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5th International Workshop on High Temporal Resolution Water Quality Monitoring and Analysis

The James Hutton Institute, Aberdeen, Scotland
17th-19th of June 2024



River Dee, Scotland
www.glendell.co.uk

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Scientific Description

This meeting follows a series of scientific workshops previously held in Uppsala (2021), Clonakilty (2018), Sandjberg (2016), and Magdeburg (2014). These workshops provided a much-needed forum for sharing experiences and establishing best practice in application of sensor technology in water quality studies, sharing knowledge of hydrochemical processes in diverse catchments and stimulating future collaborations between the workshop's participants. High-resolution water quality technology provides opportunities for conducting joint experiments in different catchments and establishing long-term water quality experiments and monitoring networks which bridge the gap between regulatory monitoring, e.g. for compliance with the Water Framework Directive, and short-term research monitoring efforts in single catchments. In this way, high-resolution water quality monitoring can lead to further advancements in catchment science, by integrating understanding of solutes and particulates behaviour across spatial (from stream reaches to stream networks and between catchments) and temporal scales (from storm events, seasons to decades), and their extrapolation beyond single catchments. The findings from the last workshop [were summarised in a joint publication](#).

The 5th in this series of workshops will explore recent technological and scientific advances in water quality measurements allowing for high-resolution determination of chemicals in water with a range of instruments deployed in situ (optical sensors, passive samplers, wet-chemistry analysers, lab-on-a-chip) and remote sensing. The workshop will explore how these new technologies, and the new insights they enabled, are utilised to improve the effectiveness of water management and mitigation efforts.

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Organising Committee

Dr Miriam Glendell, Research Leader, James Hutton Institute
Camilla Negri, PhD candidate, James Hutton Institute
Dr Kerr Adams, post-doctoral researcher, James Hutton Institute
Dr Rachel Helliwell, Director, Hydronation International Centre
Prof Marc Stutter, James Hutton Institute
Dr Magdalena Bierzoza, Associate Professor Swedish University of Agricultural Sciences
Dr Peter Hunter, Associate Professor, University of Stirling

Outline topics

New advances in high-resolution water quality monitoring - biological monitoring, nutrients, sediments and emerging contaminants; innovative low-cost solutions

Best practice in high-temporal resolution monitoring – experimental design, data handling and assimilation, quality control

New approaches to data integration across different spatial and temporal resolution, remote sensing, modelling, and AI for improved process understanding

New understanding for management and decision support – regulatory monitoring, stakeholder engagement

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The James Hutton Institute

James Hutton Institute research is focussed on the understanding of key global challenges, including food, energy, and environmental security, and on developing effective technological and management solutions. The Institute operates from two sites in Scotland in Aberdeen and Dundee. With more than 500 scientists and support staff, Hutton is one of the biggest research centres in the UK and one of the Scottish Government's main research providers in environmental, crop and food science.

James Hutton (1726 – 1797) was a leading figure of the Scottish Enlightenment, an 18th century golden age of intellectual and scientific achievements centred on Edinburgh. He is internationally regarded as the founder of modern geology and one of the first scientists to describe the Earth as a living system. His thinking on natural selection influenced Charles Darwin in developing the theory of evolution.

Travelling to Aberdeen



Aberdeen International Airport is located 7-miles north-west of the city and is accessible by:



Bus – approximately 30-minutes in normal traffic for a fare of about £4 to the city centre.



Taxi - taking approximately 15-minutes in normal traffic for a fare of around £20 to the city centre, check **Rainbow City Taxis** <https://www.rainbowcitytaxis.com/>



Flights to Glasgow International Airport and Edinburgh Airport can be considered, however, connecting buses and trains will be required to travel to Aberdeen.

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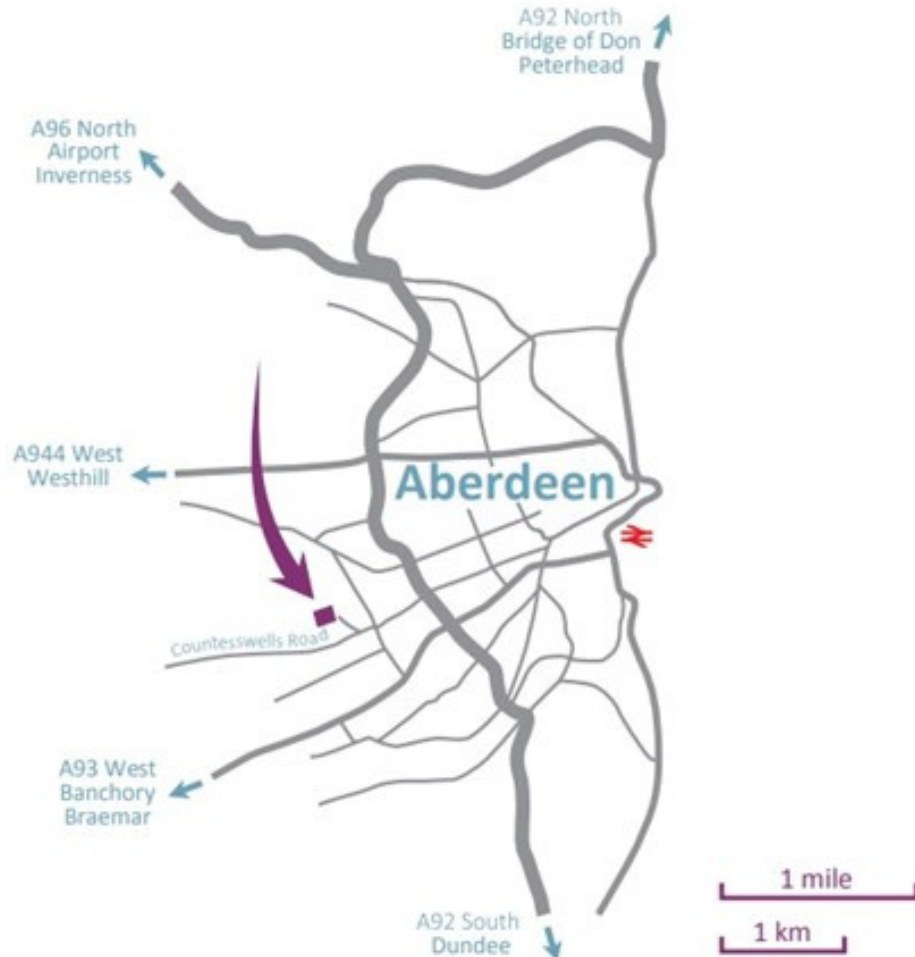


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Travelling to The James Hutton Institute





The James Hutton Institute is accessible from the city centre using the 11A or 15 bus. No. 19 also stops within a walking distance of the Institute. You can check the schedule via [First Bus](#), or download the First Bus app.

Taxis are also available from Union Street and the Train Station. Please note uber is not supported in Aberdeen.



Staying in Aberdeen

There are a variety of places to stay in Aberdeen, below are options both close to the James Hutton Institute and in the City Centre:

-  **The Palm Court** is closest to the James Hutton Institute and where the conference dinner will take place. However, rooms are limited. Use the discount code CORPORATE.
-  **Great Western Hotel** - 1.6 miles from the James Hutton Institute
-  **Holiday Inn Express Aberdeen City Centre** - 2.2 miles from the James Hutton Institute
-  **Leonardo Hotel Aberdeen City Centre** - 2.6 miles from the James Hutton Institute

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Guidelines for presenters

To ensure smooth running of the conference, we kindly ask our conference speakers to keep to the following times:



Highlight speaker: 15 minute talk + 5 minutes Q&A



Session speaker: 10 minute talk + 2 minutes Q&A

Please use Powerpoint widescreen format. We kindly ask that presentations are sent to hrmw@hutton.ac.uk no later than 18:00 GMT on Thursday the 13th of June 2024.



Poster presenters: Please ensure posters are A0 sized and portrait. All poster presenters will be asked to provide a 1-minute poster pitch to the audience before the poster session begins.

Field Trip

We will meet at the James Hutton Institute in front of the main entrance on Wednesday 19th of June at 08:45, the bus departing at 9:00 from the rear of the building. Packed lunch will be provided. Be prepared for all weather and uneven ground for walking. The following is required:



Walking boots



Spare socks



Insect repellent



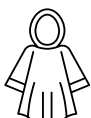
Wellies



Hat/Cap



Checking for ticks



Waterproofs



Suncream



Bottled water

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5th International Workshop on High Temporal Resolution Water Quality Monitoring and Analysis

Programme Outline

17/06/2024		18/06/2024		19/06/2024	
09:30	Arrival, registration, coffee	9:30	Welcome	08:45	Meet at JHI
		9:35	Keynote speaker and Q&A	09:00	Departure for field trip
10:30	Welcome	10:00	New approaches to data integration across different spatial and temporal resolution, remote sensing, modelling, and AI for improved process understanding	09:45	Beltie Burn
10:40	Keynote speaker and Q&A				
11:00	New advances in high-resolution water quality monitoring - biological monitoring, nutrients, sediments and emerging contaminants; innovative low-cost solutions	11:00	Coffee break		
		11:30	New approaches to data integration across different spatial and temporal resolution, remote sensing, modelling, and AI for improved process understanding		
12:30	Lunch	12:30	Lunch	12:00	Packed Lunch and transfer
13:40	Highlight speakers and Q&A	13:40	Highlight speaker and Q&A	12:30	Glensaugh
14:00	Best practice in high-temporal resolution monitoring - experimental design, data handling and assimilation, quality control	14:00	New process understanding for management and decision support		
15:00	Coffee Break	15:00	Coffee Break	15:00	Departure Glensaugh
15:30	Best practice in high-temporal resolution monitoring - experimental design, data handling and assimilation, quality control	15:30	New process understanding for management and decision support	16:00	Return to Aberdeen
16:30	1 minute poster pitches, poster session and networking	17:00	Closing remarks		
			End of the day		
18:00	End of the day	18:30	Conference Dinner		

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Easter Beltie Restoration Site

The Easter Beltie Restoration project returned a straightened agricultural stream to a natural meandering course, to improve habitats for nature and boost climate resilience. The benefits of the restoration are being studied by the James Hutton Institute and Napier University to evaluate the changes in the natural environment. The aim is to greatly increase habitat diversity, so that a much wider range of native species – from plants and insects to birds and mammals – can thrive at the site. The restoration project won the Nature and Climate Action award at the RSPB Nature of Scotland Awards by bringing multiple benefits for biodiversity and climate resilience.

Glensaugh

Glensaugh is managed as an upland livestock farm, just over 1000ha in area, with sheep, cattle and red deer, improved and extensive pastures, moorland, woodland and peatland. The farm has the ambition of becoming a climate-positive farm, tackling the climate and biodiversity crises with transformative farming and technological innovations.

Glensaugh has a fantastic collection of historical baseline data and scientific observation spanning many decades, which is ideal for underpinning research and demonstration of the scale and nature of transformation needed in farming, as well as the significant contribution that the sector can make towards the Government's climate and biodiversity targets. Glensaugh is also a national monitoring centre for the Environmental Change Network (ECN), Cosmic-ray Soil Moisture Observing System UK (COSMOS-UK), and the Defra Acid deposition (UKEAP) network.

