Norwegian Water Association & Norwegian Association of Consulting Engineers

Water Prize 2026

Winner

Bjørnar Eikebrokk

22nd October 2026

Coagulation-Based Water Treatment, Scotland

Paul Weir
Learning & Lean Operations Manager
Scottish Water

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Bjørnar's challenge…

"SW's operational optimization activities, new sensor applications/benefits and perhaps some information/experiences on how you successfully organized for optimum operation activities throughout entire Scotland would be interesting – you have 20 - 30 minutes!"



Four nice areas of operational focus

- Using zeta potential to optimise treatment against our NOM challenge
- Using LC-OCD to routinely monitor our NOM
- Using Bactosense to enhance our understanding of our inter-stage process performance
- Using Coaching to embed



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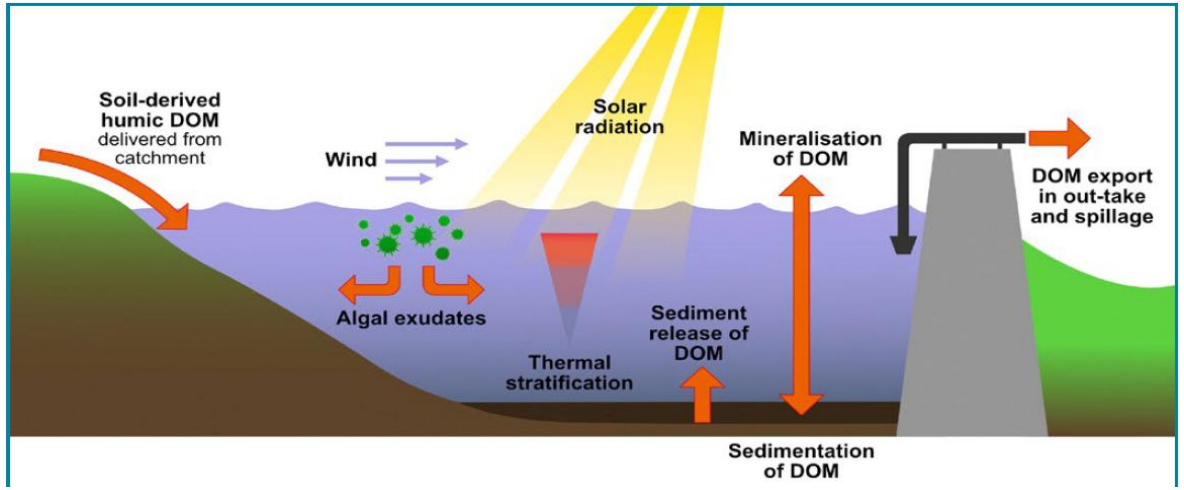
Using zeta potential to tackle the NOM challenge in Scotland

281 Raw Water Sources	224 Water Treatment Works	943 Water Storage points	49,002 km of pipe work	275 Water Supply Zones

- Coagulation/Media Filtration account for 40% of our asset base, but 90% of our water supply
- 85% of catchments supplying us with water contain organic rich soils

Coagulation

We charge neutralise - our raw waters are typically charge loaded…







Our Catchments are predominantly characterised as upland Carbon rich from land-based plants and soils (hydrophobic)

- plant litter from grasslands and forests – typically high in colour, with a high negative charge density…
- typically, produce more DBP's per mg of carbon - in the early 2000's Scottish Water had 575 THM exceedances.

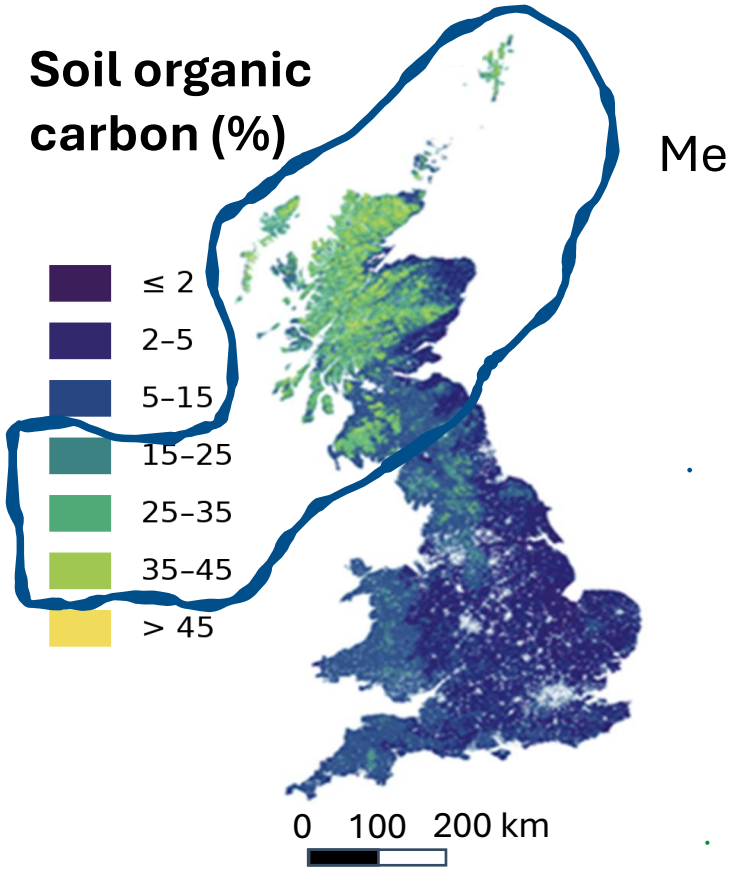


Colours can peak @ 700 Hazen
TOC @ 50mg/l
(25mg/l is pretty standard stuff…)

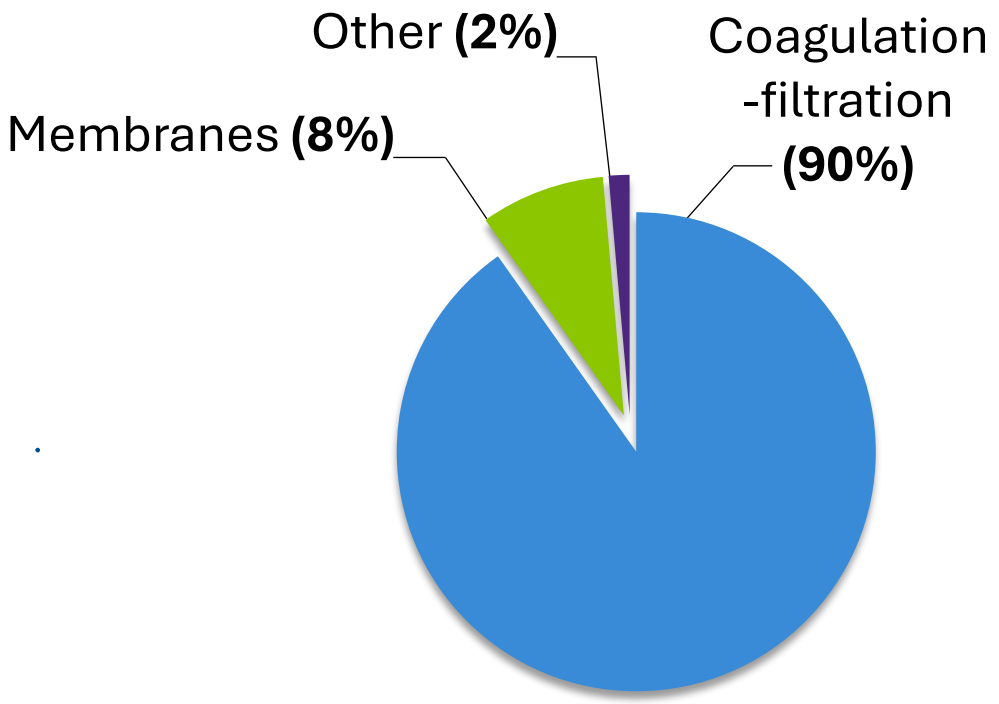


SW Internal
General

Organic carbon defines our treatment choices



Leaching of organic carbon from soil means routinely **high DOC** (> 25 mg/L) in surface water sources



