

January 2024
Environmental Chemistry Group
Bulletin



Interview: **Stuart James** tells us about porous liquids and their emergence at the forefront of separation materials. **Kiri Rodgers** reviews her varied career in the environmental sciences.

Meetings: **Laura Alcock** reports on **Symiah Barnett's** microplastics pollution webinar for World Environment Day, and **Rowena Fletcher-Wood** shares ECG outreach evaluation strategies with other science communicators at the BIG Event.

Book reviews: **Laura Alcock** reflects on *Transition towards a sustainable biobased economy*.

Articles: **John Collins, Rob Fryer** and **Fiona Regan** summarise their 2023 ECG Distinguished Guest Lecture talks on water regulation, wild swimming, and *in situ* monitoring, respectively; **Alun James** and colleagues from the UK's Environment Agency give an overview of the environmental impact of PFAS.

Environmental Brief: **Nitin Khandelwal** discusses nano-enabled sorption techniques for the amelioration of contaminated waters.

Also in this issue: **Rowena Fletcher-Wood** summarises the year in the Chair's Report.

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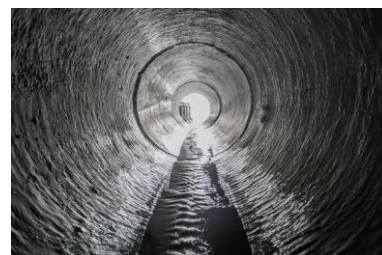
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Front Cover — Exit from the drainage sewage tunnel pipe. Concrete Drainage Pipe, collector of city sewage system.



Report

Chair's Report for 2023

Rowena Fletcher-Wood (freelance science communicator, rowena.fletcherwood@gmail.com)

Whilst our event numbers and attendances continue to fluctuate year-on-year, in 2023, we saw a return to pre-pandemic event numbers and attendances, due to our two flagship events, **#Env Chem 2023 : Chemistry of the Whole Environment** and the **Distinguished Guest Lecture**, and to a number of outreach activities, which always draw large audiences. We have also been working on the Group's website and *Bulletin* referencing style to make them consistent with RSC branding, and their accessibility.

We have had fewer committee changes in the last year, with no new recruits, and just two goodbyes: to **Dr Irene O'Callaghan** (University College Cork), who contributed to *Bulletin* editing, and **David Owen**, *Briefs* co-ordinator and Environment, Sustainability and Energy Community (ESEC) representative (pictured). David retired from the committee in September after a motor neuron disease diagnosis, and sadly died in November 2023. As a friend as well as a fellow volunteer, he will be greatly missed. Always engaged with environmental chemistry to the last, one of David's articles appears in this *Bulletin* edition (pp. 6-8). You can also read about his career in his ECG Interview (July 2022, p. 3 <https://www.envchemgroup.com/david-owen.html>).



In March 2024, we will be seeing some further committee changes, as **Dr Valerio Ferracci** retires as treasurer, and I step down as Chair. However, I continue to represent the ECG both on the committee and as an elected member of the RSC Members Community Board, who oversee RSC Interest Groups and RSC local sections.

In 2023, the committee organised eleven events, including our two flagship events **#EnvChem2023: Chemistry of the Whole Environment**, Glasgow and hybrid, 1st-2nd June (see July 2023 p. 14), and **Distinguished Guest Lecture** *Water, water, everywhere - is it still safe to drink? The pollution impact on water quality*, 22nd May 2023, hosting **Professor Barbara Kasprzyk-Hordern** as the Distinguished Guest (see July 2023 p. 10).

The postponed **State of the Art in the Analysis of Complex Environmental Matrices** was held as a series of four 90-minute lunchtime webinars on 9th, 23rd January and 6th, 20th February (see July 2023 p. 7). **Symiah Barnett** (Loughborough University) also ran her RSC outreach grant-funded event *Become a Chemist for a Day* at Reading University on 3rd April (see July 2023 p. 9), and gave a pollution awareness webinar for World Environment Day, 5th June, at Edwards Ltd (see p. 9). **Niall Marsay** led a team of volunteers to two outreach events: **ATOM** in Abingdon and IF Oxford, where we performed public demonstrations such as the smoking ocean acidification (see July 2019 p. 22) and hands-on family-friendly science activities. In addition, I showcased our evaluation outreach activity *Float or Sink?* at the British Interactive Group (BIG) Event 28th July (see p. 10).