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While you're in Aberdeen

The city of Aberdeen is located in North East Scotland and its economy is mostly based on the offshore petroleum industry. It is also known as the “Granite City” for its many Greystone buildings. Aberdeen city centre (Union Street) is also home to a large street art collection that grows larger every year. An updated map of the collection [can be found here](#). We encourage you to network with new and old friends during free time, here are some options for where you can meet:

Landmarks



Marischal College - Monumental Victorian landmark in the city centre



Old Aberdeen - The historic heart of the University of Aberdeen (founded 1495), with buildings dating to the 15th century



Footdee - Historic fishing village located near Aberdeen harbour

Walks



Duthrie Park



Seaton Park



Cruickshank
Botanic Gardens



Aberdeen Beach



Hazlehead Park



Dunnottar Castle
(Stonehaven)

Cafes, Pubs & Restaurants



Figment



Noose & Monkey



Maggie's Grill



Food Story



SASC



Nargile

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Detailed Program Day 1: 17th June 2024

09:30	Arrival at the James Hutton Institute, Registration & Coffee	
10:30	Welcome	Deb Roberts, Director of Science, James Hutton Institute
Theme	New advances in high-resolution water quality monitoring - biological monitoring, nutrients, sediments and emerging contaminants; innovative low-cost solutions	
10:40	Phil Jordan	Physicochemical water quality data frequency: reflections on the highs and lows
11:00	Alasdair Clark	Nanoscale Taste Buds for Monitoring Drinking Water Treatment Sites
11:12	Daniel Ruth	Optimising Water Treatment: Harnessing Online Monitoring for Enhanced Coagulation Control and Improved Drinking Water Quality
11:24	Giovanni Sandrini	Online continuous water quality biomonitoring: an early warning system for pollutants in surface water used for drinking water production
11:36	Elena von Benzon	Hydrobean: a low-cost sonde for citizen science river water quality monitoring
11:48	Oliver Hofmann	Lab Quality Testing in Near-Real-Time? Simply Miniaturise the Lab and Take it to the Water!
12:00	Arno Hooijboer	Field comparison of eight ammonium sensors and analyzers
	Discussion	
12:30	Lunch	
Theme	Best practice in high-temporal resolution monitoring - experimental design, data handling and assimilation, quality control	
13:40	Joachim Rozemeijer	Best practice in high-frequency water quality monitoring for improved management and assessment; a novel decision workflow
14:00	Remi Dupas	What can we learn when high-frequency time series increase in length and number of parameters monitored?
14:20	Shulamit Nussboim	Fate and transport of pesticides and pharmaceuticals in an agricultural Mediterranean area field and catchment scale
14:32	Sofie G. M. van't Veen	A cost-efficient method for quality assurance and quality control of high-frequency sensor data in freshwater systems - SentemQC
14:44	Discussion	
15:00	Tea break	
Theme	Best practice in high-temporal resolution monitoring - experimental design, data handling and assimilation, quality control	
15:30	Ivana Huskova	AI System for Real-Time Monitoring of Water Quality
15:42	Richard Gardiner	Automatic quality control of time series data and its role in preserving the Great Barrier Reef
15:54	Inge Elfferich	Interpretation of water quality data is strongly controlled by measurement frequency and time of day
16:06	Jakob Benisch	Would short term online monitoring improve the WFD-sampling strategy in Saxony?
16:18	Discussion	
16:30	1-minute poster pitch, Posters Session & Networking	
18:00	End of the day	

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Detailed Program Day 2: 18th June 2024

09:30	Welcome	Rachel Helliwell, Director, Hydro Nation International Centre
Theme	New approaches to data integration across different spatial and temporal resolution, remote sensing, modelling, and AI for improved process understanding	
09:35	Richard McDowell	A national approach to detecting changes in water quality
10:00	Luigi Spezia	Bayesian modelling of hydrological non-linear time series
10:12	Kimia Motevalli	Leveraging high-frequency data to model and better understand the oxythermal conditions and light environments along a latitudinal gradient from meridional to arctic lakes
10:24	Thomas Cornulier	COVID-19 RNA monitoring in wastewater: adjusting for uncertainty due to dilution and lab effects
10:36	Tom Lendrem	scan sensors and academia - a collaborative journey
10:48	Discussion	
11:00	Coffee break	
Theme	New approaches to data integration across different spatial and temporal resolution, remote sensing, modelling, and AI for improved process understanding	
11:30	Dalia Grendaitė	Optical Remote Sensing and Machine Learning for Monitoring Algal Blooms in Inland Waters: A Case Study in Lithuania
11:42	Ionut Paun	Analytics pipelines to integrate complex national scale data on river ecosystem quality
11:54	Jacopo Furlanetto	Multi-Risk Dynamics of Water Quality under Climate Change and Anthropogenic Pressures: An AI Approach Across Spatial Scales
12:06	Camilla Negri	Testing the transferability of a Bayesian Belief Network to diverse agricultural catchments using high-frequency hydrology and land management data sets
12:18	Discussion	
12:30	Lunch	
Theme	New process understanding for management and decision support	
13:40	Roland Bol	Long-term integrated observation at the TERENO test site Wüstebach – One blueprint for the new eLTER initiative
14:00	Golnaz Ezzati	Understanding catchments' behaviour and nutrient dynamics in view of the changing weather patterns: Insight from high temporal resolution data
14:12	Carolin Winter	Drought-induced shifts in hydrological and biogeochemical processes revealed by multi-solute high-frequency monitoring
14:24	Michael Rode	Diurnal nitrate retention patterns and their shifts during droughts
14:36	Magda Bierozza	Assessing biogeochemical function of remediated streams with high-frequency water quality measurements
14:48	Discussion	
15:00	Tea break	
Theme	New process understanding for management and decision support	
15:30	Bridget Rusk	How's the Water? Improving Recreational Water Quality Monitoring and Forecasting in the River Almond Catchment
15:42	Aaron Packman	Long-term high-resolution monitoring to understand urban stormwater discharge and storage in embedded prairie and wetland ecosystems
15:54	Maria Kämäri	High frequency sensors in detection of stream water quality trends and impacts of gypsum soil amendment at different scales
16:06	Nick Chappell	High frequency measurement of phosphate, nitrate, DOC and turbidity for NbS evaluation
16:18	Russell Adams	Towards an Improved Framework for Modelling Mitigation Measures with High-Resolution Water Quality Data
16:30	Edward Burgess	Agricultural Stakeholder Engagement in a High Resolution Water Quality Monitoring Programme: Experiences gained over 15 years in the ACP
16:42	Discussion	
17:00	Closing remarks	
17:30	End of the day	
18:30	Conference Dinner	For those with a conference dinner booking, please join us at the Palm Court

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Detailed Program Day 3: 19th June 2024

08:45	Arrival	Meet at the James Hutton Institute reception
09:00	Depart	A Bus to depart the back entrance of the James Hutton Institute
09:45	Stop 1	Arrive at the Beltie Burn
12:00	Lunch	Lunch will be provided on the coach as we transfer to Glensaugh
12:30	Stop 2	Arrive at Glensaugh
15:00	Depart	Depart Glensaugh and travel back to Aberdeen
16:00	Return	Return to the James Hutton Institute

Please remember to bring the items outlined in the 'Field Trip' section of this booklet. The field sites will involve walking over rough and in some parts steep terrain. If you have any concerns regarding travel or when out in the field, please notify a member of the team (hrmw@hutton.ac.uk).

Poster session Day 1: 17th June 2024 16:30-18:00

Faith Luciana Imhanze	Understanding how reservoirs influence riverine ecosystem: Investigating ecosystem health in a changing climate
Sandhya Devalla	Surface-enhanced Raman Spectroscopy as a Promising Tool for High-Resolution Water Quality Monitoring
Aaron Neill	A mobile, trailer-based platform for high temporal resolution water quality monitoring
Liam Kelleher	SMARTWATER: Diagnosing controls of pollution hot spots and hot moments and their impact on catchment water quality
Yu-Ting Chen	Integrating high-frequency water quality monitoring with long-term conventional algal assessment for reservoir algal bloom monitoring
Maelle Fresne	Evaluating the efficacy of agri-environmental measures on nutrients and suspended sediments concentrations in agricultural catchments using sub-daily stream water quality monitoring
Suzanne Jacobs	Nine years of high-resolution river monitoring with in situ sensors in Kenya – What did we learn?
Josie Ash	Understanding interannual seasonal variability in concentration-discharge relationships: integrating routinely collected data with targeted research
Kenneth Gutiérrez	Differentiating between catchment and in-stream processes by using multivariate and multisite high frequency data
Eva Skarbovik	Sensors for stakeholders?
Emma E. Lannergård	High frequency monitoring of dissolved oxygen in streams - a useful tool for water management
Paul Quinn	Using high resolution temporal data and modelling to better target the impact of Nature-Based Solutions on N, P, and sediment pollution in the future.
Joachim Rozemeijer	High-frequency water quality monitoring to support a spatial targeting approach for nutrients in two agricultural catchments
Peter Hunter	The Forth Environmental Resilience Array (Forth-ERA) – monitoring water quality at scale from source to sea

Abstracts

Keynote Speakers

Physicochemical water quality data frequency: reflections on the highs and lows - Day 1, 10.40

Jordan, P.

School of Geography and Environmental Sciences, Ulster University, Coleraine, N. Ireland

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The automation of in situ physicochemical water quality monitoring means that the high frequency of measurement can equal or exceed the temporal scale of underlying processes. These data can often be shown in near real-time and so be similar to other environmental surveillance parameters such as river flow and weather. The advances over a few decades have been astonishing and range from blue skies research on process understanding, catchment science applications, and now-casting for water utilities' management. Applications can be varied from short term assessments of changed land-to-water or in-stream pollution dynamics where granular detail at small spatial scales is required, to long-term time-series data collection over larger spatial scales that also record the interplay of river flow and weather effects in a changing climate. These advances, however, also come with the additional requirements of extreme data management, new methods for data quality control, and new technology skills to ensure continuity. In other words, investment far beyond the cost of the equipment. Here, best-practice for high frequency water quality monitoring is considered that is counter to an often perceived 'plug-and-play' outlook with in situ equipment. Beyond this, recent innovations are presented that include new off-grid mobile labs for upstream-downstream nutrient pollution dynamics and display that have been influenced by the needs of farming stakeholders. New findings on sensor quenching are also presented that question the environmental ranges of certain equipment along hydrological continua. Finally, the presentation will consider compromises between high and low frequency water quality monitoring, specific to research objectives and practical constraints, but which can only be validated by periods of high frequency data capture.

Monitoring to detect changes in water quality to meet policy objectives - Day 2, 09:35

McDowell W.^{1,2}, Noble A.¹, Kittridge M.³, Ausseil O.⁴, Doscher C.², Hamilton D.P.⁵

¹AgResearch, Lincoln Science Centre, Lincoln, New Zealand

²Faculty of Agriculture and Life Sciences, Lincoln University, Lincoln, New Zealand.

³Headwaters Hydrology, Christchurch, New Zealand

⁴Traverse Environmental, Wellington, New Zealand

⁵Australian Rivers Institute, Griffith University, Queensland, Australia

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Detecting change in water quality is key to providing evidence of progress towards meeting water quality objectives. A key measure for detecting change is statistical power. Here we calculate statistical power for all regularly (monthly) monitored streams in New Zealand to test the effectiveness of monitoring for policy that aims to decrease contaminant (phosphorus and nitrogen species, E. coli and visual clarity) concentrations to threshold levels in 5 or 20 years. While >95% of all monitored sites had sufficient power and samples to detect change in nutrients and clarity over 20 years, on average, sampling frequency would have to double to detect changes in E. coli. Furthermore, to detect changes in 5 years, sampling for clarity, dissolved reactive phosphorus and E. coli would have to increase up to 5-fold. The cost of sampling was predicted to increase 5.3 and 4.1 times for 5 and 20 years, respectively. A national model of statistical power was used to demonstrate that a similar number of samples (and cost) would be required for any new monitoring sites. Our work suggests that demonstrating the outcomes of implementing policy for water quality improvement may not occur without a step change in investment into monitoring systems. Emerging sampling technologies have potential to reduce the cost, but existing monitoring networks may also have to be rationalised to provide evidence that water quality is meeting objectives. Our study has important implications for investment decisions involving balancing the need for intensively sampled sentinel sites where changes in water quality occur rapidly versus other sites which provide long-term time series.

Abstracts

Highlight Speakers

Best practice in high-frequency water quality monitoring for improved management and assessment; a novel decision workflow - Day 1, 13:40

Rozemeijer, J.¹, Jordan, P., Hooijboer, A., Kronvang, B., Glendell, M., Hensley, R., Rinke, K., Stutter, M., Bieroza, M., Turner, R., Mellander, P., Thorburn, P., Cassidy, R., Appels, J., Ouwerkerk, K., Rode, M.

¹Deltares, Subsurface and Groundwater Quality Department, Utrecht, The Netherlands

Joachim.rozemeijer@deltares.nl

The use of high-frequency water quality sensors and in-situ auto analysers has increased over several decades. This has mostly been motivated by curiosity-driven research on hydrochemical processes and their potential for pollution detection by water utilities. However, to date there are fewer examples of sensor use as part of statutory environmental obligations to monitor state, trends, and loads of polluting substances such as nutrients, sediment, and other biochemical parameters. Here, the preferred monitoring method is time-proportional sampling where few samples are collected at many locations using a cyclic conventional grab sampling approach. Low-frequency hydrochemical data are routinely used to review environmental policies but are prone to missing important event-driven processes linked to diffuse and point source pollution that can be only detected with high-frequency sampling. Nevertheless, the increasing presence and development of high-frequency water quality monitoring equipment, coupled with a changing climate where such event-driven processes are more likely to occur and have a greater impact, means that adoption of the technologies for environmental monitoring is becoming more pressing.