Volume of drinking water produced by WTW type

Coagulation is our primary approach to organic matter removal

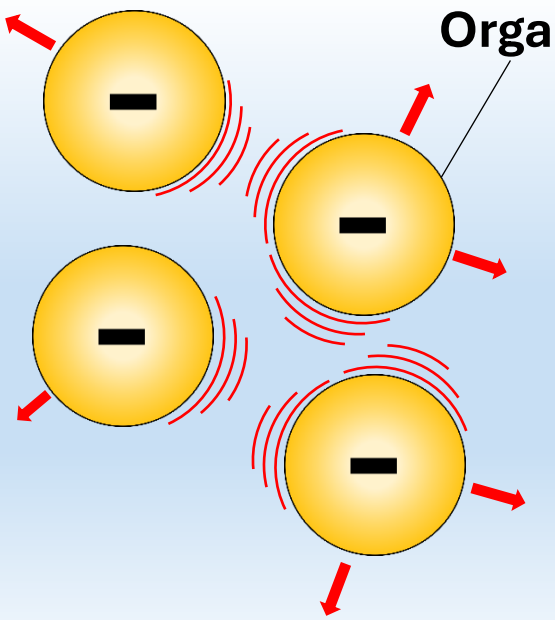
70 – 90%

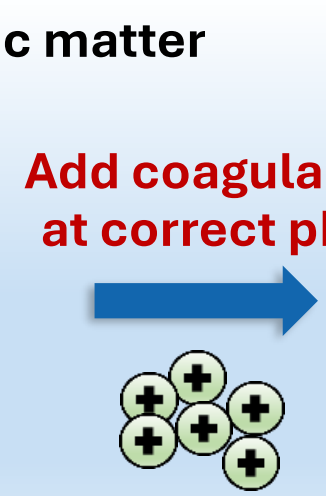
typical DOC removal rate at our conventional WTWs

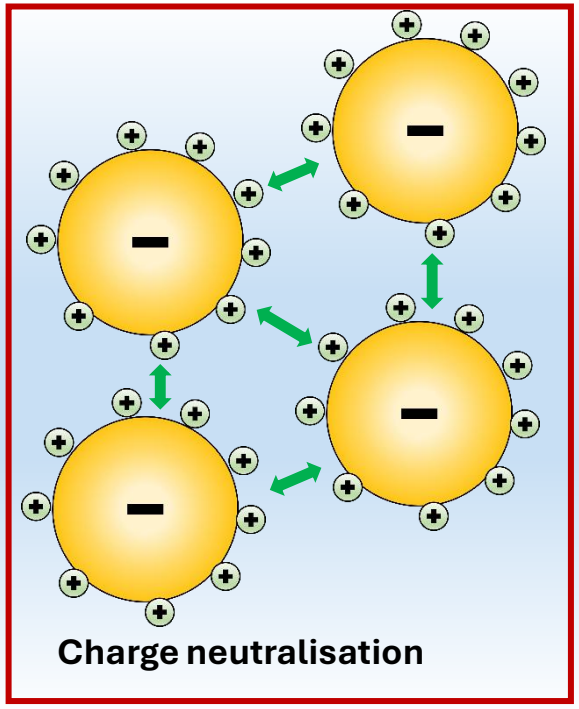
High DOC removal rates can be achieved with coagulation, due to high organic matter aromaticity/hydrophobicity.

Mahmood, S., Wilebore, B., Jenkins, R., Willis, K. J., Macias-Fauria, M., & Ebrahim, S. M. (2024). A High-resolution Soil Organic Carbon Map for Great Britain. Sustainable Environment, 10(1)

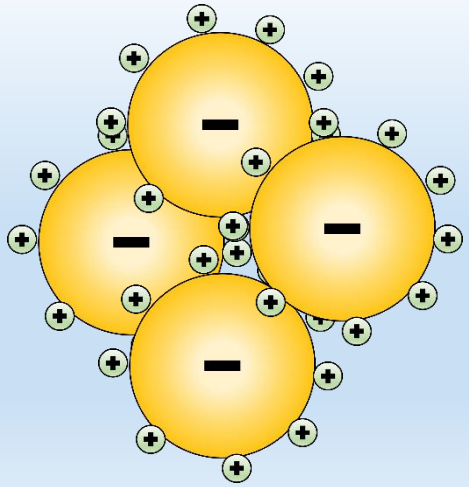
Zeta gives insight into our coagulation processes













Zeta below -5 mV

Measure zeta potential at this stage, just after coagulant addition and rapid mixing.