Our events totalled:

- 185 in-person attendees (excluding outreach)
- 215 online attendees
- ~170 meaningful outreach engagements (and ~1400 festival attendees)
 - 39 oral presentations
 - 1 round table discussion
 - 22 posters

Our website has also seen a good number of visits. We saw more than **11,300 unique visits** January-October 2023, and over 15,000 page views. Analytics show that most (~89%) of viewers come through Google. With 158 views, our *Environmental Briefs* steal the lead for most visited web page, followed by the 2007 article on climate change, methane and ozone (<https://www.envchemgroup.com/climate-change-methane-and-ozone.html>), which was most popular

last year.

We also announce the creation of a new ECG website. Symiah Barnett has redesigned the existing site to make it look more consistent with the parent Royal Society of Chemistry website. Our new website is found at rsc-ecg.com, whilst legacy pages have been retained at [envchemgroup.com](https://www.envchemgroup.com). In particular, you can find historic ECG Newsletters and ECG *Bulletins* from 1995 at <https://www.envchemgroup.com/pdf-bulletins.html>. The new look is part of our drive to create consistent branding and, hopefully, more accessible *Bulletin* publications. You may also have noticed a move towards RSC formatting and referencing style (<https://edu.rsc.org/download?ac=522463>), present in the last two ECG *Bulletins*. Work is still progressing in this area.

Interview

The ECG Interview: Dr Kiri Rodgers

(University of the West of Scotland, kiri.rodgers@uws.ac.uk)

Kiri completed her PhD degree in environmental geochemistry at the University of the West of Scotland in 2017. Since then, Kiri has been a postdoc, R&D tax specialist, research fellow, and now a lecturer in environmental science. Her research started with steel waste characterisation and remediation, and now she focuses on environmental antimicrobial resistance.

What inspired you to become a scientist?

I wanted a job that challenged me and was never boring. Growing up, I was obsessed with CSI, the excitement of different crimes and amazing science that answered all their questions! This led to analytical chemistry at the University of Plymouth.

How did you come to specialise in environmental geochemistry?

During my undergraduate degree, we were exposed to a wealth of different applications and research. I was lucky, and worked with Dr Miranda Keith-Roach, looking at the immobilisation and/or remediation of environmental radionuclides. This project highlighted the importance of caring for the environment, but also fixing the damage we have already caused. That was it, I was hooked! I graduated around the time of the Fukushima nuclear disaster, and that solidified my interest in tackling environmental problems. I worked for the environment protection agency (EPA), but then a PhD on mitigating environmental impacts of steel waste pollution came up. This study opened my eyes to industry, as well as environmental and scientific techniques that could be used to tackle environmental questions. This led to geochemistry postdocs tackling antimicrobial resistance, making me an interdisciplinary scientist, and letting me travel and explore the world.

Could you describe your current job? I am now the programme leader of a brand-new Applied Environment Science and Sustainability course at the

University of the West of Scotland. This role allows me to teach the next generation key environmental science concepts to tackle global threats. My research includes antimicrobial resistance and impacts of climate change.

What advice would you give to anyone considering a career in environmental chemistry?

Follow what interests you! Environmental chemistry is the basis of a broad range of career options and disciplines, whether you want to work in the field, lab, office, industry or politics. Also explore different areas; I have worked for the EPA in both industrial and research laboratories, and for a corporate company. Some positions seemed like a step back, but every role contributed to the researcher and academic I am today.

What are some of the challenges facing the environmental chemistry community?

Action! It is easy to talk about problems and solutions, but implementing change is the real challenge. We as scientists need to focus our efforts on networking with people who can implement change.

What is the most rewarding aspect of your career so far?

There are two contrasting moments in my career to date:

1. Since finding my niche area of research, “role of the environment on the prevalence of antimicrobial resistance”, I have worked with stakeholders to influence policy in India. This is working progress, but it’s great to see research influencing change.
2. At a science festival, I witnessed primary school children educating their parents on recycling and not using glitter. The next generation leading the way for environmental change!

If you weren’t a scientist what would you do?