To prepare regulators and agencies for this reality, this paper reviews international best practice in high-frequency data provision. Our objectives were (1) to summarize the added value of high-frequency water quality monitoring, (2) to describe sensor and analyser field practices, and (3) to evaluate experiences with high-frequency data cleaning. We propose a decision workflow that includes considerations of monitoring data needs, sensor choice, maintenance and calibration, and structured data processing. The workflow fills an important knowledge-exchange gap between research and statutory surveillance for future high-frequency water quality sensor uptake by practitioners and agencies.

What can we learn when high-frequency time series increase in length and number of parameters monitored?

Day 1, 14:00

Dupas R., Fovet, O.

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High frequency monitoring of water quality has become widespread in wealthy countries in the last two decades. Some high frequency monitoring programs, such as in the Kervidy-Naizin research catchment (AgrHyS CZO, western France, 5km²), have been running continuously for more than a decade, and the number of water quality parameters monitored at sub-hourly frequency has increased during this period. What have we learned from the now available multi-year and multi-parameter time-series?

We focused our analysis on solute dynamics during storm events. The first studies using continuous and high-frequency data enabled us to i) confirm the dominant concentration-discharge patterns already described thanks to grab-sampling data or automatic sampling during few storm events; ii) gain insights into seasonal variability in concentration-discharge patterns, because events during specific conditions such as the rewetting season or successive events were missed by the automatic sampling (Fovet et al., 2018). Today, the monitoring period is long enough to capture extreme events with a return period longer than 1 year. In the context of ongoing climate change, such extreme events that can be captured only in a multi-year monitoring scheme can be seen as sentinels of future hydroclimatic conditions (Dupas et al., in review).

Along with maintaining the initial monitoring equipment, we increased the number of chemical elements monitored at high-frequency using a so-called Riverlab. Our assumption was that multiple elements bring multiple and non-redundant information that is necessary to constraint the transfer and transformation processes that control stream water quality. We share our experience of running field laboratories to give an overview of the technical and organizational points that we identify as critical, and to provide guidelines for the successful implementation of future projects running such equipment. We show how the original data sets obtained with this equipment enable an analysis of temporal synchronies between major ions during storm events. In particular, this allows identifying solute pairs, for which a simple two-end-member mixing model is sufficient to explain their variations during storm event (Brekenfeld et al., 2023).

Brekenfeld N, Cotel S, Faucheux M, Flouy P, Fournier C, Gaillardet J, et al. Using high-frequency solute synchronies to determine simple two-end-member mixing in catchments during storm events. *EGU sphere* 2023; 2023: 1-27.

Dupas R, Faucheux M, Senga Kiessé T, Casanova A, Brekenfeld N, Fovet O. Storm-induced transfer of nitrate and phosphorus in a small agricultural catchment in the context of climate change. in review.

Fovet O, Humbert G, Dupas R, Gascuel-Oudou C, Gruau G, Jaffrezic A, et al. Seasonal variability of stream water quality response to storm events captured using high-frequency and multi-parameter data. *Journal of Hydrology* 2018; 559: 282-293.

**Long-term integrated observation at the TERENO test site Wüstebach – One blueprint for the new eLTER initiative
Day 2, 13:40**

Bol R.¹, Batsatsashvili, M.¹, Bogena, H.¹, Katsanou, K.², Pütz, T.¹, Trust, B.², Wenninger, J.², Zacharias, S.³, Vereecken, H.¹

¹Institute of Bio- and Geosciences, Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

²IHE Delft Institute for Water Education, Delft, the Netherlands

³UFZ Helmholtz Centre for Environmental Research, Permoserstraße 15, 04318 Leipzig, Germany

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In this presentation we highlight the multiple benefits of long-term, high quality, multiscale high-resolution monitoring of water quality in catchments. We exemplify this through past, present and future research activities at the Wüstebach forest catchment (Eifel, Germany). The Wüstebach catchment covers 38.5 ha and is typical of low mountain regions in Europe (altitudes between 595 m and 628 m and a humid, temperate climate with annual precipitation of ~1200 mm). In late summer of 2013, a clearcut of ~8.6 ha of Spruce stands close to the stream took place to allow for ‘natural’ regeneration of deciduous Beech.

The site was first instrumented in 2004. More and more high-resolution equipment came on site after 2008, when it became one of the Eifel/Lower Rhine Valley observatories of TERENO (Terrestrial Environmental Observatories) initiative. Since 2011 it has been part of the LTER (Long Term Ecosystem Research) network and now is one of the 50 forest sites in the new eLTER initiative (Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research). eLTER aims to apply a whole System Approach on observations at different spatial hydrological states and fluxes (e.g. soil moisture, ET, stream flow, nutrients) across a climate and biogeophysical gradient. Thereby gathering detailed information documenting the long-term development of ecosystems.

The presence of such a unique research site leads to ongoing knowledge gain rewards, but it enables easy add-on or build-in of new research. For example, wavelet transform coherence (WTC) analysis was undertaken using the existing water quality and discharge of the 10-year time series (2010–2020). It showed that the deforestation in 2013 affected the coupling of stream water S and C cycling more strongly than “natural” decadal environmental change. It also revealed that “underlying” changing strengths and directions of the main correlations between DOC, nitrate and discharge operated on different time scales. Furthermore, in 2023 we recorded water temperature variations (every 25 cm) throughout the Wüstebach stream using distributed temperature sensing (DTS). The study expanded on the previous observations and existing Wüstebach data on the seasonal flow variation interactions between surface and groundwater, by providing more precise timing and stream locations.

Nanoscale Taste Buds for Monitoring Drinking Water Treatment

Sperling J. R.¹, Poursat B.¹, Savage L.¹, Christie I.¹, Cuthill¹, Aekbote B. L.¹, McGuire K.², Karimullah A.S.², Robbie J.³, Sipperley C.⁴, Schick R.⁴, Sloan W. T.¹, Gauchotte-Lindsay C.¹, Peveler W. J.², **Clark A. W.¹**

¹James Watt School of Engineering, Advanced Research Centre, University of Glasgow, UK

²School of Chemistry, University of Glasgow, Glasgow, UK

³School of Law, University of Glasgow, Glasgow, UK

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We present a cross-reactive nanoplasmonic sensor capable of identifying and classifying complex liquid mixtures. Analogous to biological tastebuds, our plasmonic sensor shows promise in a variety of industrial applications as a simple, real-time, small-footprint quality control measure. Here, we will present our work on water quality monitoring and the deployment of this tool as monitoring device for deployment at drinking water treatment sites.

Our taste bud sensor arrays are composed of millions plasmonic nanostructures, each approximately 100nm x 100nm. Made from gold, these tastebuds provide a plasmonic response (a coloured resonance response) that is highly dependent on the refractive index of their immediate surroundings.

Through specific chemical modification of each sensor in the array with a different non-binding chemical group, we can segregate and measure the molecular components within each liquid sample. In doing so we can produce a unique statistical score based on the cross-reactive colour response from dozens of sensors.

Using machine learning, this score can be linked to broad properties of the water (e.g. linked to a specific filter failure in a treatment site, or a drift away from acceptable baselines), or to very small, specific changes in water content (e.g. the presence of a particular contaminant).

The low-power, real-time nature of the technology, along with its ability to detect small changes in water composition, makes it a good candidate as a future, on-site monitoring tool for both centralised and remote water treatment facilities.

Optimising Water Treatment: Harnessing Online Monitoring for Enhanced Coagulation Control and Improved Drinking Water Quality

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This study evaluates the effectiveness of online charge-linked monitoring for optimising the coagulation process at a Scottish Water treatment works. It focuses on measuring UV_{254} and turbidity in water samples to assess the impact of fluctuations in natural organic matter (NOM) on water treatability. Additionally, online zeta potential measurements were used to explore how varying charge optimisation levels affected water quality and disinfection by-product (DBP) levels. Increased UV_{254} and turbidity were recorded after heavy rainfall following dry spells, whereas prolonged rainfall typically diluted these measurements. Zeta potential monitoring identified optimal, under, and over-dosing of coagulants, with optimal dosing resulting in the lowest turbidity residuals (0.09 NTU). Using zeta potential analysis, optimal coagulant to UV_{254} ratios (Al: UV_{254}) were found to occur between 9.0 and 10.5 mg Al/L per cm^{-1} . Despite similar final water UV_{254} concentrations ($0.04 cm^{-1}$) under different treatment conditions, optimal treatment groups removed more NOM, significantly reducing THM and HAA concentrations by up to 26% and 10% respectively in 2022 compared to 2021. These results support implementing online UV_{254} and daily zeta potential monitoring to refine coagulation dosing, improving water treatment efficacy and reducing DBPs.

Online continuous water quality biomonitoring: an early warning system for pollutants in surface water used for drinking water production

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Evides Water Company supplies drinking water to ~2.5 million customers in the southwest of the Netherlands. Most of the raw water originates from river water, which is stored in large reservoirs or dunes. Besides employing sensors to continuously measure physical and chemical parameters, online continuous biomonitoring with water fleas (*Daphnia magna*) and mussels (*Dreissena bugensis*) is employed at the intake points, as an early warning system and to ensure that the water quality in the reservoirs does not deteriorate. Ten water fleas are incubated separately and their movement is tracked with cameras. In addition, sensors are attached to eight mussels per location to monitor their valve position. Abnormal behavior automatically stops the intake of river water and subsequent manual chemical analysis of water samples is then used to try to identify the cause(s).

We will present operational experience of both biomonitoring systems, including data-handling. This century, several incidents occurred in the Dutch river systems. Different industrial and agricultural pollutants were identified in samples taken after an alarm of a biomonitor. In 2015, an industrial pollutant was present during a long period. This incident eventually led to a stricter discharge permit for chemical industry and increased monitoring of effluent water quality. The incidents prove that the chosen monitoring strategy is successful.

In conclusion, online continuous biomonitoring techniques are an important tool to safeguard the raw water quality used for drinking water production.

Hydrobean: a low-cost sonde for citizen science river water quality monitoring

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Real time water quality monitoring using sensor networks can provide valuable insights into the state of our rivers. However, sensor networks require frequent maintenance and ongoing observation to ensure that they are performing properly in harsh and changeable UK river environments. Given the appropriate low-cost technology and training, non-professionals can act as citizen scientists by deploying and maintaining sensor networks in rivers, saving professional servicing costs, enhancing community involvement in local issues and producing reliable, high-quality data sets. Sondes designed for use by citizen scientists must be fit-for-purpose including being: simple to use, lightweight, robust, and easy to maintain. We present a low-cost wireless sensor - Hydrobean - designed for use by citizen scientists monitoring water quality in rivers. Hydrobean measures the temperature, depth and electrical conductivity of water and transmits these data wirelessly to a cellular networked receiver on the riverbank. Hydrobean is specifically designed for long-term, low-maintenance operation, and has undergone extensive field and lab testing to assess its robustness and to compare the quality of the data it produces with professional standard sondes. The data reported by Hydrobean can be used to understand complex temporal variations in water chemistry and capture serious, but often short-lived, contamination events. To increase the usefulness of its output, we have developed a model that uses the depth and specific conductivity data gathered by Hydrobean to infer the water quality status of sites across our test catchment, the River Ken in Devon, in real time. Future deployments of Hydrobean will test citizen science user interactions, assess model performance and explore its application in a wider range of freshwater settings.

Lab Quality Testing in Near-Real-Time? Simply Miniaturise the Lab and Take it to the Water!

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When monitoring catchments, a common issue is balancing the need for high frequency data with the need for high accuracy data. Too often there must be the choice between using low-cost swarm sensors that can provide frequent indicative data but struggles with high precision and may require frequent maintenance, and grab samples taken to a lab which may only be taken weekly or less. This makes producing an accurate model of the catchment very difficult.

Using advanced microfluidic or “lab-on-a-chip” technologies, SouthWestSensor provides a sensor solution which can produce data that is both high frequency and lab-quality. Measuring ammonia, phosphate, and nitrate/nitrite, the sensor probe uses the gold standard reagents to measure its assays, the same reagents that are used in labs across the world. The sensors use oil in the system, which separate the flow into individual droplets, preventing sample smearing and allowing for better mixing and therefore lower volumes of sample and reagent are required. The probe can take measurements up to every ten seconds, but due to the ultra-low reagent consumption it can go three months at a time without maintenance. The oil also coats the inside of the tubing which stops anything from sticking to it, thereby preventing biofouling.