Zeta above +3 mV

Increase coagulant dose

Between **-5 and +3 mV** offers best performance

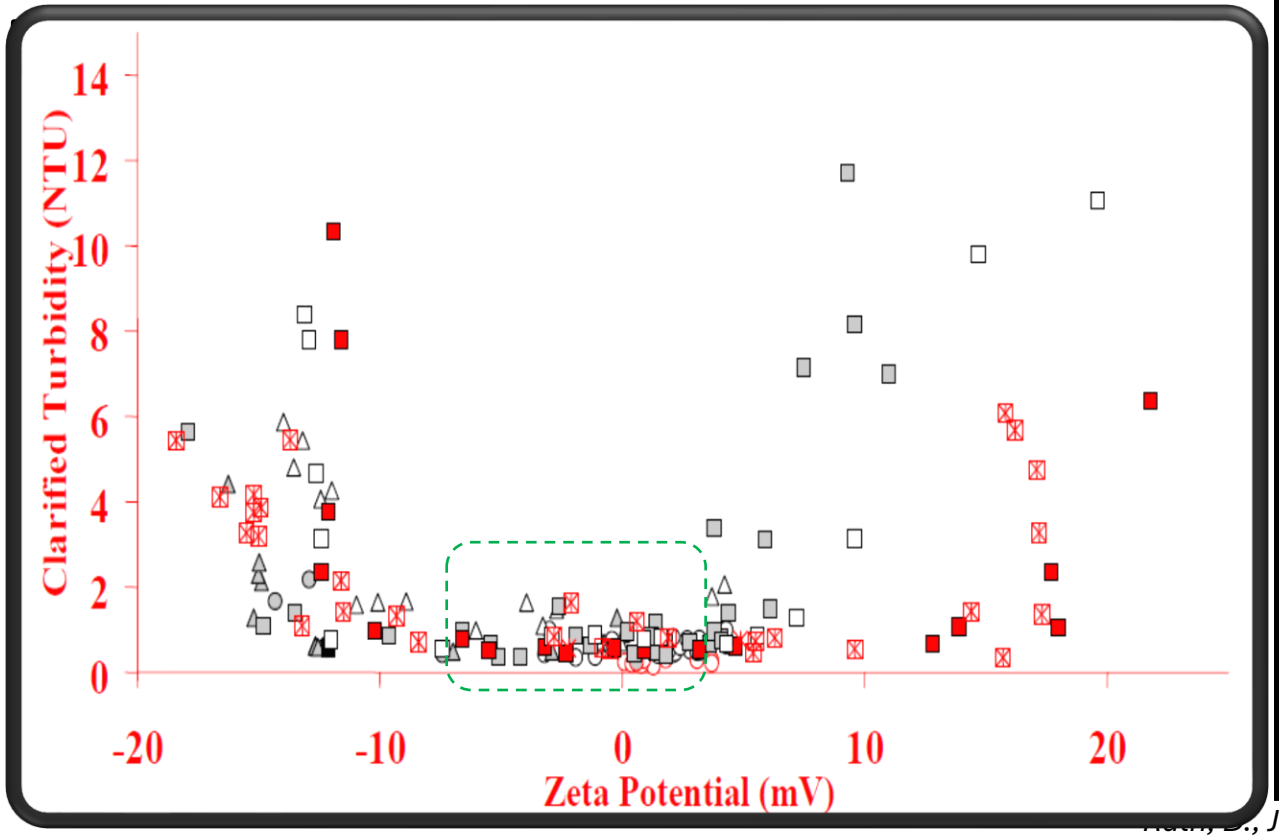
Reduce coagulant dose

Getting zeta right improves our plant performance

Advised operational range is -5 to +3 mV

Performance rapidly declines beyond -10 mV

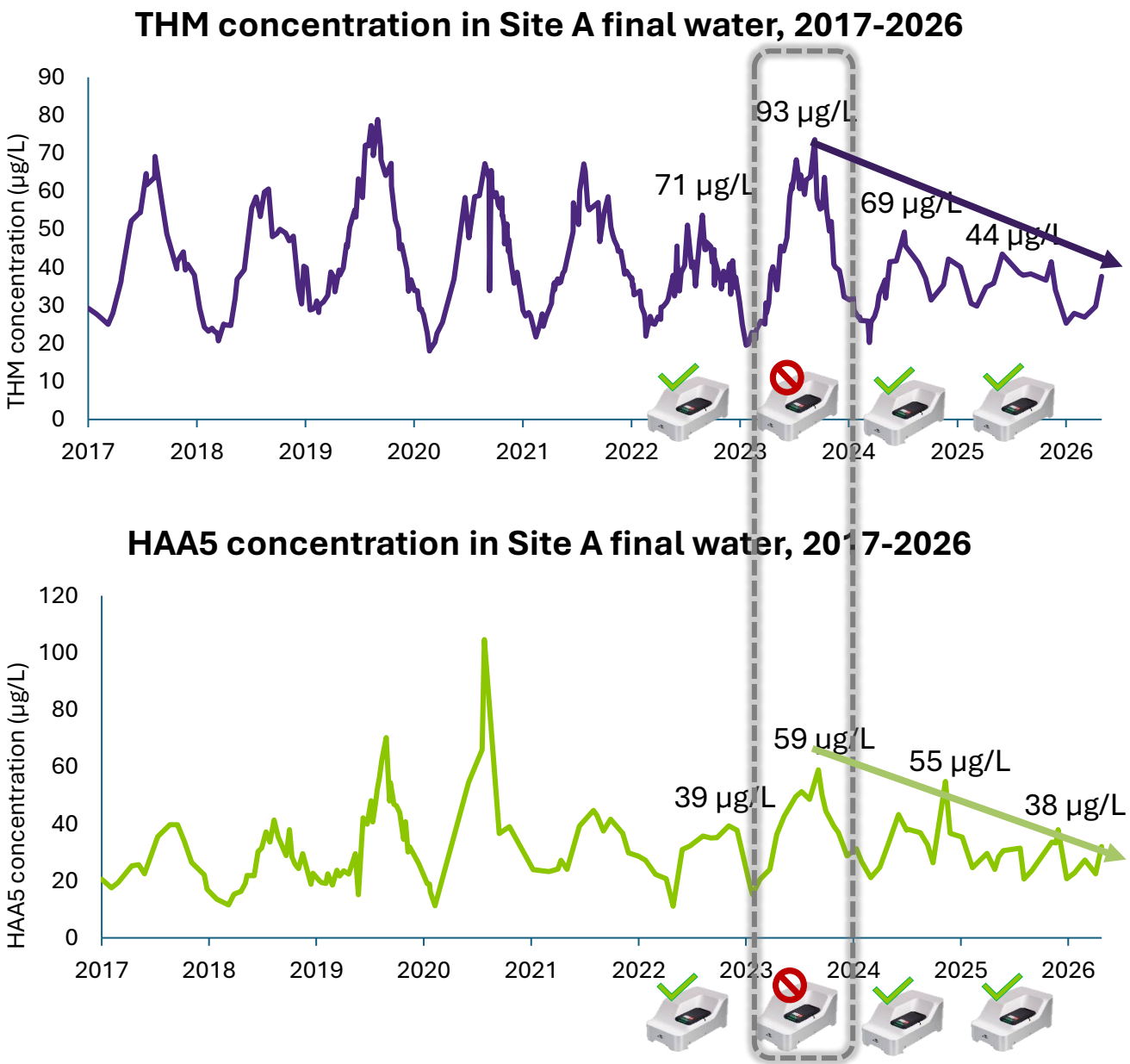
Flocculation improves in this range, lowering clarified/filter turbidity



Zeta Potential (mV)	Water Quality Risk	Action
Above +3	Overdose, potential for re-stabilisation.	Reduce coagulant dose *or* increase coagulation pH.
+3 to -5	Lowest risk, optimal organic matter removal.	No action required.
-6 to -10	Higher risk to water quality.	Increase coagulant dose *or* decrease coagulation pH.
Below -10	**Serious** risk to water quality.	

Jefferson, B., Pereira, R., Moore, G. and Jarvis, P. (2026) 'Charge measurements for optimised NOM characterisation and removal by coagulation', Journal of Water Process Engineering, 86, 109916.

Getting zeta right reduces DBP levels



Site A is a conventional coagulation/filtration site using alum

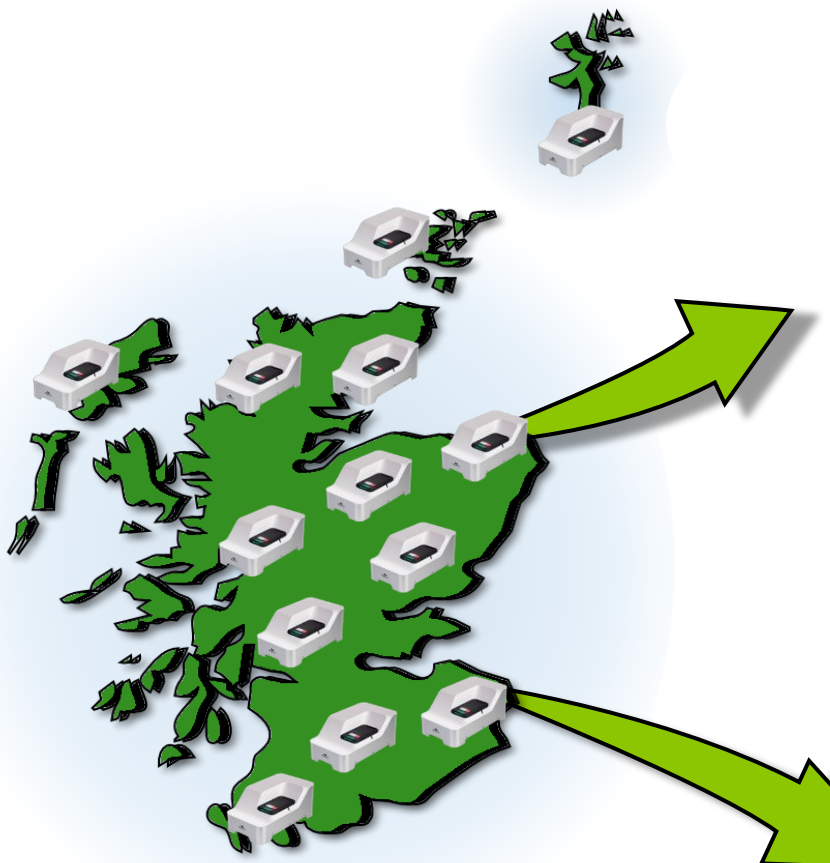
Zeta potential used for coagulation control in 2022 and 2024-onwards, **not 2023**

Algal-impacted raw water with seasonal DOC variation between 5-12 mg/L

Consistent DOC concentration in raw water across period of study

THM and HAA concentrations reduced in final water when zeta potential used for control

Adoption of zeta offers multiple benefits



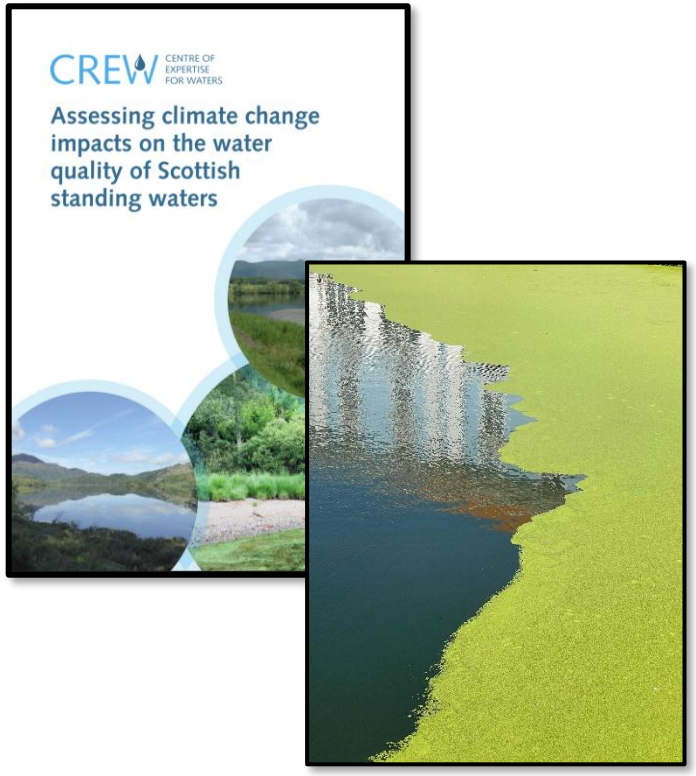
Over 50 sites now use zeta to manage coagulation

3 THM Exceedances in last 4 years

Zeta has played a role in improving DBP compliance



Fault-finding during raw water quality incidents/equipment. Failure resolution is expedited