I can’t imagine myself in any other role; however, I believe I would be working in politics to implement change.

And what do you do when you are not working?

Going on hill walks with my precious puppy, Lola. My dog is my world!



Book review

Transition towards a sustainable biobased economy

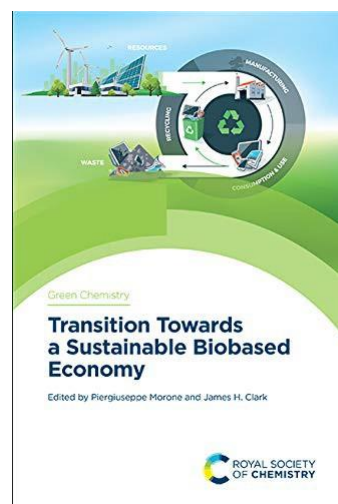
Laura Alcock (Edwards Ltd,
laura.alcock@edwardsvacuum.com)

This book, by two leading experts in green chemistry and the green economy, Morone and Clark, analyses the sustainability impact of transitioning from fossil-based to biobased products, primarily (though not exclusively) from an environmental perspective.

The opening sentence of the introduction to *Transition Towards a Sustainable Biobased Economy* states that “Europe is confronted by the depletion of natural resources due to, among other issues, their unsustainable use, increased global competitiveness, the global population growth rate, and other challenging environmental and economic issues”. This stark statement sets the precedent upon which the need for transitioning to a more sustainable production economy is further explored and is reinforced with the suggestion that biobased products offer an opportunity to utilise more renewable resources to meet industrial needs. The authors explore multiple renewable resources as well as a substantial number of potential applications for each in industry.

The book provides a “scientifically based harmonised approach for environmental, social and economic sustainability assessments”, highlighting that techno-economic uncertainty can be reduced by internal cost and benefit analysis, whilst environmental and social uncertainty are addressed through assessing external costs and benefits. With this information, tools can be defined for reducing market and policy uncertainty and encourage uptake of biobased products. It is not until reaching sections 1.3 and 1.4 that the book’s objectives are more clearly outlined, providing explanations for the jargon used in earlier sections. There is then a clear outline of each chapter set out and the uncertainty domains of analysis and impact for each.

Chapter 2 identifies the disproportion in available literature primarily in favour of biofuels, rather than other biobased products. It then goes on to analyse the comparative sustainability of various renewable resources as feedstocks up to their entry into the factory where they are processed to become raw materials for bioproduct manufacture. The chapter draws attention to the fact that environmental impact is not limited to



greenhouse gas emissions and carbon footprint, meaning that further aspects must be considered when assessing sustainability. Chapter 3 assesses the environmental impact of the final product after the raw material has been processed for its application.

Chapter 4 challenges the concept that economic growth should not be dependent on the use of resources, nor resource use directly correlate to a negative environmental impact. It goes on to analyse the techno-economic efficiency of biobased products and the manufacture routes from raw materials to produce them. Chapter 5 then presents an analysis of the market dynamics to identify sustainability criteria which can be easily understood by all consumers looking to understand and improve their sustainability. Chapter 6 assesses the social life cycle of the products to determine the impacts on human health and provide indicators for use by policymakers seeking to transition towards a biobased economy.

Chapter 7 considers the interesting instances, where land use change may produce a negative result in order to meet the resource demand for biobased products as the economy expands. The environmental and social impacts of this are considered and compared. Finally, it provides a risk management method to mitigate the negative impacts of this growth.

This book provided a new and somewhat refreshing lens to review the sustainability of renewable resources and the methods through which they are utilised to manufacture alternative products to fossil fuels. Errors in grammar disrupt the flow and readability of the text, but the book is an interesting and insightful one, providing an excellent source of information to anyone looking to understand the impact of biobased products and how to move towards an economy reliant on them.

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Interview

Porous liquids: An interview with Professor Stuart James

Rowena Fletcher-Wood (freelance, rowena.fletcherwood@gmail.com) and David Owen (TreatChem Ltd, david.owen@treatchem.co.uk)

In July 2023, **Dr Rowena Fletcher-Wood** and **David Owen** of the ECG interviewed **Professor Stuart James**, Queen's University, Belfast about his work on porous liquid technologies. This new technology has recently emerged at the forefront of separation materials which have applications in green chemistry.