By using our sensors to produce a “truth point” it would be possible to combine the data with low-cost swarm sensors or satellite data to produce models or allow for soft or inferred sensing for more difficult to monitor pollutants such as phosphate. All of this together could give a higher resolution picture of the health of the catchment.

Our nitrate and phosphate sensors are being used for the Forth ERA project for this reason, to improve the macro data being produced for the catchment, and to provide phosphate data.

Field comparison of eight ammonium sensors and analyzers

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In the Netherlands, 70% of the surface waters don't meet the water quality standards for ammonium. High ammonium concentrations are toxic for aquatic species and ammonium contributes to the eutrophication of natural waters. Based on common monthly grab sampling data, the reasons behind non-compliance and concentration peaks are usually not understood. In general, ammonium partly comes from anthropogenic sources (agriculture, waste water) and partly from natural sources (mineralization of subsurface organic matter).

High-frequency monitoring of ammonium has proven to reveal the detailed variations in ammonium concentrations, enabling identification of sources, transport pathways, and biochemical processes. Two common methods for high-frequency ammonium measurement are wet-chemical analyzers and Ion Selective Electrodes (ISEs). Little is known however about the practical applicability of different methods and the difference between brands of high-frequency ammonium measuring devices.

To fill in this knowledge gap we ran a pilot in which four ammonium ISEs and four analyzers were tested against laboratory samples in natural water during six weeks. At the end of this period, several spike tests were performed with artificially elevated pH, EC, ammonium and potassium concentrations, in order to evaluate how the sensors respond to variations in chemistry.

The four wet-chemical analyzers showed the most stable measurements, although differences between brands occurred. In particular, low temperatures in the container caused disruptions in some analyzers. Another disadvantage of some analyzers was the large production of chemical waste from the reagents.

The ISEs are commonly known to be unstable. In this pilot the offset and drift of the measurements with the four ISEs were however quite small. The spike test revealed a large influence of pH and Potassium on the measured ammonium concentrations. ISEs are smaller and have a lower power consumption and are therefore more suitable in remote areas, although frequent maintenance visits are required.

This pilot clearly shows the difference between methods and brands and will be helpful for the choice of a high frequency ammonium measuring method.

Fate and transport of pesticides and pharmaceuticals in an agricultural Mediterranean area: field and catchment scale

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Pesticides and pharmaceuticals are emerging contaminants in agricultural catchments. Pesticides leach into the environment from excess application, and pharmaceuticals emerge as a result of irrigation with treated water. Authentic field data collected without intervention are rare and utilized in this research to describe transport processes.

Mediterranean regions are characterized by episodic, short, and intense storms, resulting in flash floods, where discharge can rise two orders of magnitude in a few hours. A sampling at a sub-diurnal or hourly frequency aligns with the rate of pollutant transport; however, it requires intensive fieldwork. A programmed autosampler is optional to track developing hydrographs. Nonetheless, sampling triggering can miss the hydrograph rise, and a combination of methods is recommended. Sub-diurnal and diurnal processes also occur in subsurface and groundwater,

We monitored groundwater, subsurface, and stream outlet during a storm in a Mediterranean area. The subsurface water was also monitored during irrigation. Sub diurnal time series were collected for the stream outlet and the subsurface, and groundwater was collected every two to three days. Each time series, which totaled 4 to 7 samples, was analyzed for 81 organic pollutants. More extensive time series for sediments and nutrients are available at the stream outlet. For sediments, up to 24 samples per storm have been available for each storm in the last three years.

Concentration changes in groundwater and subsurface flow presented patterns describing translatory flow and leaching, both for subsurface and groundwater. The patterns found to indicate preceding concentration in upper layer and mobility of the compounds. The translatory flow occurred within special conditions of non-saturated field, shifted within sub diurnal processes into full saturated. Lower frequency would have missed such processes. Stream outlet analysis showed larger spatial scale transport and are also used to calibrate pollutants fate and transport models in hourly time step.

A cost-efficient method for quality assurance and quality control of high-frequency sensor data in freshwater systems - SentemQC

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We need smart, cost-efficient methods to ensure the quality of sensor data by performing data quality assurance (QA) and quality control (QC) on large volumes of high-frequency sensor data. In this study, a simplified and robust novel QA-QC approach for high-frequency sensor data from multiple sensors and freshwater systems was developed and tested. The method is called SentemQC (QA-QC of high temporal resolution sensor data). In specific, the novel QA-QC method was applied to high-frequency nitrate, turbidity, oxygen, and pH sensor data from the four different freshwater ecosystems in Denmark: Horndrup stream, Lyby-Grønning stream, Lake Ormstrup, and several experimental ponds in Lemming.

Our SentemQC method is computationally efficient, developed in the open-source programming language Python, and has a user-friendly setup while being easy to understand. It identifies and marks anomalies in the raw data by using five moving windows. These moving windows allow each data point to be connected to neighboring data points as well as data points further away. As a result, the method can identify not only single outliers but also clusters of anomalies.

Our study of different sensor parameters and freshwater ecosystems showed that SentemQC is robust and easy to set up and apply. All the tested sensor data types were efficiently QA and QC by using our novel method. SentemQC requires the following specific steps: i) maintaining sufficient electronic logbooks; ii) clear communication between sensor field technicians and QA-QC performers. However, this newly developed QA-QC method cannot stand alone. There is still an urgent need to perform additional QA-QC steps, such as calibrating the sensor data against grab samples to correct for zero offsets or performing gap-filling methods before using the sensor data for the final real-time concentration and load calculations.

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Keywords: Quality Assurance, Quality control, High-frequency sensor data, Data handling

AI System for Real-Time Monitoring of Water Quality

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Continuous monitoring of water quality is crucial for safeguarding environmental integrity and public health. Traditional methods often rely on periodic sampling and laboratory analysis, which may delay the detection and response to contaminants. This delay can negatively impact water management. NIVA's research, conducted by [Czyczula Rudjord et al. \(2022\)](#), aims to address this gap by developing a system capable of real time monitoring and identification of chemical pollutants in water supplies. The method leverages cutting-edge in situ sensor technologies and artificial intelligence (AI).

The methodology integrates multivariate statistical methods with machine learning algorithms to establish a robust framework for anomaly detection. This hybrid approach allows the system to differentiate between normal variability in water characteristics and potential harmful deviations caused by chemical pollutants. The real-time data processing capability of this system is underpinned by AI, which analyzes data streams from ultraviolet spectroscopy (UV-spec) and fluorescence sensors, ensuring high-resolution detection of contaminants.

The system was rigorously tested in a series of controlled laboratory experiments using municipal drinking water spiked with several known chemical compounds representative of typical contaminants. The findings confirm the system's capability to detect and classify anomalies in water quality by identifying deviations with high accuracy. This indicates a significant improvement over traditional monitoring methods, which are often slower and less responsive.

The developed system and test results validate the feasibility of using AI-enhanced sensor technologies for real-time water quality monitoring. The system supports the growing emphasis on developing more dynamic and responsive environmental monitoring systems. The research also opens new possibilities for the deployment of such technologies in diverse aquatic and urban environments, potentially revolutionizing water management practices and ensuring better protection of water resources.

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Automatic quality control of time series data and its role in preserving the Great Barrier Reef.

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The Great Barrier Reef stretches 2300km down the east coast of Queensland, Australia, covering an area roughly the size of Germany. It is inscribed on the UNESCO World Heritage list, but faces a variety of threats, including water quality discharged from coastal waterways.

In addition to a substantial sediment, nutrient and pesticide monitoring program (the Great Barrier Reef Catchment Loads Monitoring Program), the federal and state governments have funded the installation and operation of a network of 50 Trios OPUS nitrate nitrogen (NO₃-N) sensors. Time series data from these probes enables greater understanding than was previously possible from a discrete water quality sampling program. Peak concentrations are captured, as well as information on diurnal processes and the rate of concentration changes due to runoff and groundwater/surface water interactions.

In situ probes typically return a parameter which is similar to, but not precisely the same as a laboratory analyte. Despite this, excellent correlations exist between near real-time variables such as NO₃-N and lab derived nitrate nitrogen, or turbidity and total suspended solids. Once a strong correlation is obtained at a site, the concentration data can be multiplied with river flow data to derive near real-time loads. Further insights are then possible, including the timing of peak pollutant loads, which do not necessarily coincide with peak concentrations.

Stakeholders can use this wealth of near real-time data to inform proactive management actions. The real-world results of these management actions on the waterways are then available in near real-time, without substantial delays for laboratory analysis, loads calculations and reporting.

Although the probes involve a significant capital outlay, and require frequent maintenance from well-trained field staff, there may be scope to offset these costs by reducing, or even halting laboratory sample collections at the site. While some down time is inevitable, the volume of information gathered is typically much higher, more detailed than traditional methods.

Typically reading every 15 minutes, the program could feasibly collect one million NO₃-N data points every seven months. When additional variables and probe types are considered, the volume of data collected makes manual Quality Assurance and Quality Control (QC) a Sisyphean task. This presentation will outline the methods developed to automatically QC the data from various probes within the cloud, in near real-time, and the significance of having this data available for management decisions.

Interpretation of water quality data is strongly controlled by measurement frequency and time of day

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Declining water quality of lakes and rivers in the UK has led to an increasing interest in environmental monitoring with sensors. Sensors can enable high temporal frequency monitoring to capture a detailed picture of environmental stressors and ecosystem response. However, a balance needs to be struck between expenditure on sensor maintenance, sensor lifetimes, data management versus accurate representation of environmental and biogeochemical conditions. To understand the best approach to this problem, high frequency hydrochemical data (dissolved oxygen, pH, electrical conductivity, turbidity, water temperature, total reactive phosphorus, total phosphorus and nitrate) from six UK catchments were analysed to 1) understand the lowest measurement frequency to accurately capture the variation in the data; and 2) investigate bias caused by sampling at certain times of the day.

This study found that reducing the measurement frequency from hourly to four-hourly, twelve-hourly, daily, weekly, or monthly, increasingly changed the interpretation of the data by altering the calculated median and data range. From all 45 individual datasets (six to eight parameters in six catchments), four-hourly data captured most of the hourly range (>90%) for 37 datasets, and 41 had limited impact on the median (<0.5% change). Twelve-hourly and daily data captured >90% of the range with limited impact on the median in approximately half of the datasets. Weekly and monthly data only captured >90% of the range with limited impact on the median in a few datasets. The individual parameters that were most affected by reducing frequency depended on the catchment.

Many parameters showed significant intra-daily variation caused by diurnal patterns, which changed seasonally and depended on catchment characteristics including size, baseflow index (groundwater influence) and land use (urban and agricultural use). To design an optimised monitoring program, key catchment characteristics should be considered. Ideally very high frequency (at least four-hourly) monitoring should be deployed for test periods to test biogeochemical response and understand whether lower frequency regimes can capture the required variation in water quality parameters.

Would short term online monitoring improve the WFD-sampling strategy in Saxony?

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The European Union Water Framework Directive (European Commission, 2000) aims to achieve a good ecological and chemical status of all bodies of surface water by 2027 and has developed an integrated guidance on surface water chemical monitoring (e.g. WFD Guidance Document No. 7/19, Hanke et al. 2009; WFD-CIS 2003) which is transferred into national German law (Ordinance for the Protection of Surface Waters, OGewV, Bundesministerium der Justiz und für Verbraucherschutz, 2016). For the majority of compounds, this act requires a monthly sampling frequency to assess the chemical water quality status of a surface water body.

To evaluate the representativeness of the sampling strategy under the OGewV, high-frequency online monitoring data is investigated under different sampling scenarios and compared with current, monthly grab sampling strategy. About 23 million data points were analyzed for this study, three chemical parameters (dissolved oxygen, nitrate-nitrogen, chloride concentration) and discharge data were selected from four catchment of different sizes ranging from 51 391 km² to 84 km². In this contribution we want to (I) compare the results of conventional grab sampling with short-term online-monitoring (STOM), where online sensors are applied over a limited duration and return interval in the investigated rivers, (II) to use discharge data as proxy for the event mobilized pollutants to investigate the different performance of STOM.

Results show, that STOM outperforms grab sampling for parameters where minimum/maximum concentrations are required by law as the probability to catch a single extreme value is higher with STOM. Furthermore, parameters showing a pronounced diurnal pattern, like dissolved oxygen, are also captured considerably better. The performance of STOM did not provide improvements for parameters with small concentration variability, as Nitrogen-Nitrate and Chloride showed no substantial improvements by STOM monitoring. The analysis of discharge events as surrogate parameter for event-mobilized pollutants proved that the probability of capturing samples during events is significantly increased by STOM.

