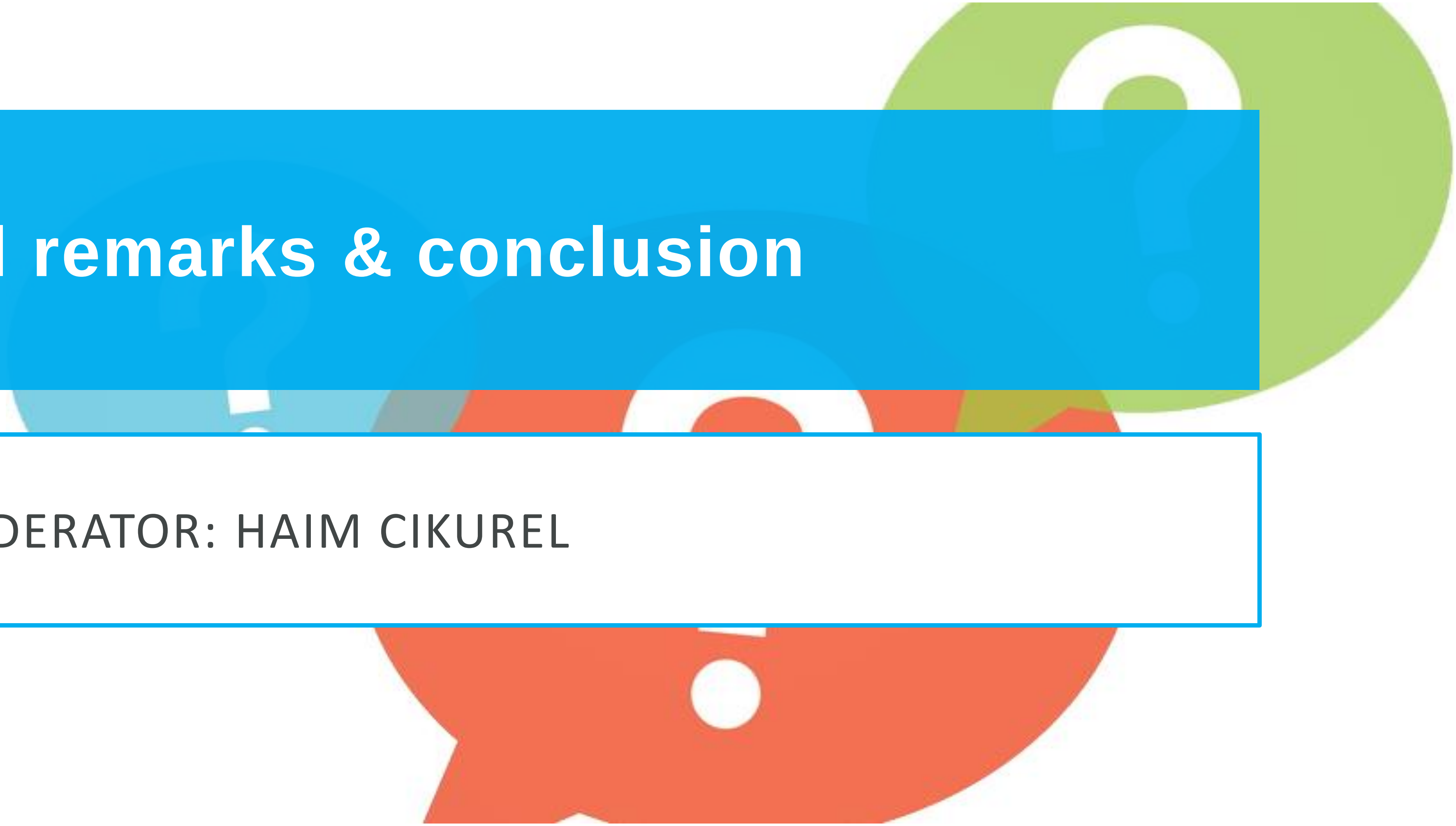
CERCA Centres de Recerca de Catalunya

Universitat de Girona

Q&A Discussion & Poll

MODERATOR: HAIM CIKUREL

the international water association



Final remarks & conclusion

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