Concept

Can you start by outlining how you first developed the concept of porous liquids?

I came up with the concept of porous liquids in 2007. I co-founded *Porous Liquid Technologies* to spin out this technology in 2017 and implement greener, more sustainable processes.

This followed an initial spin-out in mechanical chemistry. I have a strong interest in solvent-free chemical syntheses. People use solvents, but instead, you can simply grind solids together and get reactions to go. It seems very primitive, it seems like it shouldn't work, but actually, it can work very well.

What started as curiosity became a spin-out company (then called Morph Technologies). Now, the area of mechanical chemistry has boomed over the last 20 years.

Is that where the goal of all your work lies, in green and sustainable chemistry?

It has become that way, I think largely because of global drivers. Maybe it takes a bit of a crisis, for example, the need for sustainability, to make people rethink the ways we are doing things. Then we transition to new technologies. My personal driver was inventing something new; a new idea, a new technology, something that had never been done before. But inevitably, you start to think, how could we apply this to something usefully?

Technology

Can you tell us more about how porous liquid technology works?

Imagine a gas dissolving in a liquid, that could be, for example, carbon dioxide from the air dissolving in water,

there is a limit to how much gas can dissolve in that liquid. But what causes that limit? One factor is that if a gas molecule dissolves in a liquid, the liquid molecules have to get out of the way. You have to separate the liquid molecules, and ones such as water stick together very strongly through hydrogen bonds.

So, what happens if you make holes in the liquid? The gas molecules don't have much work to do. They don't have to separate the liquid molecules anymore; the holes are already there. The gas can dissolve in the liquid much more easily and you can get much more gas into the liquid.

That's what we call a porous liquid, a liquid with permanent holes. Each hole is microscopic: about the size of a gas molecule. They're not bubbles; they are far too small to see. Dissolution is the enthalpically driven.

We have increased the solubility of the gas, and so changed the thermodynamics. Empty porous liquids contain naked surfaces, which are thermodynamically unfavourable in terms of ΔH . Binding a gas molecule to the walls of the hole through dipole-dipole interactions is exothermic, giving a more negative Gibbs free energy.

How do you introduce holes to liquids?

We have discovered various ways to create these holes. When we first proposed the idea of porous liquids, we built organic cages called metal organic frameworks (MOFs) that could be suspended in a solvent. It was a proof of principle experiment, and it worked.

This was, however, a very time-consuming process, it would take about six months to make 1 ml of porous liquids. But if we were going to ever apply this, we realised this approach would never work. It was far too expensive.

Instead, we discovered that a very simple approach was to disperse a zeolite in a liquid with molecules too big to fit in the zeolite pores, creating something that looks like milk. If the dispersion was stable enough, it could last for a few hours, days, weeks, or months. This is very economical, and it's surprising no one's done it before!

Maybe it takes a bit of a crisis, for example, the need for sustainability, to make people rethink the ways we are doing things

Choice of materials

What makes zeolites attractive for porous liquid syntheses?

A number of elements. On the one hand, they are already produced on huge scales, and there is literature and knowledge to draw upon. Also, zeolites are chemically and thermally stable, which means we don't have to worry about degradation.

What liquids do you suspend the zeolites in?

We suspend them in something, massively available, such as polyethylene glycol, which is extremely cheap. In addition, its derivatives are already used to separate CO₂ from hydrocarbons. This solvent dissolves a substantial amount of CO₂ and is soluble in hydrocarbons. Both the zeolite and solvent are now CO₂ selective, boosting the CO₂ carrying capacity by a factor of 2 or 3, and, fortunately, the pores of the zeolite are too small to let the solvent into.

However, in our porous liquids, most of the gas dissolution capacity comes from the solid, which means you don't necessarily have to stick with common, ordinary solvents. We have found we can use silicones, like polydimethyl silicone (PDMS), which is a terrible solvent for most gases. However, it is cheap, inert, and hydrophobic. We have been working on water-based liquids as well.

Applications

Can you give us some examples of key separation possibilities?