Abstracts Day 2

New approaches to data integration across different spatial and temporal resolution, remote sensing, modelling, and AI for improved process understanding

Bayesian modelling of hydrological non-linear time series

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Hydrological time series are realisations of complex stochastic systems. A few issues need to be taken into account by the modellers: non-Normality, non-linearity, non-stationarity, and long memory. Non-Normality is observed when the data density is multimodal or asymmetric or kurtic and the data cannot be considered as realisations from a Gaussian process. Non-linearity is assumed when the whole series does not show the same statistical peculiarities over all the observations, but they can be classified into a few homogeneous groups, each one with specific characteristics (e.g., different means and/or different variances). Non-linearity can also be assumed when the series exhibits asymmetries, e.g., when peaks are sharper (or more rounded) than the troughs, and/or when the cycles increase at a different rate from which they decrease. Weak non-stationarity is caused by generating processes having time-varying means and autocovariances (possibly due to periodic components and/or covariates). Finally, when the series shows high autocorrelations at the higher lags, with a slow decay, the observations are realisations from a long memory process. Because of these issues, hydrological time series can be efficiently analysed by Markov switching autoregressive models (MSARMs). MSARMs are pairs of discrete-time stochastic processes, one observed and one latent, or hidden. The hidden process is a finite-state Markov chain, whereas the observed process, given the Markov chain, is conditionally autoregressive. The dynamics of the observed process is driven by the dynamics of the latent one, so that each observation depends on the contemporary state of the Markov chain. By this theoretical structure, MSARMs allow: i) modelling non-linear and non-Normal time series by assuming that different autoregressions, each one depending on a hidden state, alternate according to the Markovian regime switching; ii) classifying the observations into a small number of homogeneous groups, labelled as the regimes of the Markov chain. We propose MSARMs within the Bayesian framework: Bayesian inference, model choice, and variable selection are performed numerically through Markov chain Monte Carlo (MCMC) algorithms. Our applications to isotope signatures, turbidity measurements, and river temperatures provide new clear examples of the suitability of the MSARMs in hydrological time series analysis in particular and environmental sciences in general. We hope our work can motivate other scientists to approach MSARMs and give their highly structured time series a valuable interpretation.

Leveraging high-frequency data to model and better understand the oxythermal conditions and light environments along a latitudinal gradient from meridional to arctic lakes

2

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Temperature, oxygen, and light are key response variables impacted by climate change that define ecological niches in lakes, such as those of cold-water fish. With climate change, lakes become warmer, more oxygen-depleted, and often darker. In recent years, we have obtained high-frequency meteorological and hydrological data from four lakes spanning from Lake Tantaré (47 °N) near Québec City to Ward Hunt Lake (82 °N) in the Canadian high Arctic to and including a lake in Bylot Island (73 °N) where the temperature has been monitored since 2012. We utilize in-site sensors to measure temperature using Minilog-II-T (Vemco, Canada) or Onset U22 temperature sensors (Onset, HOBO, USA), dissolved oxygen (DO) using MiniDOT (PME, USA), and underwater photosynthetically active radiation (PAR) using LiCOR sensors embedded in MiniPAR loggers (PME, USA).

The continuous monitoring of temperature, DO, and underwater PAR can serve as a basis for understanding the lake's responses to environmental and climate changes, offering unique insights into critical periods such as shoulder seasons, late winter - when anoxia can lead to fish kills, or during summer heat waves and short-term stability events. Despite the abundance of high-frequency datasets worldwide brought about by increasingly available sensors, the data is arguably under-utilized. We explore how process-based modelling approached, using 1D lake models such as the MyLake matlab code, can simulate oxythermal and optical conditions in the aforementioned lakes in order to predict the collective response of those variables under climate change. The results show that MyLake has performed well for temperature, with low RMSE for the temperature ranging from 0.37 to 1.44°C, but less for DO concentration well in perennially ice-covered lakes with RMSE ranging from good (1.38 mg/L) to bad (5.61 mg/L). As this is, to our knowledge, the first time a hydrodynamic lake model has been used for high-Arctic Lake, we explore, in this talk, where there is room for improvement.

COVID-19 RNA monitoring in wastewater: adjusting for uncertainty due to dilution and lab effects

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Wastewater based epidemiology (WBE) has been a tool to monitor the presence or abundance of pathogens in sewage for many years, but it has seen a dramatic increase in use during the COVID-19 pandemic with many countries around the globe using wastewater monitoring as a tool to measure the spread of the virus. The Scottish COVID-19 wastewater monitoring program has been regularly taking samples from wastewater treatment works since May 2020. Biomathematics & Statistics Scotland (BioSS) has been analysing these data and reported results to Scottish Government from Winter 2020/21 until March 2024. In order to give interpretable values, the raw qPCR readings from the lab need to be normalized and adjusted for various factors like dilution (e.g., caused by rainfall) but also lab processing and amplification variability, using values from replicates and positive control samples going through the lab's entire preparation and qPCR process. In this presentation we will present recent work of the BioSS wastewater analysis group on models that allow to simultaneously estimate and adjust for these dilution and lab effects whilst propagating uncertainties from multiple sources into the normalised data. Although the approach was developed specifically for COVID-19 RNA measurements, we believe that similar methods will also be relevant for other water monitoring systems.

s::can sensors and academia - a collaborative journey

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For 25 years, s::can water quality sensors have been used by academia and research groups worldwide to monitor both pollution levels and the effects of climate change on our world's most precious natural resource.

This research has formed an integral part of s::can's journey to becoming a leading-edge provider of optical water quality sensors for environmental monitoring applications. Acquired in 2020 by US company Badger Meter Inc, an industry-leading global provider of water solutions, s::can technology can now push past being a pure sensor provider and complete its package with an expanded telemetry and data visualization offer.

In this presentation, we will detail how important research groups and academia have been to the development of the s::can sensors, and how now that s::can are part of the Badger Meter group, remote water quality monitoring goes beyond water quality sensors into providing a full end to end solution for research and academia.

Optical Remote Sensing and Machine Learning for Monitoring Algal Blooms in Inland Waters

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Intensive algal and cyanobacterial blooms pose a significant challenge in inland waters, impacting water usability. Optical remote sensing offers a valuable means to monitor algal blooms more frequently than traditional in situ methods. Sentinel-2 mission from European Commission Copernicus programme has a sufficient spatial resolution sensor for observation of spatial patterns of pigment chlorophyll distribution in large lakes and reservoirs, as well as determination of chlorophyll-a concentration as derived from Sentinel-2 data using various models.

We employed a biophysical classification approach to categorize lakes based on their optical properties, grouping them into four classes: Clear, Moderate, Chla-dominated, and Turbid. Subsequently, we developed two random forest-based models to estimate chlorophyll-a concentrations. The first model, trained on Clear class observations, exhibited an R of 0.54 and an RMSE of 4.1 mg/m, while the second model, encompassing Moderate and Chla-dominated classes, achieved an R of 0.71 and an RMSE of 11.5 mg/m.

Applying these models to 357 lakes and ponds in Lithuania revealed that 23% of these water bodies experienced chlorophyll-a concentrations exceeding 50 mg/m, indicative of significant algal blooms. Notably, lakes characterized by annual blooms typically reached peak concentrations in August or September. Furthermore, the models showed promise in identifying representative locations for in situ observations, particularly in larger water bodies such as the Kaunas reservoir (area 63.5 km²), facilitating a more comprehensive assessment of water body status.

These findings underscore the potential of optical remote sensing coupled with machine learning techniques for effective monitoring and management of algal blooms in temperate inland waters, with implications for both research and practical applications.

Analytics pipelines to integrate complex national scale data on river ecosystem quality

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In recent times, our rivers have been affected by a combination of contaminants of interest (e.g. pharmaceuticals, pesticides, micro plastics), leading to declining water quality and loss of freshwater species and biota. Our understanding of the impact of the contaminants on the surrounding ecosystem has been constrained by examining contaminants in isolation, without considering their cumulative effects. In MOT4Rivers (NERC), we analyse national scale datasets across the UK and employ state of the art analytical tools to explore the consequences of prolonged exposure to mixtures of pollutants, assessing their effects on freshwater quality and the health of the ecosystem. However, the analysis of the national scale dataset presents multiple challenges as the data are large, highly complex (consisting of 94 contaminants of different types), sampled with various levels of frequency and recorded at multiple sites across the UK over a course of 20 years. This presentation will introduce our work-to-date developing an analytics pipeline to provide fresh insights into the long-term impact of pollutant cocktails on freshwater ecosystems.

Multi-Risk Dynamics of Water Quality under Climate Change and Anthropogenic Pressures: An AI Approach Across Spatial Scales

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Water quality serves as a critical determinant of ecosystem health and directly impacts water-use sectors like agriculture and public health. However, the synergistic interactions between extreme climate events and anthropogenic activities can significantly alter water quality dynamics. Furthermore, these impacts are likely to be exacerbated within the context of ongoing climate change and socio-economic development. Our work aims at understanding the multi-risk dynamics for water quality at different spatial scales in Italy (Adige river basin, Veneto Region, and national level) respectively in three different projects (iNEST, Myriad-EU, and GRINS). This is achieved by leveraging heterogeneous data at different spatial and temporal scales, e.g. climate data, land-use data, and in-situ water quality measurements by using machine learning techniques and spatial-temporal Bayesian network models. Through the development of water quality multi-risk models, we explore the synergistic impacts of climate extreme events and anthropogenic pressures on physicochemical water quality parameters (i.e. nutrients, suspended solids, DO, temperature), and other key elements (i.e., biological, chemical, overall ecological status), considering also specific vulnerabilities and exposures of river networks and basins. Land-use and climate change impacts on water quality are analyzed in GRINS and MYRIAD-EU at the national and regional scales, respectively. MYRIAD-EU explores the interaction of multiple hazards (i.e., compound hot-dry and wet-dry events) using machine learning techniques, while GRINS focuses mainly on characterizing the effect of land use/land cover changes with the Bayesian network model. Moreover, iNEST focuses on the nexus between water quality indicators and the multiple water-dependent sectors (i.e. food and energy production). These approaches are being developed as potential tools to complement in-situ measurements with additional data sources (e.g. climate, land-use, etc.) for a better understanding of the multi-risk dynamics of water quality at various spatial scales and temporal horizons.

Testing the transferability of a Bayesian Belief Network to diverse agricultural catchments using high-frequency hydrology and land management data sets

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A Bayesian Network (BN) calculating stream phosphorus (P) concentrations in agricultural catchments was parameterized with high-frequency data in a pilot study. To test model transferability, the BN was applied to three further Irish catchments with varying agricultural land use, hydrology, and P pressures, monitored by the Agricultural Catchments Programme (ACP). While the pilot catchment Ballycanew was dominated by poorly drained grassland, the further three catchments were dominated by well-drained grassland (Timoleague), well-drained arable (Castledockerell), and moderately-drained arable (Dunleer). In all catchments, the main P source came from agriculture and (minimal) domestic inputs, whilst the well-drained arable catchment also had Sewage Treatment Works (STWs). To best fit each catchment's characteristics, six different BN structures were developed and parameterized through bootstrapping of high-frequency data to obtain fitted distributions, distribution fitting of literature data, and expert elicitation to quantify in-stream P uptake processes. Model transferability and fit were evaluated using a suit of approaches: 1) percentage bias between simulated and observed distributions of Total Reactive P (TRP) concentration, 2) comparing predicted concentration quantiles and means to the observed, and 3) visually comparing the posterior distributions by plotting them against daily observations. The pilot BN structure fit the poorly and moderately drained catchments well, irrespective of the dominant land use ($76\% \leq \text{PBIAS} \leq 80\%$), confirming that the initial BN represents the catchment-specific process understanding whereby transport via quick-flow dominates P processes in these catchments. In contrast, more complex BN structures were needed for good predictions in the well-drained catchments. The additional processes included groundwater Total Dissolved P (TDP) loads, derived from observed concentrations in piezometers, STWs loads, and in-stream P uptake. These more complex model implementations yielded good results ($-5\% \leq \text{PBIAS} \leq 18\%$). The additional in-stream P removal process improved the model performance in all catchments; however, it remains a second-order mechanism.