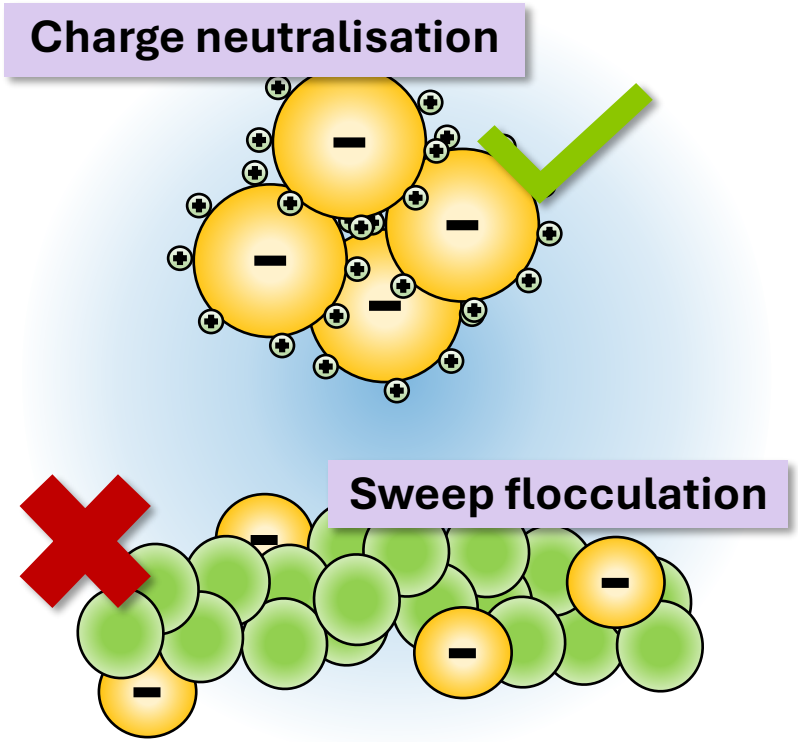
Zeta potential analysis helps to mitigate impact of 'invisible organic matter' during algal blooms

May, L., Taylor, P., Gunn, I.D.M., Thackeray, S.J., Carvalho, L.R., Hunter, P., Corr, M., Dobel, A.J., Grant, A., Nash, G., Robinson, E. and Spears, B.M. (2022) Assessing climate change impacts on the water quality of Scottish standing waters. CRW2020_01. Scotland's Centre of Expertise for Waters (CREW).

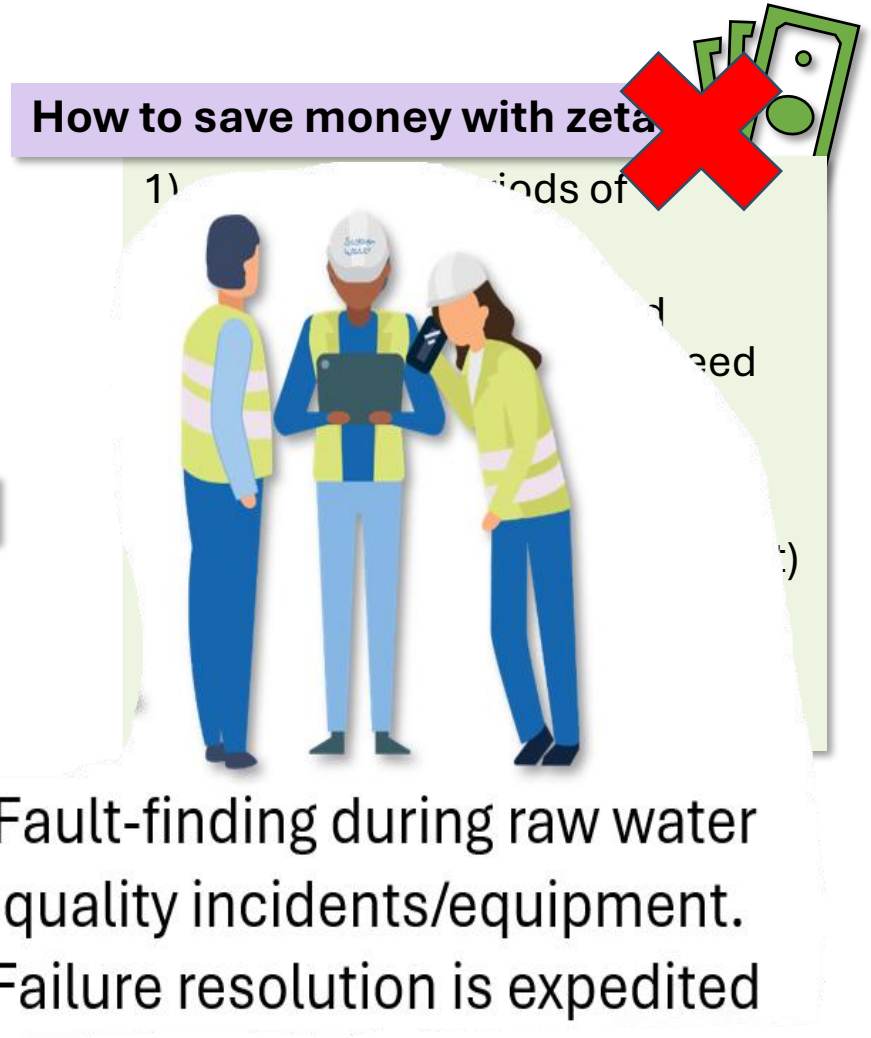
Limitations for control and cost-saving



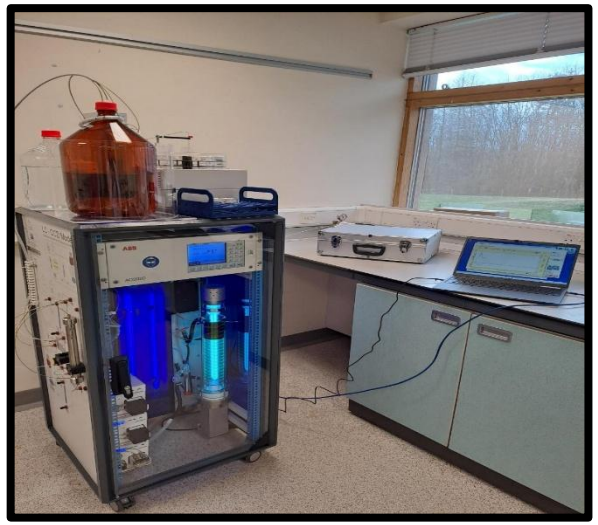
Currently only available as a benchtop analyser – no auto dosing control

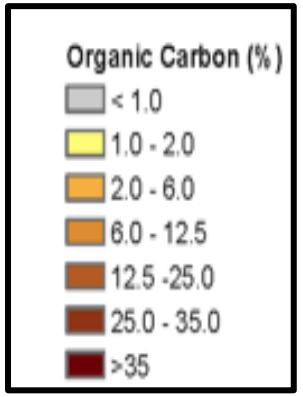


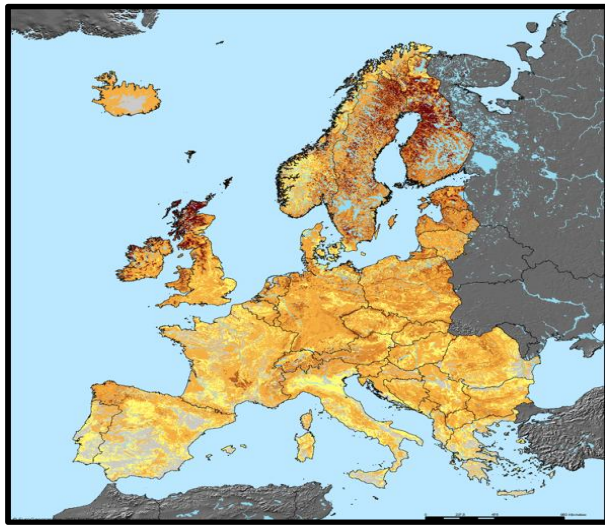
Zeta does not offer th same level of insight in sweep flocculation processes



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Using LC-OCD to enhance our organic matter understanding

LC-OCD-OND-UV

- Liquid chromatography organic carbon detection – organic nitrogen detection – UV_{254} absorbance

SW Internal
General

Why do we characterise NOM?

NOM is a complex mixture of thousands of organic molecules.