Let's say the holes are about the size of a carbon dioxide molecule, but just too small for a larger molecule like methane. This means that you selectively dissolve carbon dioxide, and exclude methane. This is useful when you have a mixture of gases. A good example is biomethane – making methane from farm waste, which presents as a mixture of methane and carbon dioxide. Although there are existing separation methods, problems such as energy costs and efficiency prevail.

We have now developed a continuous process, where a liquid selectively dissolves CO₂, pump it around, and release the methane, potentially into the natural gas grid. The porous liquid, which is now full of carbon dioxide, is heated or exposed to a vacuum, and that releases the CO₂. Now we need to think about what to do, as we don't want to release CO₂ into the atmosphere. Most likely, what's going to happen is that it's going to be pumped underground. The porous liquid then goes back to the start, where the process is repeated.

We can also separate carbon dioxide from hydrogen, for example, even though hydrogen is smaller than CO₂, so can fit into the pores of a porous liquid as well. This is needed for the purification of 'blue' hydrogen gas (H₂). However, hydrogen gas binds more weakly than a larger

molecule such as CO₂, because the covalent two-electron hydrogen bond (H₂) is not easily polarised and consequentially does not form strong interactions with the walls of the holes. There is therefore an enthalpic advantage for CO₂ binding over H₂ binding.

Current indications are that porous liquids are very effective for separating mixtures of gases at relatively low energy costs. For example, you don't have to heat the porous liquid to as high a temperature as you do with other solvents. Or you can use a vacuum.

Opportunities and challenges

How is your technology different or better from other options?

The main competing technology is aqueous, which is already established. Even if we are convinced porous liquids are better – lower energy, less toxic, less corrosive – we have to convince people to transition. The market for CO₂ solvents is still very dominated by

aqueous amines. However, these bind the CO₂ very strongly, chemically reacting to make carbonates.

Our technology operates via physisorption into the zeolite and, as such, it takes much less energy to recycle and regenerate the CO₂.

Could you tell me about the challenges or limitations

you're facing?

Our main competition at the moment is incumbent technology. Changeover is challenging. For example, if you propose an organic synthesis, one of the first questions chemists ask is "Which solvent are we going to use?" They never almost never stop to consider whether we actually need a solvent. We do think it's going to become clearer and clearer over the coming years that porous liquids have clear advantages over existing technologies – and it's hard to see the limitations. But the devil with these applications is always in the detail. At every single stage, you've got to go through the TRL process, technology readiness level, where you evaluate your progress towards application.

This is certainly our challenge for biogas applications. We're around about four out of nine on the scale with biogas in the sense that we've demonstrated it in principle in the lab. What we're now doing is going on site to demonstrate it there. That's what we need to do to get to five. The challenges we expect include a dirtier mix of gases and contaminants like water and hydrogen sulfide in small amounts. In these biogas plants, the gas is already passed through a column to take out virtually all of the hydrogen sulfide and ammonia, but there's still going to be traces left afterwards. But we're fairly confident the zeolites can tolerate these and won't chemically react. The performance of our porous liquid may decrease a little as it absorbs more contaminants,

There are also potential applications in the hydrocarbon industry, such as separating ethane and ethene, (ethylene). This is done on a massive scale worldwide

but we can mitigate that by heating it up to a higher temperature than we would do for a normal regeneration every few cycles.

We are also looking at post-combustion carbon capture. That presents challenges include much larger volumes of water vapour. Zeolites are highly hydrophilic and absorb water quite strongly, creating competition with CO₂ absorption. We have managed to formulate some porous liquids which do selectively take CO₂ instead of water.

What are the future possibilities? Have you looked at syn gas (H₂ and CO)?

We haven't looked at syn gas yet, but there are many possibilities.

We also know that the gases are available for reaction and incorporation into the liquid. Normally, this is done under high pressure, but with a porous liquid, you don't need such high pressures. We think that there is a potential use in reducing the pressure needed to do reactions with dissolved gases.

There are also potential applications in the hydrocarbon industry, such as separating ethane and ethene (ethylene). This is done on a massive scale worldwide. Currently, this is performed by cryogenic distillation, which is very energy-hungry, because you've got to cool and to distil. You might selectively dissolve one in a solvent to separate them, but the problem is there aren't any solvents that really discriminate between ethane and ethene as they're too chemically similar. There are one or two that people have made, but they have never been applied as far as I know. This is much easier with solids.