Understanding catchments' behaviour and nutrient dynamics in view of the changing weather patterns: Insight from high temporal resolution data

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Surface water quality is already under pressure in agricultural catchments and assuming that no changes in the management decisions are made, it will undergo further degradation due to the changing weather patterns. The more frequent occurrence of extreme weather events create multi-stressor environments that requires development of efficient climate-smart adaptation measures appropriate to individual catchment characteristics. However, understanding the type and extent of the impact of climate change on water quality requires in-depth analysis of long term high temporal resolution data that have captured any (subtle or extreme) changes in nutrient dynamics along with changes in the climatic data. Importantly, such information ought to be collected from catchments with different typologies in order to provide a comprehensive picture of nutrient dynamics in diverse geological locations, once subject to extreme hydrological events.

In Ireland, the nutrients and sediment concentrations and loads in the surface water of six hydrologically contrasting agricultural catchments, and with different management factors in place, have been monitored on a 10-min basis by the Agricultural Catchments Programme since 2009. Climatic data have been collected with the same temporal resolution. This unique world-class database has provided great potential of investigating the dynamics of Nitrogen, Phosphorus, and sediment losses, as well as the processes involved (nutrient delivery and mobilisation). Until now, different water quality modelling (optimisation or simulation) have been used to understand the relationship between trends in within-stream nutrient concentrations and drivers of losses. The study results have shown that while climatic drivers (i.e. temperature, precipitation, potential evapotranspiration) are strongly contributing to the increases in nutrient concentrations, nutrient sources, soil chemistry, soil temperature, drainage status, and farming calendar (management practices) are the explanatory factors of the significance of correlation between changes in the weather patterns and observed increasing trends in nutrient concentrations.

Drought-induced shifts in hydrological and biogeochemical processes revealed by multi-solute high-frequency monitoring

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Droughts can substantially alter hydrological and biogeochemical processes within a landscape, posing a threat to catchment functioning in providing good-quality fresh water. Particularly in fast-responding headwater catchments, the availability of high-frequency data on discharge and solute concentrations is essential for comprehending catchment functioning during and following periods of anomalous dryness. The Lab in the field (Freyberg et al., 2017) presents a unique framework for monitoring high-frequency solute concentrations, measured hourly at the outlet of the pre-alpine Erlenbach catchment (0.7 km²). Throughout the dry summer of 2018, we observed notable shifts in water quality, indicating the depletion of specific catchment storages and potential alterations in nutrient uptake rates in shallow and redox conditions in deeper layers. The wide set of water quality parameters enabled the disentanglement of hydrological and biogeochemical mechanisms underlying the observed drought response. While evidence is growing that droughts can severely impact freshwater quality (van Vliet et al., 2023; Li et al., 2022; Winter et al., 2023), it is especially this mechanistic understanding, derived from multi-solute high-frequency measurements, that is lacking for effective safeguarding of freshwater resources against the increasing risk of intense and prolonged droughts (Hari et al., 2020).

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Diurnal nitrate retention patterns and their shifts during droughts

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High-frequency nitrate-N data are increasingly available, while accurate assessments of in-stream-N retention in streams and rivers require a better capture of complex river conditions. We identified characteristic diurnal nitrate uptake pattern for analysing the importance of autotrophic and heterotrophic uptake processes at deviating stream orders. Continuous 15-min estimates of nitrate-N retention were derived in a 1st and 6th-order stream of the lower Bode river network using long-term sensor monitoring data during a period of normal and drought flow from 2013-2022. For the 6th order stream we used additional hydrodynamic modelling to infer in-stream retention as the differences between conservatively traced and reactively observed nitrate signals. In the 6th order stream the unique nitrate-N retention estimates, together with metabolic characteristics, revealed insightful patterns (from high net autotrophic uptake in late-spring to lower uptake, to net heterotrophic release during autumn) and drought-induced variations of those patterns (reduced levels of net uptake and autotrophic nitrate uptake largely buffered by heterotrophic release processes, including organic matter mineralization). Four clusters of diel uptake patterns were identified, potentially representing changes in dominant nitrate-N retention processes according to seasonal and hydrological conditions. For example, dominance of autotrophic nitrate retention extended more widely across seasons during the drought years. Such cross-scale patterns and changes under droughts are likely co-determined by catchment and river environments (e.g., river primary production, dissolved organic carbon availability and its quality), which resulted in more complex responses to the sequential droughts. Interestingly we found similar diurnal N uptake pattern in the 1st order stream but drought impacts were less pronounced. Inferences derived from this diurnal uptake pattern provide new insights into nitrate dynamics and ecosystem function of streams with deviating order, as well as their responses to climate variability. We show that this approach can be used across sites and scales, thereby complementing high-frequency monitoring to identify in-stream uptake processes and to inform river management.

Assessing biogeochemical function of remediated streams with high-frequency water quality measurements

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In this study we showcase the application of high-frequency water quality measurements of turbidity, nitrate-nitrogen, dissolved organic carbon, specific conductivity and dissolved oxygen in two remediated streams to infer information about their biogeochemical function. First, we used dissolved oxygen data to estimate daily rates of stream metabolism that was then cross-analysed with nitrate and carbon data across flow ranges. We found out that despite high level of pollution in the stream from catchment agricultural inputs, there were periods of balanced nitrogen supply and metabolic demand during receding flows. During storm events, we observed contrasting flushing patterns for nitrate and respiration (dilution pattern) and carbon and productivity (concentration effect), suggesting complex interplay between flow and biogeochemical drivers. In the second example, we show how combined turbidity and specific conductivity data provide insights into sediment and solute sources and mobilisation in a small stream network. Here, storm event responses show a large variation in terms of flushing patterns, indicating an important role of local stream channel conditions. Together, these studies show that high-frequency water quality measurements can be used to infer information about catchment pressures in relation to in-stream cleaning capacity, much needed for successful water quality management in human impacted landscapes.

How's the Water? Improving Recreational Water Quality Monitoring and Forecasting in the River Almond Catchment

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Recreational waters in Scotland are a vital asset to public well-being, environmental health, and local economies. However, many of these same waters receive sewage discharge, which degrades the aquatic environment and creates a public health risk. At present, there is increasing pressure from the public, regulators, legislation, and international environment agreements, to improve surface water quality in Scotland. However, monitoring is expensive and time-consuming, so often we are not aware of how much sewage is in the river, nor how long it can present a health risk to recreational water users. New and innovative methods are needed to improve the frequency of water quality monitoring in an economically feasible way.

The River Almond - impacted by urban wastewater, agricultural runoff, and legacy mine water discharge - is one of Scotland's most polluted rivers. Scottish Water has prioritized improvements to the River Almond catchment, with ambition of achieving Good Water Quality status by 2027. This presentation will outline the high frequency monitoring being implemented in the Almond catchment, and highlight the efficacy and potential limitations of using novel sensors to monitor microbial water quality in real-time.

Long-term high-resolution monitoring to understand urban stormwater discharge and storage in embedded prairie and wetland ecosystems

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Increasing urbanization and climate change are driving widespread interest in deployment of green infrastructure to reduce climate vulnerability, improve biodiversity, and reduce inequitable access to greenspace. However, little is known on the ecohydrological functioning and sustainability of native ecosystems within urban environments. To improve understanding of links between stormwater dynamics and habitat conditions in urban greenspaces, we deployed a high-frequency monitoring network within a range of natural and restored prairie-wetland systems in the Indian Boundary Prairies complex. IBP is a headwater system spanning the flood-prone municipalities of Markham, Midlothian, and Harvey in the Chicago metropolitan area (Cook County, Illinois, USA). The sensor network provides semi-continuous observations of both surface and groundwater levels, along with temperature and electrical conductivity data that we used to assess propagation and storage of urban runoff. We found that surface-groundwater interactions play a key role in storing urban runoff both on storm-event scales and longer-term seasonal scales. Extensive urban runoff into the prairies and short-term storage (days-to-weeks) substantially reduces stormwater flows to downstream urban communities. Longer-term subsurface storage (weeks-to-months) supports hydric prairie and wetland ecosystems through the spring and early summer seasons. Both natural and restored prairie-wetland systems provided strong benefits for stormwater storage, suggesting that renaturalization of degraded urban lands can be an effective strategy for stormwater management in low-lying landscapes. Contaminants derived from urban runoff, such as road salt, were observed to propagate to the interior of prairies and into central wetland systems, but salts do not appear to accumulate as they are flushed seasonally by high-precipitation events in the spring. Through the new NERC-NSF SmartWater project, we will establish the role of headwater ecosystems such as IBP in mediating contaminant source activation and track contaminant pulses through urban stream networks in Chicago, Birmingham, and London.

High-frequency sensors in detection of stream water quality trends and impacts of gypsum soil amendment at different scales

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Water quality variation has been continuously monitored by sensors in Finnish agricultural and mixed land use catchments over a decade. We explore water quality trends based on hourly water quality sensor data collected at two sites during 2011–2023. The Vantaa River is a relatively large (1 680 km²) mixed land use catchment that discharges into the Gulf of Finland in the Helsinki metropolitan area. The river has a total length of 101 km. A water quality station is situated approximately 10 km upstream of the river mouth. The second study site is the Lepsämänjoki River (23 km²) sub-catchment of the Vantaa River, which is dominated by agriculture (36,5%). In the 2018–2019 period, 40% of the fields in the Lepsämänjoki catchment were treated with gypsum. The purpose of the gypsum treatment is to reduce erosion and P losses, particularly from clayey soil fields. In these two sites in-situ turbidity, nitrate-nitrogen and total organic carbon sensors have been operational since 2010. Furthermore, our results are analysed in relation to an earlier study by Tattari et al. (2017), who conducted a temporal analysis of trends in concentration and loads of total nitrogen (TN) and total phosphorus (TP) over the period of 1981–2010. Two of the four agricultural sites in their study exhibited a significant increase in TN trend, while TP concentrations exhibited a weak downward trend. No trend was observed for TN or TP concentration in the mixed land use catchments. Our preliminary results of the Mann-Kendall trend test suggest an overall decreasing trend for flow-weighted TN concentration ($p=0.003$) in the Vantaa River. However, no trend was observed for TP or total suspended solids. Therefore, the positive effects of the gypsum treatment observed in the Lepsämänjoki sub-catchment were not reflected on a large scale.

*We wish to mention that the Vantaa River monitoring station has been renewed in 2023 and it has now brand-new sensors for turbidity, nitrate-nitrogen, fDOM and tryptophan monitoring.

High frequency measurement of nitrate, DOC and turbidity for NbS evaluation

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Water quality problems within streams in the UK and internationally are often most severe during flood events. Quantifying such 'hot moments' requires high frequency measurements of the water quality variables of concern and the controlling stream discharge. This is particularly the case when we attempt to quantify potentially beneficial changes arising from Nature-based Solutions (NbS) to mitigate the problems. High frequency (sub-hourly) continuous monitoring does however, remain technologically challenging for some key water quality variables.

We bring together our learning from high frequency continuous monitoring of turbidity (calibrated to suspended sediment concentration), dissolved organic carbon and nitrate for a range of NbS. Recommendations for delivering concentrations and loads (fluxes) sufficiently accurate for time-series analyses using System Identification Models (eg CAPTAIN for Matlab), are illustrated with examples from our sites in tropical Malaysia and temperate UK. Our ongoing measurement challenges are highlighted.

Towards an Improved Framework for Modelling Mitigation Measures with High-Resolution Water Quality Data

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The advances in collecting high-resolution nutrient data from small, agricultural catchments over the past decade have enabled catchment modellers to gain unparalleled access to sub-daily or even sub-hourly monitoring data. Arguably, the existing catchment-scale hydrological models have not made full use of the vast opportunities available from using these datasets. This applies to the simulation both of baseline hydrological conditions as well as scenarios to assess the impacts of mitigation measures on point and diffuse nutrient pollution. The two main limitations have been: (i) a use of the daily time step in simulations, which tends to result in the sub-daily signals of nutrient responses (mostly phosphorus (P), but occasionally nitrate-N too) not being picked up, and therefore omitted in the modelled processes; (ii) mitigation measures being represented rather crudely in the models often as a simple “removal efficiency”, applied to reduce the loads of sediment and nutrient transported through the catchment outlet by a fixed ratio.

The development of an enhanced version of the Catchment Runoff Attenuation Flux Tool (CRAFT) is presented here that can address these shortcomings firstly by running on an hourly time step using re-scaled hourly nutrient, sediment and discharge data from the Irish Agricultural Catchments Programme (ACP). The new variant can firstly simulate the impact of offline storage ponds, which although originally developed for flood mitigation schemes can also when combined with sediment traps, add ecosystem functions to the scheme by removing sediment, particulate forms of P and potentially nitrate as well through uptake. Preliminary simulations from two ACP catchments (dominated by grassland and arable respectively) are applied here to several years of hourly data from the entire catchments as a “best case” scenario to enable the impact of various mitigation scenarios to be evaluated. This research will be extended to look at inline measures such as multi-stage ditch experiments to mitigate nutrient pollution in first or second order channels.