Natural Organic Matter (NOM)

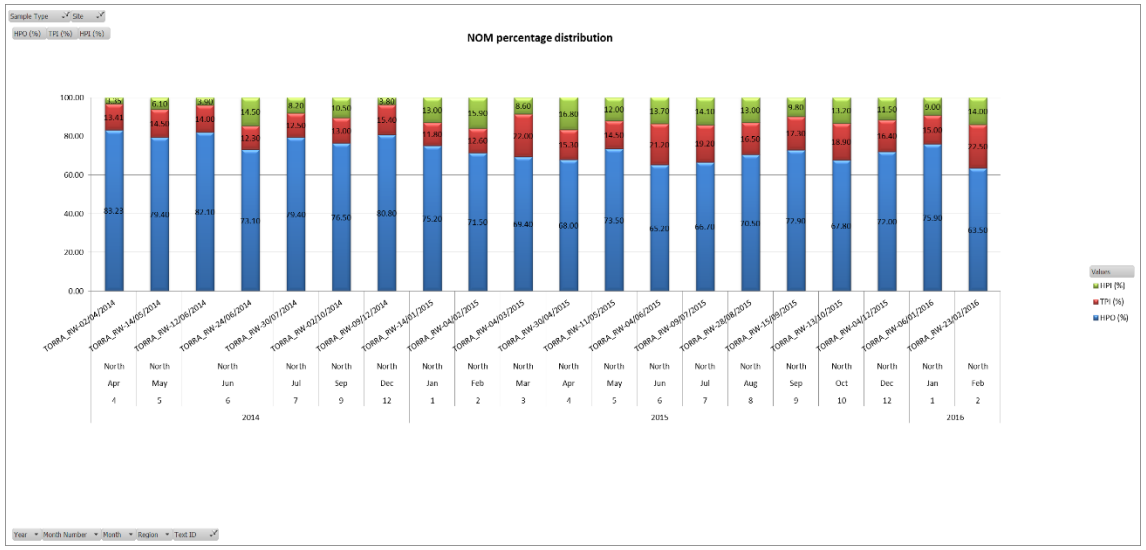
- Charge → **Coagulation Chemisty?**
- Bioavailability → **Biostability?**
- Hydrophobicity → **Susceptibility to Treatment?**
- Molecular weight → **Process selection?**
- UV absorbance → **Fast, can we ‘see’ it analysis**
- Reactivity → **DBP’s**

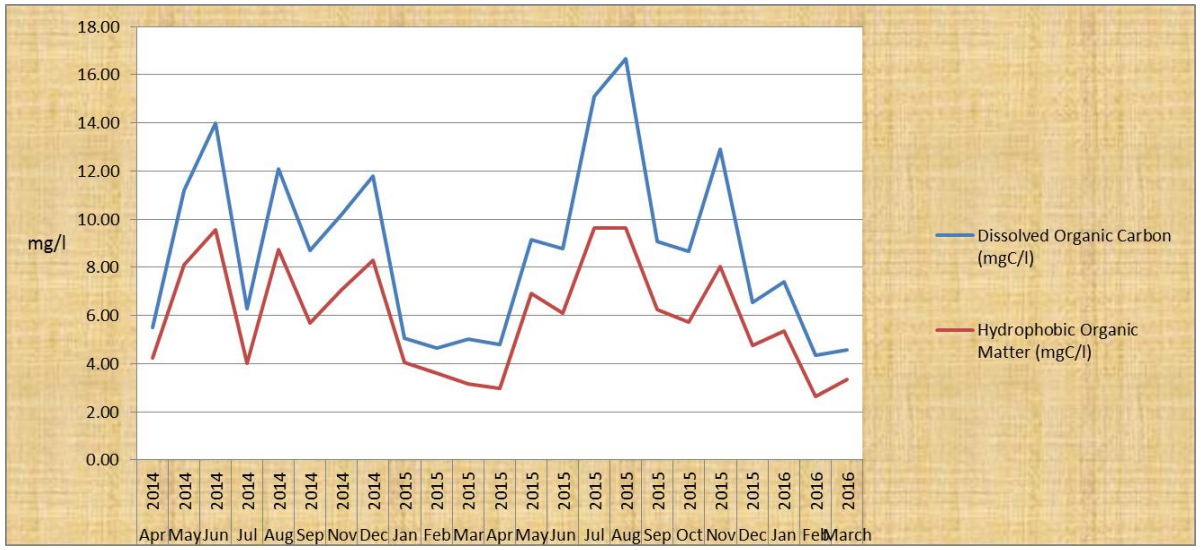
DOC alone is not good enough to understand treatability and risk

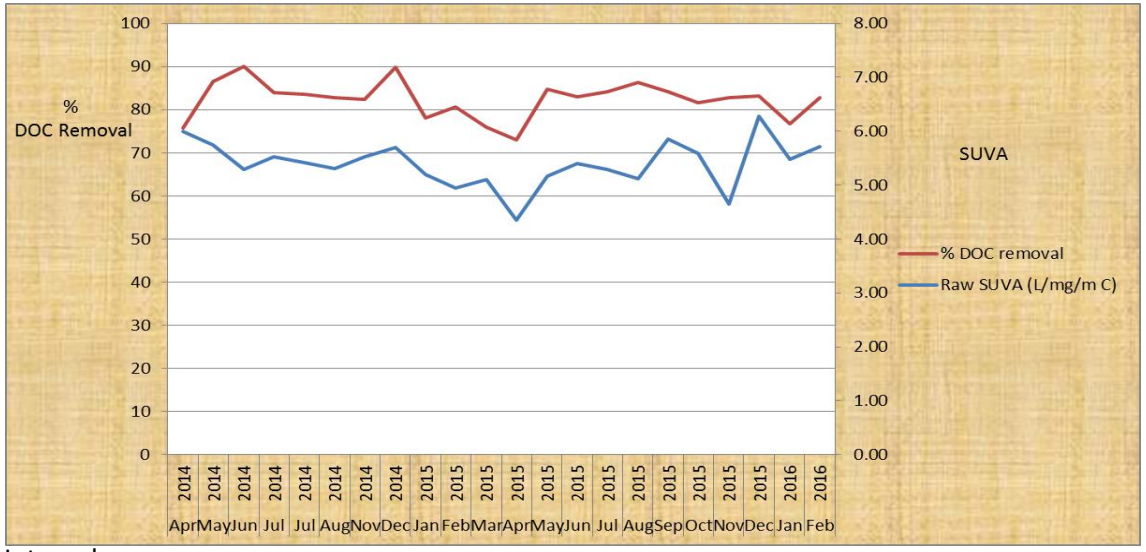
SW Internal
General

How we historically characterised NOM?

10 years of XAD Fractionation – monthly analysis of our high-risk sites







Aspect	Average	Max	Min
General Hydrophobicity of Raw Waters (%)	70.84%	85.92%	27.61%
General Hydrophilicity of Raw Waters (%)	15.62%	54.15%	1.15%
General THM-FP Raw Waters (ugTHM/mgC)	120ug/l	265ug/l	46ug/l

WTW Seasonal Variation in Raw Water DOC (mg/l)	7.9mg/l	15.6mg/l	4.1mg/l
WTW Seasonal Variation in Raw Water Hydrophobicity (%)	26.75%	33.86%	15.88%
WTW Seasonal Variation in Raw Water Hydrophilicity (%)	19.96%	30.60%	14.07%

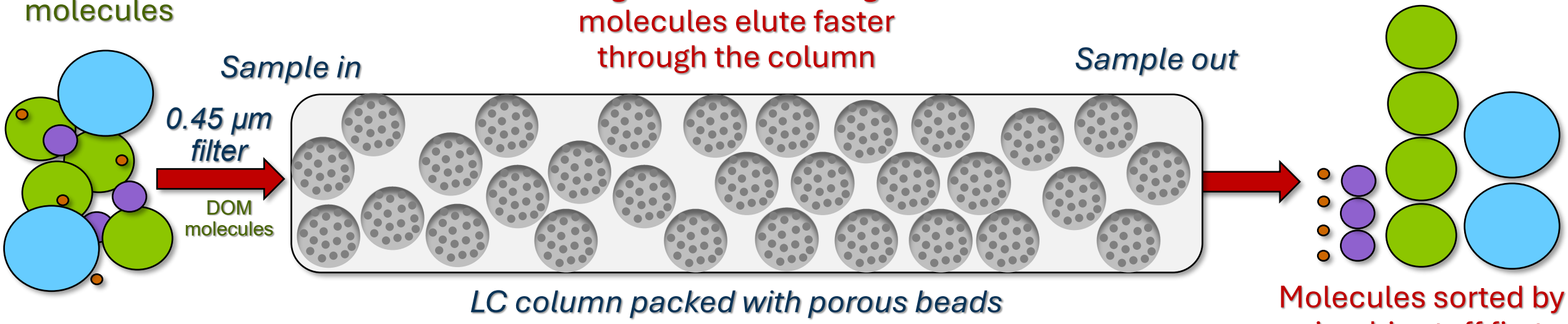
% DOC Removal	72%	90%	38%
% Hydrophobic Removal	80%	90%	44%
% Transphilic Removal	73%	83%	50%
% Hydrophilic Removal	44%	55%	36%