About the interviewers

Rowena Fletcher-Wood, ECG Chair and *Bulletin* Executive editor, has a background in zeolite chemistry and works as a science communicator.

David Owen, *Bulletin Briefs* commissioning editor, was a former industrial chemist and founder of TreatChem Ltd.

A selected bibliography on porous liquids and porous materials

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Call for volunteers

ECG Committee conversations

The Environmental Chemistry Group is looking to facilitate and film conversations between some of our youngest Interest Group Members and some of our oldest and most experienced Interest Group Members.

In this series of conversations, our youngest interest group members will have the opportunity to ask questions of our older and more experienced group members about the differences in scientific study, setting out on a career in science, and how they reached their ultimate or current roles.

This is also an excellent opportunity for early career scientists to discuss with established (or retired)

members of the scientific community the issues currently faced and those which needed to be addressed at the start of their careers.

We are looking for volunteers from across the age range of our membership (<20 to 100+ years!) to take part in these conversations. Format and locations are to be decided. The conversations will be recorded on camera and posted online for RSC members to view. ECG will support travel to the filming location.

Registering interest

To participate, contact ECG Secretary Laura Alcock (laura.alcock@edwardsvacuum.com) with your age group, years of science experience, and preference for speaking to older and/or younger ECG members.

Meeting report

Microplastics pollution webinar

Laura Alcock (Edwards Ltd, laura.alcock@edwardsvacuum.com)

Edwards Ltd's *Product Company Clevedon* (PCC) considers itself an environmental company, manufacturing equipment to reduce customers' carbon footprint by up to 95%. For World Environment Day, 5th June 2023, Edwards created a programme of activities, including a beach clean, and a pollution awareness webinar on microplastics by **Symiah Barnett**, ECG Committee.

Symiah's webinar began with an introduction to plastics and polymers, inviting the audience to consider the plastics that they had to hand, including PET (polyethylene), PS (polystyrene), ABS (acrylonitrile butadiene styrene), and HDPE (high-density polyethylene); highlighting the statement "Due to their prevalence, this current era has been described as the plasticine era of life".

Symiah explored the definitions associated with the names for different sizes of plastic: macro-, micro-, nano-, etc. (**Figure 1 and Table 1**); highlighting the definition for microplastics: "Extremely small pieces of plastic debris in the environment resulting from the disposal and breakdown of consumer products and industrial waste".

Throughout the presentation, Symiah ensured accessibility for 154 online and 60 lecture theatre attendees, including engineers and chemists, and non-scientific personnel. She identified the main sources of primary consumer microplastics and the methods by which secondary microplastics enter the environment. She presented some of the problems microplastics

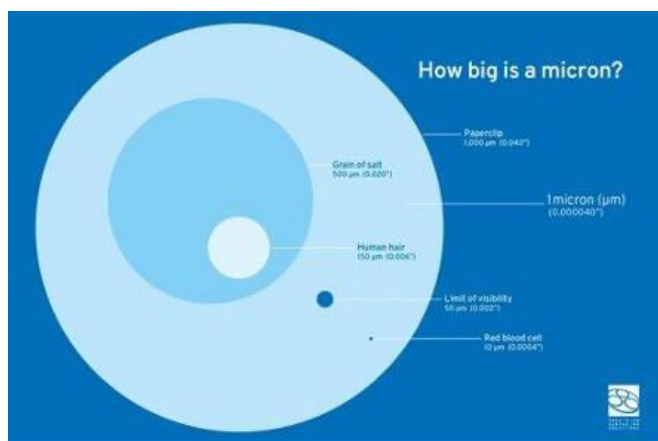


Figure 1. Graphic illustrating the scale of micro- and nanoplastics compared with everyday items.