Agricultural Stakeholder Engagement in a High Resolution Water Quality Monitoring Programme: Experiences gained over 15 years in the ACP

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The Agricultural Catchments Programme (ACP) has been working with over 300 farmers in six contrasting small agricultural catchments for 15 years, monitoring water at a high resolution to evaluate the Nitrates Action Programme (NAP) regulations. Engagement with the programme has evolved over that time and contrasts significantly between the different agricultural sectors practiced in the six catchments, Dairy, Tillage, Beef and Sheep. Farmer engagement is driven by the provision of a free agricultural advisory service to those with land within the catchments. Nutrient management advice accompanying soil analysis had the biggest impact when the programme commenced. ACP farm advisors do not focus solely on water quality issues, and provide a broad advisory service also covering husbandry, financial and scheme related issues.

The ACP has been served well by taking an informal approach to the provision sites for monitoring equipment and personal intrusion on the landowner should always be considered when selecting suitable locations. Cognisance of individual circumstances, preferences and personalities is always important and co-operation should never be taken for granted. While collaboration with other projects has many advantages, there are also risks, and an understanding of the established relationship between individual farmers and the ACP is essential.

More recently, pressure to reduce farm stocking rates and consequential financial implications has led to a significant increase in engagement from the dairy sector, focusing on results from the catchment that best represents intensive dairying. This is not just from the farmers managing land with the catchment, but also from dairy co-op's, farm organisations, regulating agencies, politicians and the media. The robust nature of results achievable from high temporal resolution monitoring over a long timeframe is key to this increased engagement.

Poster Abstracts

Understanding how reservoirs influence riverine ecosystem: Investigating ecosystem health in a changing climate

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This study focuses on assessing the risk posed by UK reservoirs as sinks and sources of pollution to downstream river ecosystems. Globally, reservoirs are increasingly acknowledged due to their pivotal ecosystem service roles in the maintenance of water supply, regulation of terrestrial hydrology, carbon sequestration, and global biodiversity. Other key functions include water storage, flood control, hydroelectric power generation, irrigation, providing recreational spaces, supporting wildlife habitats, and contributing to aesthetic landscapes. Within the UK, 274 reservoirs account for over 91% of the UK's stored water.

Reservoirs, usually formed by the damming or impounding of a river valley, are often characterized by limited horizontal water movement, and hence, exhibit heightened sensitivity to environmental changes and anthropogenic influences. They have critical impacts on river systems through the interruption of the natural hydrology, sedimentation, and water chemistry, and through compensation outflow discharges which deliver both water and sediment to downstream water bodies. Existing research marks reservoirs as important sinks for nutrients, pollutants such as persistent poly- and perfluoroalkyl (PFAS), bisphenol analogues, pharmaceuticals, alkylphenols, heavy metals, polycyclic aromatic hydrocarbons (PAH), herbicides, phthalate esters, fungicides, organophosphate esters, pesticides, etc. Despite this established consideration, little is known about phased out contaminants that constitute legacy pollution and how these can become future pollution sources, due to contaminant desorption, resuspension, and re-release into the water column, in response to environmental change (i.e. drought, wind, increased temperature, flooding, cascade events) and reservoir operational activities (draw down, artificial aeration).

To bridge this knowledge gap, this study will combine field and laboratory empirical measurements, to characterise the reservoir-river ecosystem (inlets and outlets). We will collect sediments samples from reservoirs to create a chemical fingerprint to identify what is present in the samples and characterise chronological historical records of contaminants in the sediments using ²¹⁰Pb dating of sediment cores. Paleolimnological records of reservoir sediment will be cross-referenced with known dates of ban/phasing out of contaminants and re-introduction of alternatives or replacements (as is the case of BPA and BPS, pesticides and anti-biotics) to trace anthropogenic impacts. Analytical extraction (solid phase, BCR sequential, Soxhlet, pressurised liquid) followed by separation with Chromatography tandem Mass spectrometry (LC/MS/MS, GC/MS/MS, HPLC/MS/MS, UPLC/S/MS, ICP/MS/MS) will be used to analyse sediments for compounds flagged by the Water Framework Directive (WFD), Drinking Water Inspectorate (DWI) and Severn Trent Water Company.

The findings of this study will provide the first, detailed characterisation of overlooked contaminants in UK reservoir sediments and contribute to a better understanding of the scale of risk associated with reservoir systems in terms of ecosystem function, water quality, regulatory compliance, and drinking water security. The results will be crucial for informing management strategies aimed at mitigating the adverse effects of reservoir pollution on aquatic ecosystems and human health.

Surface-enhanced Raman Spectroscopy as a Promising Tool for High-Resolution Water Quality Monitoring

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Surface enhanced Raman spectroscopy (SERS) is an analysis technique where the weak Raman scattering signals emitted by molecules are amplified when they are adsorbed or in proximity to metal nanostructures. Although SERS has been widely used in biomedical applications, it is now emerging as a promising technique for environmental applications. While SERS may not match the sensitivity levels of sophisticated techniques like GC-MS and LC-MS/MS, these techniques are slow and labour-intensive. In contrast, SERS provides distinct spectral signatures for molecules compared to techniques such as UV-VIS and fluorescence spectroscopy, which are often used for high-temporal chemical data acquisition. Combined with its portability, low cost, and ease of use SERS emerges as an ideal sensor tool for environmental monitoring and assessment, as an aid for water management. Application of SERS can broadly be categorised into two types- targeting specific analytes with enhanced sensitivity and selectivity through surface modification/functionalisation of SERS substrates, and second, employing it more as a fingerprinting tool in combination with digital/statistical tools (such as principal component analysis and Machine learning). The latter application is suitable in areas such as high temporal water quality monitoring and source tracking of waste discharges. SERS for environmental applications is still an evolving field. The development of reliable and reproducible SERS substrates, standardisation of measurement protocols, interpretation of SERS spectral features are ongoing challenges. Scientists are investigating various digital techniques that can be used in conjunction with SERS data for various applications. The presentation will explore some of the applications of SERS in environmental monitoring and share some initial findings.

A mobile, trailer-based platform for high temporal resolution water quality monitoring.

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High temporal resolution monitoring of water quality parameters, hydrometrics and stable water isotopes can yield significant insights into the processes and flow paths driving impaired water quality. Advances in instrumentation, including field-deployable hyperspectral UV spectrometers and laser spectroscopes, have prompted the development of high-resolution, in-situ water quality monitoring systems. Generally, however, such systems are restricted to sampling one or two water sources in a single location, limiting the potential for developing a holistic understanding of catchment functioning. Here, we introduce the Water Analysis Trailer for Environmental Research (WATER), a mobile, trailer-based platform capable of evaluating a variety of parameters for up to 12 water sources. The temporal sampling resolution for each water source depends on the total number of water sources under consideration (between ~20 minutes and four hours for one to 12 water sources, respectively). A hyperspectral UV spectrometer measures nitrate, total and dissolved organic carbon, and total suspended sediments. Meanwhile, electrical conductivity, pH and water temperature are measured with a multi-parameter probe. Stable water isotope composition can be assessed via a cavity ring-down spectroscopy system, whilst a custom-made automatic sampler can collect and freeze up to 288 water samples for later analysis in the laboratory. Water sampling can also be complemented by data (e.g., soil moisture and temperature) collected via a remote sensor network linked to WATER. To demonstrate the potential and value of WATER for advancing understanding of water quality dynamics through high temporal resolution monitoring, we will provide an overview of the data and insights gained from the platform's initial deployment to the Schwingbach Environmental Observatory in Hessen, Germany.

Integrating high-frequency water quality monitoring with long-term conventional algal assessment for reservoir algal bloom monitoring

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Risk of algal blooms has been a key component of management for drinking water reservoirs in the southwest of England. Across the region, the measures implemented aim to reduce cell densities of blue-green algae (BGA) blooms to 20,000 cells mL⁻¹. Traditionally, monitoring of algae is undertaken through microscopes for species enumeration and quantification fortnightly/monthly to inform any potential blooms. Recently, the advances in high-frequency sensors have provided opportunities for continuous monitoring of proxies for algae concentration, typically as fluorescent values.

However, the results of the two monitoring methods may not always correlate depending on the composition of algal species, environmental conditions and stress. This results in challenges in data integration and estimation of continuous algal concentration/cell densities critical to water supply and treatment works in response to the timing, duration and magnitude of blooms. Additionally, there is little discussion on how to optimise the use of fluorescent sensors with the incorporation of historical long-term water quality datasets to inform reservoir algal bloom monitoring and forecasting. Therefore, in this study, we aim to link results from traditional algal analyses (microscopic and pigment concentration analyses) with high-frequency monitoring data (fluorescent sensors) along with basic water quality parameters to develop appropriate approaches for reservoir algal monitoring and data integration.

Three reservoirs subject to risks of BGA blooms in the southwest were selected for this study. We will perform multiple regression analysis for weekly/monthly grab samples over two decades to investigate 1) whether there is any relationship among BGA, other algal species and the parameters of water temperature, pH, conductivity, turbidity of reservoir raw water; 2) whether it is achievable to use high-frequency multiparameter sondes which include fluorescent measurements of phycocyanin, chlorophyll-a and other water quality parameters to approximate continuous BGA concentration and cell densities based on the site-specific relationship and seasonal pattern established.

Sensors for stakeholders?

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Are high resolution real-time sensor data primarily a tool for science, or can they also be directly useful for managers and other stakeholders? Can they contribute to awareness and creating increased interest for local water quality in streams? These questions are asked in the EU-funded [NORDBALT-ECOSAFE Project](#), where the practical use of sensors for stakeholders is explored in six North-European countries (Denmark, Finland, Latvia, Norway, Poland and Sweden). We focus on sensors that can monitor turbidity and nitrate in streams, but also other relevant parameters are included wherever data are available (e.g., pH, conductivity and temperature). Our team has asked stakeholders in the six countries of their views on the usefulness of sensors, especially related to the needs for monitoring rivers under the EU Water Framework Directive. Questions have been asked in the form of quizzes by using an interactive presentation software in regional stakeholder meetings, whereas a questionnaire was developed and used to perform more in-depth interviews with national managers. Presently, real-time data from local streams are now displayed on the project internet page as well as national web pages, and we will monitor if stakeholders check in on these web-pages and ask them to which extent they find the data useful (<https://projects.au.dk/nordbalt-ecosafe/sensor-monitoring>). A challenge is that real-time data are not yet quality controlled or calibrated, and we have therefore provided information on typical errors or anomalies in sensor data on the website. To trigger more interest, we have also prepared a [4-page policy brief in both English and national languages](#), where we outline advantages and challenges with sensors, and where we also summarise how sensors are used by managers in different countries. The project is mid-term, and this poster will display the current status and point to the upcoming activities on sensors in the NORDBALT-ECOSAFE Project.

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Evaluating the efficacy of agri-environmental measures on nutrient and suspended sediment concentration in agricultural catchments using sub-daily stream water quality measurements

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Hydrologically dynamic river systems are a challenge for entirely sensor-based, bankside monitoring systems. Rapid fluctuations in river levels, sediment laden waters and debris disturbance to equipment or intake pipes can lead to instrument failure and data gaps at critical periods. This was the challenge in Northern Ireland where high-resolution monitoring stations were required within agricultural catchments for the long-term evaluation of the efficacy of Nutrients Action Programme regulations and agri-environmental scheme measures. After consideration, a combination of sensor-based hourly monitoring and 24-7 hour sampling with laboratory analysis was adopted. Permanent mains powered kiosks were established in four 4 - 8 km² agricultural catchments representing a variety of farming intensities and pressures. Hourly physico-chemical measurement (conductivity, turbidity, dissolved oxygen and temperature) and wet chemical analysis of phosphate are conducted and data telemetered. River water level is measured every 15 min and discharge is derived from rating curves. Underpinning this real-time setup, refrigerated 24-bottle autosamplers continuously take a stream water sample every 7 hours. Each sample is analysed for the main P and N fractions in the laboratory following collection once per week. Suspended solids concentration is determined for every sixth sample. One of the objectives of the stations is to provide the evidence with which to better target nutrient and sediment mitigation measures and further improve water quality in agricultural catchments. For example, following the implementation of Environmental Farming Scheme (EFS) measures in 2021 in one catchment, seasonal median suspended solids concentrations decreased by 8-31% in 2022, and by 34-76% in 2023, this decrease being more pronounced in summer and autumn. In comparison, in another catchment without implementation of EFS measures, spring-summer suspended solids concentrations were 13-16% lower in 2022 but 42-95% higher in 2023, and winter concentrations increased by 52-95%. The 24-7 hourly stream water quality monitoring provides a reliable reference to assess the efficacy of agri-environmental measures on inter-annual and seasonal changes of stream water quality. The hourly data are needed to further understand catchment response in the shorter term (e.g., during rainfall events) but are more challenging in terms of instrument maintenance and data quality control. The kiosks have shown to be an attractive tool for communicating water quality research and findings to farmers and scientists.