SW Internal
General

Since January 2026, we've introduced LC-OCD-ON

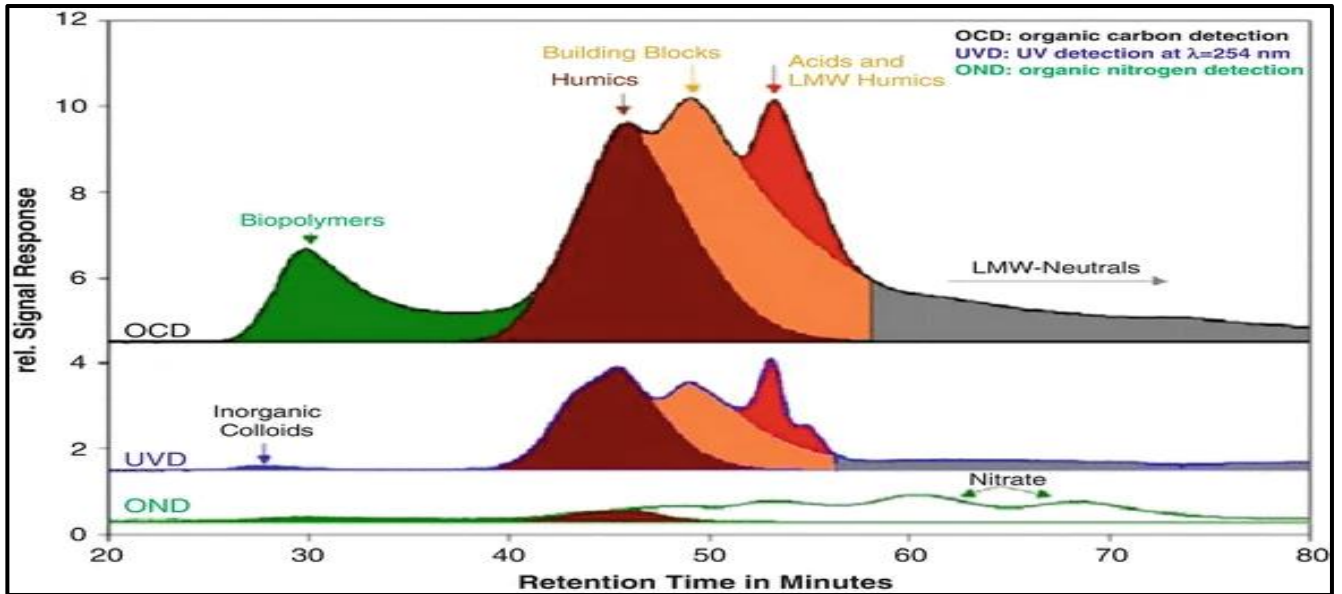
NOM molecules

Larger molecular weight molecules elute faster through the column



This stream of molecules, sorted by size, is then 'seen' by three detectors:

1) UV_{254} detector
2) Organic carbon detector
3) Organic nitrogen detector



SW Internal General

What do the fractions tell us?

Biopolymers

- Algal/microbial sources
- Large molecules
- 70-90% removal with coag
- Membrane fouling

Humic substances

- Dominant fraction in our source waters
- Highly UV_{254} absorbing
- Over 80% removal with coag
- Largest THMs and HAAs potential

Building blocks

- Breakdown of humics
- 30-60% removal with coag
- Seems to form fewer DBPs than humics

Low molecular weight acids

- Present in very low quantities in our source waters
- Not likely to be a major factor in treatment/DBP risk

Low molecular weight neutrals

- Very poor removal rate with coag (~20%)
- Lower risk for THMs & HAAs

- **Treatability**
- **Performance Assessment**
- **DBP Risk**

SW Internal
General

Early LC-OCD benefits

LC-OCD has 4x higher capacity for samples than existing XAD resin method

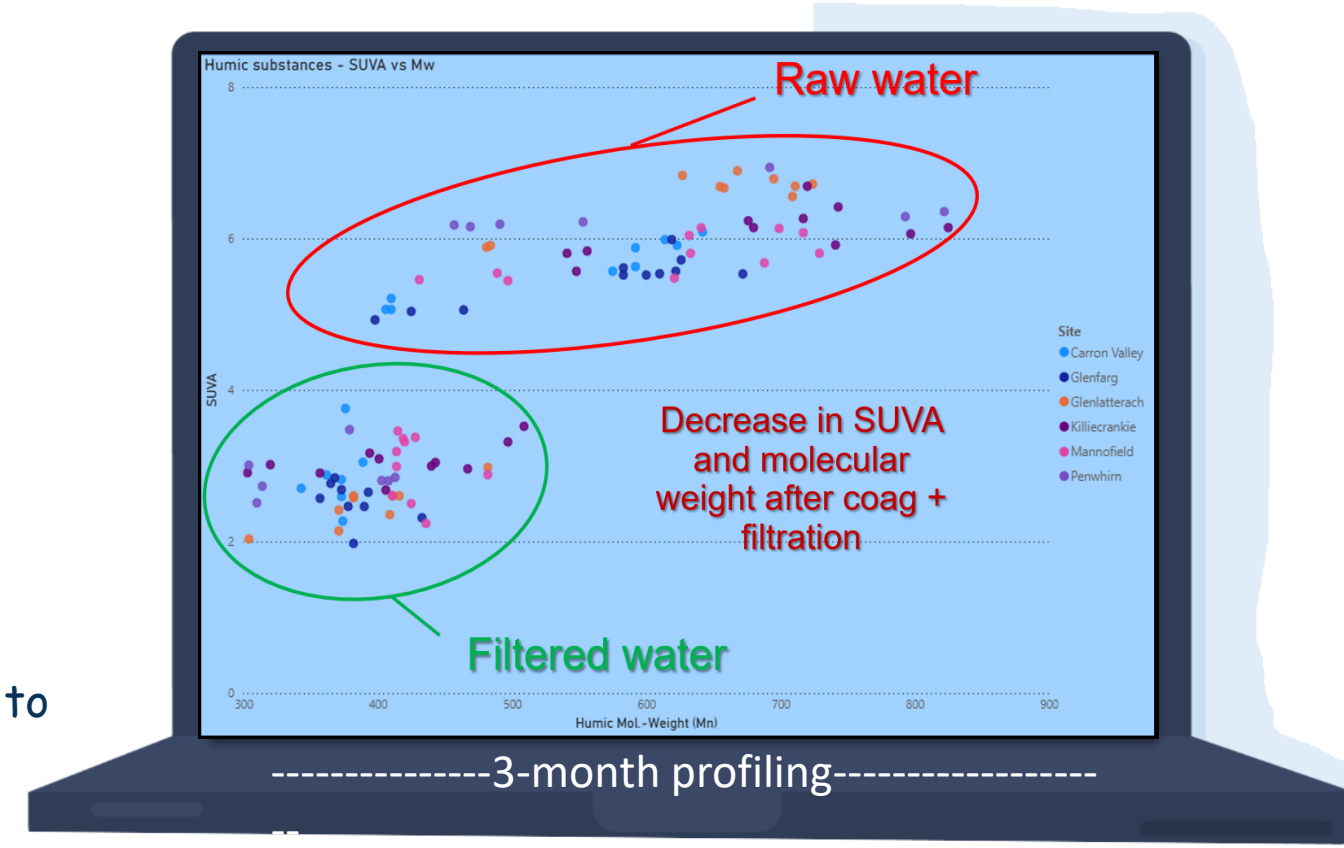
More sites, more frequent sampling, better resolution/profiling/faster identification of change

(c.160 samples per month against the c.40 previously)

From monthly to (at least) weekly for high-risk WTWs

Higher sensitivity and accuracy

Rapid method of ascertaining short/medium term risks to Water Quality, which can be integrated into our Risk prediction tools