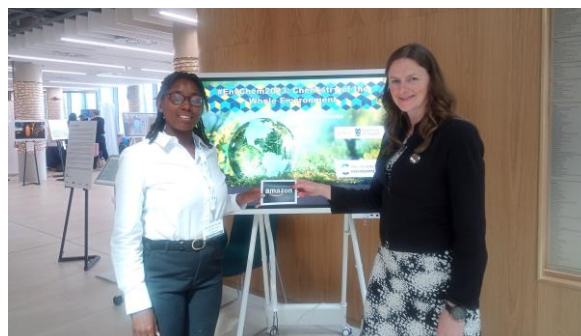


Figure 2. Symiah Barnett received a gift voucher from Laura Alcock on behalf of Edwards Ltd at #EnvChem2023.

cause in the environment, including impacts on the thermal and chemical properties of aquatic ecosystems, illustrated by examples such as impaired fertility in oysters exposed to microplastics.

Symiah's research

Her current research relies on the spatio-temporal measurement of micro- and nanoplastic contaminants in riverine and marine environments, providing a better understanding of their transportation, fate, and consequences. This includes developing methods of sampling, extraction (separation and removal of organic material), and analysis of water and sedimentary samples. She shared photographs of her sample collection techniques, which involved free-diving. A few examples of sample analysis provided insight into micro-FTIR and SEM images. The talk concluded with a lengthy Q&A.

The webinar was highly engaging and well received, with employees discussing opportunities to reduce their own contributions to microplastic pollution. A gift voucher was presented to Symiah at our #EnvChem2023 event in Glasgow (**Figure 2**).

Table 1. Plastic sizing terminology.

Terminology	Size range
Macroplastics	>20 mm
Mesoplastics	5-20 mm
Large microplastics	1-5 mm
Small microplastics	1-1000 µm
Nanoplastic	<1000 nm

Meeting Report

Accessible Evaluation at the BIG Event

Rowena Fletcher-Wood (freelance science communicator, rowena.fletcherwood@gmail.com)

On 26th-28th July 2023, the *ThinkTank* Museum in Birmingham hosted the BIG Event, the British Interactive Group's annual conference for science communicators to share skills and experiences, develop professional links and keep up-to-date with the STEM engagement field. The content is created by its members for its members, and on 28th July, I ran a workshop on *Accessible Evaluation* with **Dr Sarah Bearchell** to showcase our learning and experience.

The workshop addressed several aspects of outreach activities, but we will focus on the contribution of the ECG's Float or sink? game¹, which we introduced interactively: participants not only heard about what it was and its results, but also had a go.

Float or sink? is a guessing game where participants look at five types of plastic and post a coloured paper vote into a box before testing the materials in a pot of water to see if they were correct. People voted blue (float) or red (sink) for each of the materials.

At the conference, to mix things up a little, the various plastic items and vote boxes were placed around the room, some in easy-to-reach places and others in more challenging locations. The aim was to demonstrate how small access barriers massively decrease the amount of engagement with an activity, and that it is always important to think about your audience – whether they are tall or short, on foot or in a chair, colourblind or partially sighted, or anything else.

We wanted to showcase this activity because it is particularly good for engaging the hard-to-engage, such as adults who are with children (who push their children forwards but won't take part themselves) or people who don't want to get sticky or dirty or take anything home. The anonymous nature also means they can always lie about how wrong they were if you ask them directly!

What is it good for?

This activity not only boosts the number of engagements and gets people working together in their groups or competing, but also provides a source of evaluation, letting us know how many meaningful engagements took place, and how much people know about plastics.

Results

Most people guess correctly that a crayon would sink (red) and a plastic bag float (blue) (71-90% across all events), even when told that the plastic bag would be filled with water and submerged – it is the *material* being tested here, not the shape. However, silicone proves misleading, with ~80% of voters suspecting it would float – when in fact it sinks.

The pilot of *Float or Sink?* is discussed in the ECG *Bulletin*, July 2022¹, and has subsequently become an outreach staple. Evaluation of results at BIG 2023 showed that people were 50% more likely to do an evaluation activity that was easy to get to and reach than one placed slightly out of reach, and that professional science communicators guessed whether a plastic object sinks or floats *incorrectly* 40% of the time, the same as the general public.

References

1. Float or Sink pilot – see ECG *Bulletin*, July 2022, p.7.



Sink or float?

- Anonymous
- Diverse representation
- High participation
- Embedded in activity

Meeting report

Regulating for the water environment

John Collins (EA, john.collins@environment-agency.gov.uk)

As part of the ECG's Distinguished Guest Lecture and symposium at Burlington House on 22nd May 2023, **Dr John Collins** (Environment Agency) gave an overview of the history, current state and impacts of Water Regulation in England.