The Forth Environmental Resilience Array (Forth-ERA) – monitoring water quality at scale from source to sea.

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This poster will introduce the Forth Environmental Resilience Array (Forth-ERA), a catchment-scale digital observatory for the Firth of Forth catchment that combines data from sensor networks, satellite observations and models to improve the monitoring and management of water quality at scale. Under the umbrella of Forth-ERA, we are installing state-of-the-art sensors for high frequency water quality measurements on a number of rivers, lakes, reservoirs and within the Forth estuary itself. These data are being used simultaneously to support the calibration and validation of a fully operation satellite water quality monitoring service. The integration of machine learning and artificial intelligence is enabling the automation and scalability of data processing and analysis. Ultimately our ambition is to create a digital twin that can be replicated internationally at scale, to transform environmental monitoring, management, and resilience planning.

Nine years of high-resolution river monitoring with *in situ* sensors in Kenya – What did we learn?

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High-resolution water quality data can provide useful insights into hydro-biogeochemical processes – information which is urgently needed to inform sustainable land and water resource management in regions undergoing rapid climate and land use change. However, the long-term deployment of *in situ* sensors for water quality monitoring is still rare in Africa, despite the continuous development of new and improved sensor technologies as well as their decreasing costs. In 2014, we established a hydrological monitoring network covering three sub-catchments of 27 to 33 km², characterised by either natural forest, smallholder agriculture or commercial tea and tree plantations, within a 1021 km² catchment in the Sondu Basin in western Kenya. We instrumented the outlet of each (sub-)catchment with a UV-Vis spectrophotometer for nitrate, turbidity and dissolved organic carbon, a sensor for electrical conductivity and stream temperature, and a radar-based water level sensor. All data are recorded at 10-minute intervals. Here, we present the scientific knowledge we gained from the high-resolution data, but also our experience running such a network in a rural tropical setting. We will discuss aspects concerning setting up a monitoring network, maintenance of the measurement systems, data management and interpretation, highlighting technical and logistical challenges. The lessons learned from the Kenya experience can be of use for others who (plan to) work in similar settings or use similar measurement systems.

Understanding interannual seasonal variability in concentration-discharge relationships: integrating routinely collected data with targeted research

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The concentration-discharge (*c-q*) relationship in streams and rivers often displays temporal variability on diurnal, event, seasonal and annual scales. This variability 1) captures information on sources and the conditions (antecedent and event) for contaminant mobilisation; and 2) provides insight into catchment functions affecting pathways and transport between sources and monitoring locations. This has been widely demonstrated through scheduled sampling, targeted storm sampling and *in-situ* high-frequency collection of water quality data. However, high-frequency data collected over limited field seasons may not represent the complexity of the catchment responses during rainfall-runoff events. In particular, seasonally important catchment functions may be masked if either field seasons are limited, or data collected for longer periods are aggregated annually for analysis.

Within the UK high-frequency water quality data from surface waters is collected routinely by the water industry, with an operational focus for source protection. Even with recent advances, outside dedicated research programs these operationally focused records are one of few sources of multiannual high-frequency water quality data. As such, these data may be crucial in improving our understanding of catchments. However, key limitations in the use of these data include undefined uncertainties and missing data, monitoring design, and limited metadata.

Combining routinely collected data with targeted research demonstrates a range of benefits, including: 1) coordinated collection of calibration samples and investigation of site-specific interferences; 2) integration of medium to long-term analysis with understanding gained from short-term laboratory analysis; and 3) investigation of spatial influences. Reducing the limitations of these datasets can potentially unlocking value in both routine and targeted data. Combining routine and targeted high-frequency data enables the investigation of seasonal change on relation to antecedent and event controls; gives context on changing interactions and effects due to changing climatic and catchment drivers; and provides insight into catchment resilience to extremes and changing stressors.

Using high resolution temporal data and modelling to better target the impact of Nature-Based Solutions on N, P, and sediment pollution in the future.

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The Catchment Runoff Attenuation Flux Tool (CRAFT) is a catchment scale rainfall runoff model that uses hourly data (operating between 1-10km² ideally). CRAFT is designed to investigate the impact of different flow pathway management strategies on nutrient (N and P) and sediment fluxes in the three main flow pathways: the fast near surface flow (which includes overland flow and near surface flow), subsurface flow (including drain flow), and slower groundwater flow. Evidence from the AiMNbS project (Scot Gov), Slowaters (Irish EPA/OPW) and The Woodland Water Code (Forestry Services) will be used. The model now contains functions to emulate increased buffering capacity of the landscape using both online (buffer zones and sediment traps) and offline (flood storage areas and wetlands) NbS measures. Soil health is represented in the model using the infiltration capacity of the lower edge of the cultivation zone. Sediment trap storage with a specified sediment removal rate is included. The buffering capacity of both passive and engineered buffer zones will be shown. The potential of woodland buffer zones (and larger plantations) on farms is also included. An 'aggregate buffering' term (that correlates to existing published residence times and nutrient retention rates parameters) is used to simulate change in Q, N, P and sediment at the catchment scale.

The 11km²Ballycanew catchment in Co. Wexford is presented as a case study as it has suitable high resolution data sets (Irish Agricultural Catchment Programme). Using 10+ years of high frequency water quality and flow data, CRAFT has simulated the following: 1) current land use and weather patterns are generating very large runoff and nutrient losses for long periods of the year (both chronic and acute). 2) The flux of nutrients in small, medium and large storms (flood level) is quite distinct in pattern and hence NbS measures must be targeted at differing parts of the hydrograph to achieve realistic benefits. 3) Future larger storm events will need specific measures to reduce nutrient losses. 4) The amount of NbS interventions needed to have an impact will have to be significant and operate highly effectively. Results show that changing flow pathways using NbS features can significantly reduce the diffuse pollution levels leaving the catchment but only if implemented in a targeted way.

High frequency monitoring of dissolved oxygen in streams - a useful tool for water management

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Levels of dissolved oxygen (DO) in streams is vital for various ecological processes, and could serve as an indicator of water quality. Low levels of DO affect aquatic organisms, but could also shift the biogeochemical dynamics in the system (e.g. favouring phosphorus release from the sediment). Low oxygen levels could indicate pollution problems, but might also be caused by excessive plant growth (decomposition) and low flow/high temperature conditions in the summer. High frequency dissolved oxygen has been monitored with in-situ sensors at 8 streams in Sweden (between 3-6 years), partly funded by the National Monitoring Programme and partly by research projects. The aim of this project was to explore periods of low oxygen conditions and hypoxia in the different streams, e.g. severity, frequency and duration. Most sites show a strong seasonality, with low DO concentrations during summer. However, the severity and duration of these conditions varies a lot, where some streams show yearly DO levels in the risk zone while some never experience harmful conditions. Underlying reasons for the low oxygen conditions will be explored, e.g. by analysing metabolic regimes, response to events of high precipitation/discharge, and co-variability to other water chemistry parameters (high- and low frequency data). By this multi-site approach, risk factors could be identified and the usefulness of high-frequency monitoring of DO exemplified for future water quality management.

High-frequency water quality monitoring to support a spatial targeting approach for nutrients in two agricultural catchments

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During the past thirty years, the water quality in Dutch agricultural areas has improved, but still not enough to meet the goals for the Nitrates Directive and the Water Framework Directive. The national government of The Netherlands currently makes a case for a spatial targeting approach for nutrients in problematic catchments. However, without a clear image of the hot-spots and hot-moments of nutrient losses within those catchments, it is not possible to take focused and effective measures. Region-specific mitigation also requires region-specific monitoring.

The aim of this research is to explore the possibilities for supporting a spatial targeting approach for nutrients with new monitoring strategies. We designed and implemented detailed monitoring networks within two headwater catchments with intensive agricultural land use. The Vuursteentocht is a 13 km² regulated polder catchment in the clay region. The Vinkenloop is a freely draining 7 km² stream in the sand region.

In this presentation, we focus on the results from two mobile laboratory equipped with sensors and auto-analyzers for P_{tot}, TRP, NO₃⁻, NH₄⁺, EC, pH, and O₂. The continuous measurements produced valuable insights into hot-moments of nutrient losses. We registered the water quality responses to precipitation events, ditch and culvert maintenance, irrigation, weir level adjustments, and some unknown direct inputs. In combination with other monitoring data (e.g. discharge, precipitation, groundwater levels, conventional water quality sampling), the continuous data enabled closing the water and solute balance and the calculation of contributions of seepage and agricultural drainage to the total nutrient loads to the stream.

The collected monitoring information unraveled the within-catchment nutrient sources and transport routes. We consider this to be a good starting point for selecting the right mitigation options at the right locations in discussion with farmers, the water boards, and other stakeholders.

SMARTWATER : Diagnosing controls of pollution hot spots and hot moments and their impact on catchment water quality

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Water pollution is an escalating global issue, with many rivers failing to meet water quality standards. To comprehend the underlying causes, adapt strategies, and develop improved mitigation approaches, it is important to gain an understanding of average pollution conditions, as well as understanding pollution spikes. The SMARTWATER project aims to pioneer innovative solutions for diagnosing multi-contaminant water pollution hotspots (spatial) and hot moments (temporal) through 5 work-packages spanning experimental analytics, novel sensor creation, data science and mathematical modelling, and stakeholder community engagement.

A water quality monitoring network is being established across several river basins to generate high frequency data, to understand key drivers of water quality dynamics monitoring platforms will be equipped with commercial water quality sensors alongside newly developed cost-efficient sensors capable of capturing a suite of pollution indicator variables. Data science innovations will leverage new and historical data to build our understanding of the mechanisms that control the connection between pollution sources and the location of hotspots and duration of hot moments within river networks.

Having recently initiated the project, we have now established standardized sentinel measurement sites on the headwater streams of the UK rivers Trent, Severn, Thames, and in the US, the Little Calumet and Chicago River watersheds. These sites make use of in-situ fluorescence and UV absorption for nutrient and dissolved organic matter characterization, alongside other physico-chemical parameters. Existing data is being collated for modelling, where national and catchment scale hydrological modelling will focus on the use of DECIPHeR. Model uncertainty assessment and sensitivity will be evaluated using the SAFE toolbox. The SMARTWATER project is currently in the process of collecting detailed high-frequency data across several catchments and will, in the future, improve our mechanistic and predictive understanding of pollution hotspots and hot moments, and improve mitigation strategies.

Differentiating between catchment and in-stream processes by using multivariate and multisite high frequency data

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A sound understanding of hydrological and biogeochemical processes and their respective spatial and temporal hotspots is crucial for effective large-scale watershed management. However, extracting meaningful insights from large, complex datasets can be challenging. In this study Principal Component Analysis (PCA) is applied to high-resolution multivariate data and to unravel hydrological dynamics in the Bode River Basin, Germany. This catchment covers an area of 3300 km² and comprises a variety of landscapes and land uses, from forested mountains to agricultural lowlands. Six key water quality parameters were continuously monitored at five stations across the basin at 15-minute intervals from 2013 to 2020. The first principal component explained 46% of the total variance and described the interplay between base and storm flow and its effects on water quality. The second component, which explained 13% of the variance, captured the discharge of saline groundwater upwelling in the downstream reaches of the river during low water. The third component, contributing 7% of the variance, was closely related to diurnal oscillations of pH. Since the first two principal components have eliminated other effects on pH, this pattern could be attributed to the diurnal pattern imposed by algal photosynthetic activity. Remarkably, it showed not only a seasonal pattern, but also substantial short-term variability, as well as large variability between different stream reaches and between years. In particular, the warm years of 2019 and 2020 stand out in this regard. The application of high-resolution multivariate data and the use of PCA proved instrumental in discerning complex interactions within hydrological ecosystems. Further studies employing similar methodologies may improve our ability to predict and understand the impacts of anthropogenic and natural factors in large-scale watersheds.