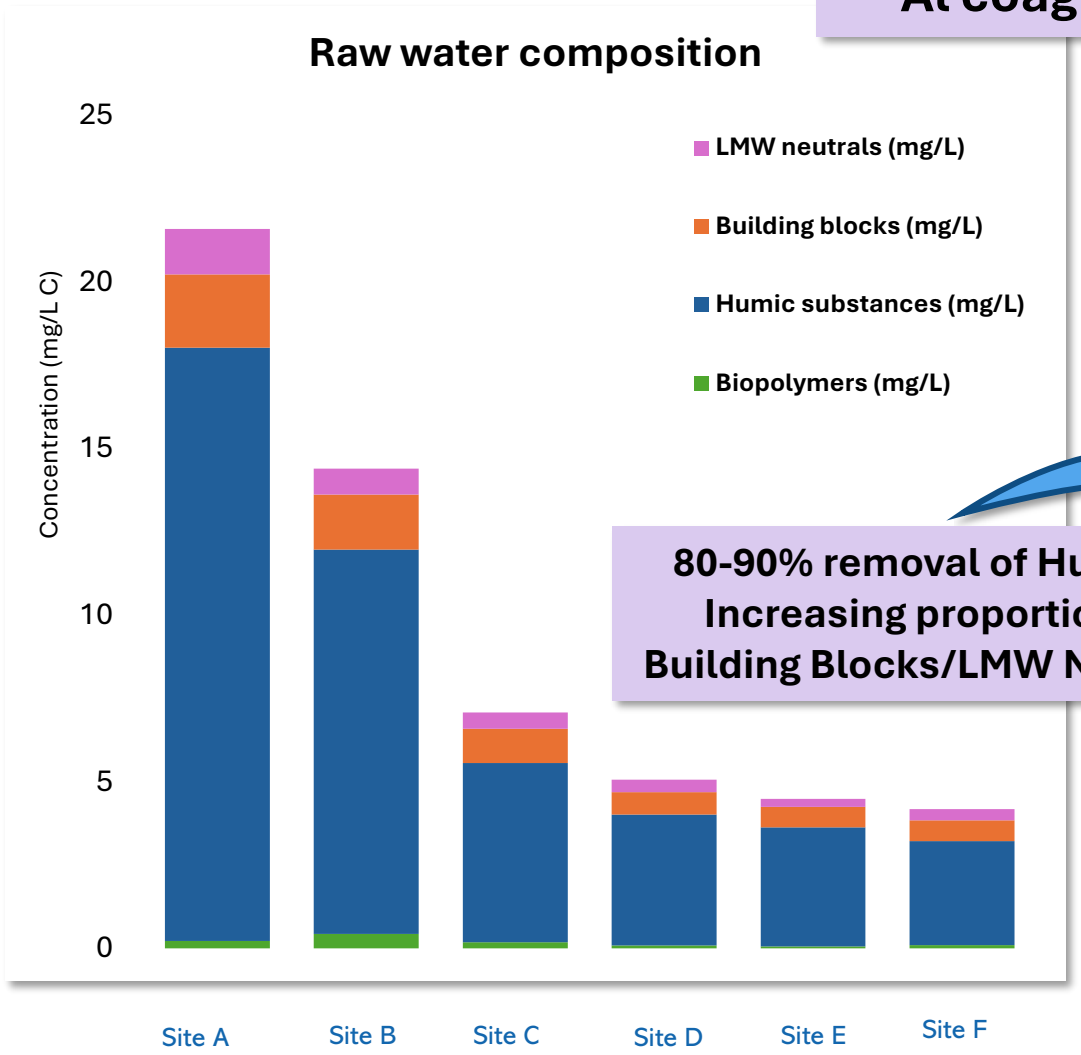
LC-OCD measures UV absorbance and DOC in the same analysis run - meaning we can calculate SUVA – generic treatability.

It calculates molecular weight for humic substances, showing interesting trends in removal characteristics.

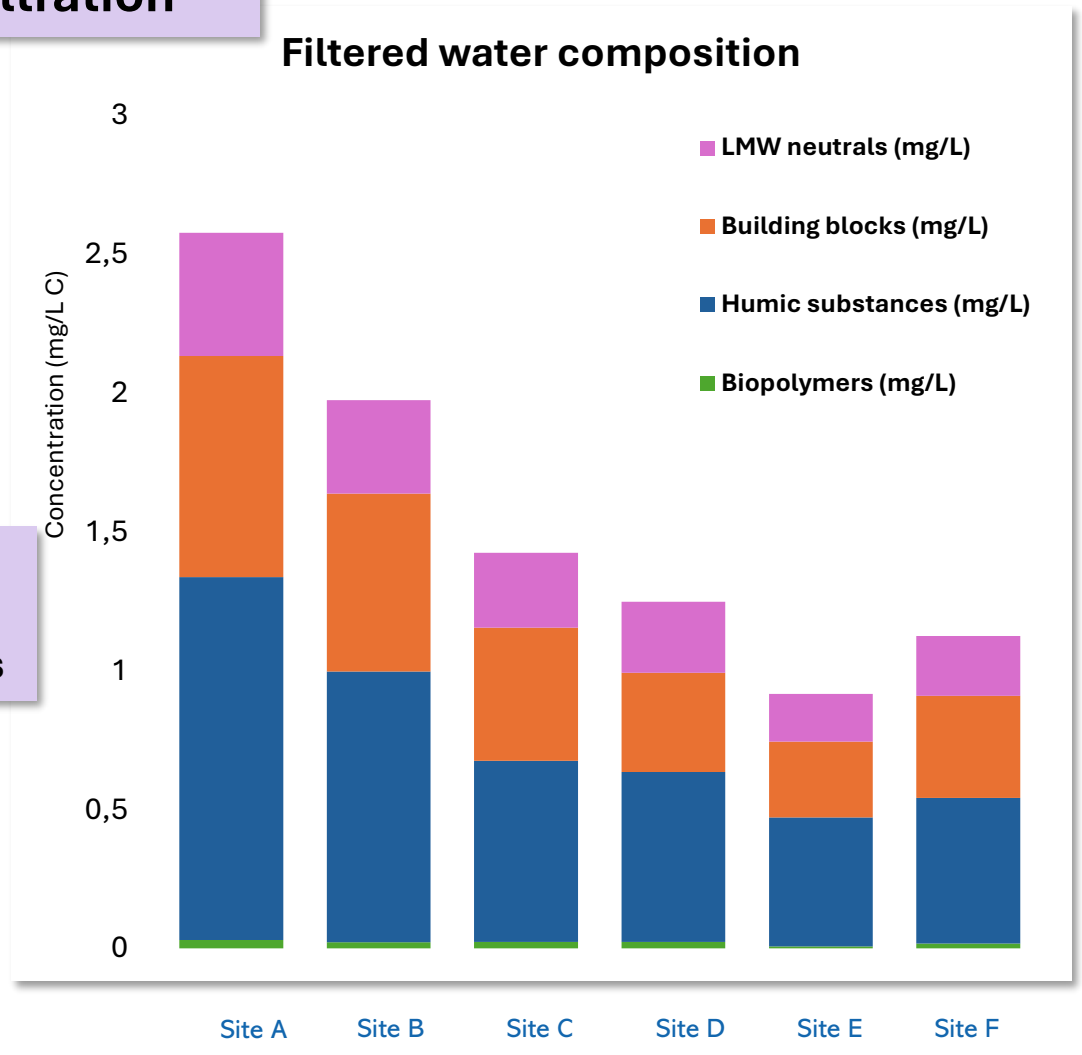
SW Internal General

What is LC-OCD telling us?

Al coag and filtration



80-90% removal of Humics. Increasing proportion of Building Blocks/LMW Neutrals

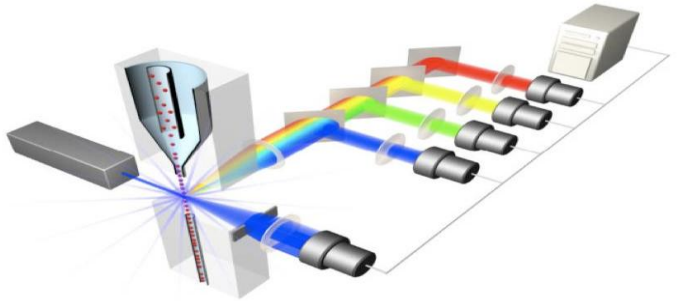


SW Internal
General

What are we using the data for?

Activity	Knowledge
Monthly/Weekly monitoring of raw and filtered water from high DBP-risk sites (samples taken same day, same time)	Identify sub-optimal treatment performance and fix before a failure occurs. Assess longer term changes related to climate and catchment
High frequency monitoring (x2-3 weekly) of select sites to understand impacts of algal blooms, extreme weather and reservoir changes	Improve understanding of what environmental changes mean for water quality risk + which interventions work best (process optimisation)
Measure efficacy of different treatment trains: MIEX, ceramic membranes, Fe vs Al coagulants, GAC etc.	Provide evidence to strategy/optioneering teams for efficient/ effective treatment upgrades
Membrane integrity trials. Highly sensitive to molecular weight – catch a failing membrane before our traditional monitoring methods?	Early warning system for membrane monitoring – tie into existing data to pre-empt failures

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Bactosense for enhanced Filtration assessment



WTW Bactosense benefits

Great for uncovering the poorest performing inter-stage locations for optimisation/investment

Great for clearly highlighting generic fluctuations in performance (seasonal, longer term climate/catchment & demand based)

Great for evidencing/embedding best practice operational activities

Great for detecting membrane breaches







10 units available on backboards for process science investigations

We use Flow Cytometry as a routine Operational Baseline Monitoring Tool (All WTW Finals and Distribution Storage Points are sampled weekly in our central Laboratories)

& Bactosense for Process SInvestigations

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General

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Developing a Water Supply Growth & Learning Framework



Technical Learning & Skills Breakdown within the LPT's

Technical Learning

- Raw Water Quality
- Coagulation
- Filtration
- Disinfection
- Specific Parameters of Note
- Site Tasks & Process Control

Transferable Skills

- Root-Cause Analysis
- Problem Solving & Decision Making
- Coaching
- Collaboration
- Communication
- Time Management
- Emotional Intelligence

Digital Skills

- Digital Task Schedules
- Power BI
- Excel
- Apps
- Data Management & Analysis

Structure



Risk Awareness

- TOMS
- Disinfection Strategies
- Operational Contingency Planning
- Treatment Control
- Water Risk Assessment Platform
- Water Operational System Plans

Learning Vehicles

- ORCA (Local Coaching)
- WTF & OMS (Local Coaching)
- SEaL (Central Academic)
- WSLL (On-Line Digital)
- Cornerstone (On-Line Digital)
- LPT's (Baseline Best Practice)
- TBT's (Last Resort!)

Auditing

- Management Systems (Yearly)
- ISO9001 & 55001 (ad-hoc)
- EU Skills Auditor (5 yearly with a mid-point 'check-in')

Successfully implemented over 18months

Last 12 months…

1

>60 Coaching Sessions (ORCA), 10 Academic Sessions (SEaL), 6 Dedicated Support Sessions (WTF/OMS)…

2

c.1500 ‘seats’ filled across all Events

3

Competent Operator Scheme Certified by EU Skills

Process confirmed in Conformance with ISO Requirements (9001 & 55001)

Multiple Process Audits completed with minimal improvement actions noted



Engagement and openness to learn has genuinely been outstanding…

SCOTTISH WATER: WATER QUALITY GROWTH & LEARNING

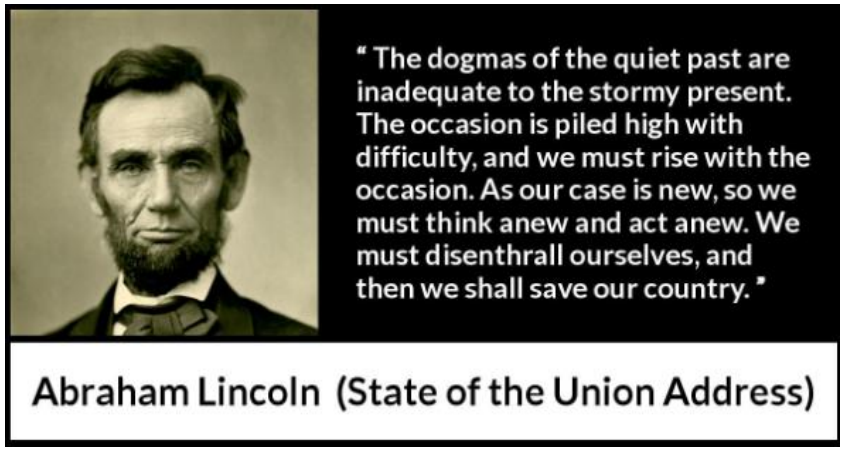
Empowering Action, Growth & Learning Excellence

Developing people resilience

Promoting inclusion and collaboration

Science Excellence and Learning

Supporting a flourishing Scotland





Supporting personal wellbeing

Paul Weir

Learning & Lean Operations Manager
Scottish Water

Contact:
paul.weir@scottishwater.co.uk

Paul Weir@ LinkedIn

Operation Resilience, Coaching & Awareness

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Encouraging solution-based conversations

Building for a resilient future

Scottish Water: A Learning Organisation



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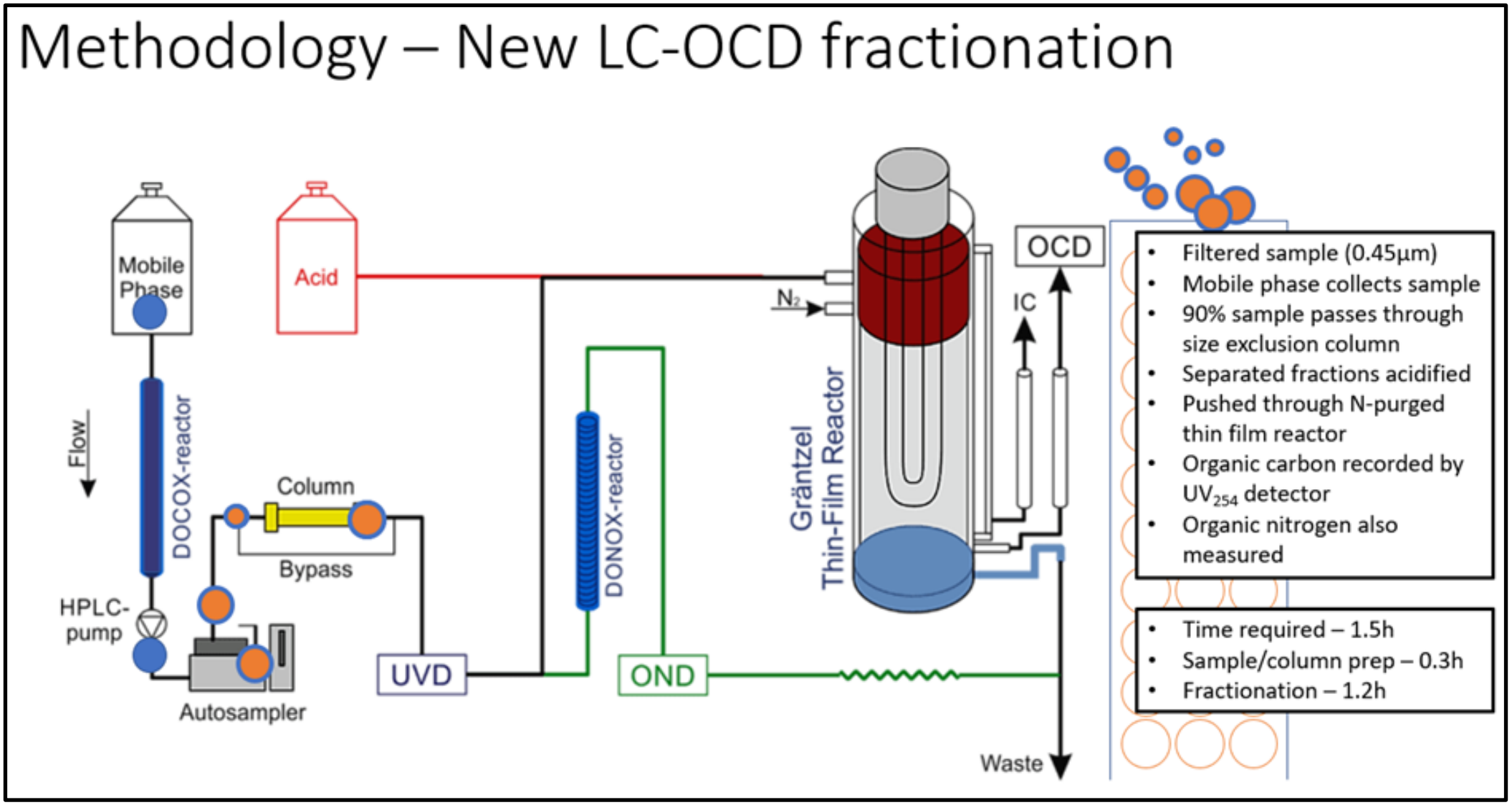
Appendix 1: NOM fractions explained…..

Fraction	*What are they?*	*How does it help us?*
Biopolymers	Biopolymers are largely understood to be low-UV absorbing, high molecular weight, low charge polysaccharides/protein complexes.	Coagulation/flocculation gives a high rate of removal. Tells us about treatability, potential algal activity, membrane fouling potential. Biopolymers won't tend to show up on UV/colour instruments, detecting them here allows us to see the proportion of 'invisible' organics. Known precursor for THMs/HAAs.
Humic substances	Humic substances are highly UV-absorbing species, coming from a range of sources. These form the bulk of the NOM in our raw waters.	For our waters, coagulation/flocculation gives a consistently high rate of removal. Provides info on treatability, changing composition of HS helps us understand our seasonal risk. Essential to classifying and understanding raw water sources. Known precursor for THMs/HAAs.
Building blocks	These can be considered as smaller breakdown products of humic substances. Highly variable regarding UV absorbance.	Not great removal rates via coagulation/filtration. This fraction can increase at the expense of the previous HS fraction, if the sample is subjected to energy input (e.g. ultrasonification). Therefore, it could tell us valuable information on the breakdown processes occurring in our raw water sources.
Low molecular weight acids	Small, organic acids, can absorb UV.	No significant concentration of these have been found in our raw/filtered waters. Known to have high bioavailability, so could be associated with microbial activity in filters/tanks/networks.
Low molecular weight neutrals	Contains smaller, low charge alcohols, aldehydes, ketones, amino acids etc. Very little UV absorbance.	Low removal via coag/filtration expected. As a fraction with low removal efficiency, gives insight into expected DOC residuals. Studies have shown these are not as reactive in forming THMs/HAAs.
Hydrophobic carbon (HOC)	HOC is explained by some compounds not eluting fully, instead 'sticking' to the column via hydrophobic interactions. Calculated by subtracting the sum of the other 5 fractions from the DOC figure obtained by running the bypass sample.	Decent, if variable removal rate via coag. More difficult to define than the other fractions, but gives an insight into larger/more hydrophobic compounds that may be present.

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Appendix 2: LC-OCD process



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