The state of our waters has become a subject of heated debate in recent years, but it has taken many decades, arguably centuries, to reach the current position. In the mid-1800s, the smells emanating from the river Thames and the identification by Dr John Snow of the waterborne nature of cholera epidemics led to legislation establishing municipal sewerage boards and funding Sir Joseph Bazalgette to develop London's sewerage system. At the time, this was a transformational piece of engineering for health and wellbeing in the capital, soon imitated across the country.

More recently, the protection and improvement of the water environment has been dominated by European legislation, particularly the Water Framework Directive (WFD), which has set targets and mechanisms for improving and protecting the water environment over the last 20 years.

Regulation of the water environment is carried out by several bodies, the largest of which is the Environment Agency. The focus of its activities can be summed up as relating to too much, too little, and too dirty water – floods, droughts, and pollution. Ofwat is the economic regulator responsible for ensuring the good management of water and sewerage companies in England. Natural England looks at water principally through the lens of protected areas.

There is much debate about how well the WFD has worked in protecting the water environment. Water has been managed in river basins and, within that, smaller water bodies are classified according to their chemical and ecological status, by assessing a combination of determinant or elements. The overall status is decided on the basis of what is known as the “one out, all out” rule. Only 16% of assessed surface water bodies achieve good or better ecological status.

However, a closer examination of the analyses underpinning this assessment shows that the underlying elements often perform somewhat better; overall 77% of individual tests would be classified as good, and 92% of ammonia and 76% of invertebrates' tests respectively achieve good status. No water body achieves good chemical status. This is largely as a result of improved analysis and identification of ubiquitous and long-lasting “forever chemicals”, such as PFAS, in the water environment. This is a common picture across Europe, particularly in the more industrialised northern countries.

A more positive story is the impact of regulation on Bathing Waters, where, over the last thirty years, achievement of good and excellent standards at bathing waters has risen from around 30% to almost 95%.

The Environment Agency regulates those who use water either by abstracting it or discharging into it. It issues permits and has powers to assess compliance with those permits and to take enforcement action, including prosecution to ensure compliance with those permits. Water and Sewerage companies are regulated in this way, and serious pollution incidents from this industry have reduced from over 500 per year in the mid-nineties to 50-60 per year in recent years (a figure which still needs to be reduced further). Recent prosecutions of water companies for pollution incidents have resulted in fines running into the tens of millions of pounds.

An analysis of causes of water bodies failing to achieve good status, reveals that while wastewater at 36% is a major cause of failure, agriculture (40%) and physical modifications to water courses (41%) are more common causes.

Efforts to improve the water environment through regulation, new policies and investments have been brought forward in the last year. These have included schemes such as Slurry Infrastructure grants, under the Government's Environmental Land Management programme, increased penalties for water companies for major pollution incidents with hypothecation of the environmental fines imposed, and the publication of the Government's integrated Plan for Water.

No water body achieves good chemical status largely as a result of long lasting and ubiquitous “forever chemicals”

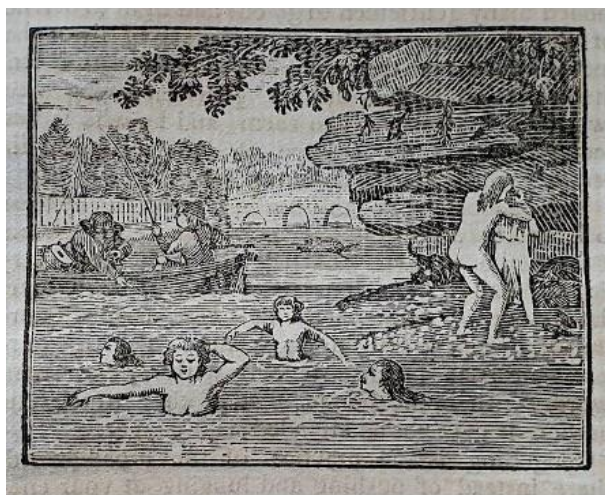
Article

Rivers of Life?

Rob Fryer (Rivers and Lakes Swimming Association, wildswim@talk21.com)

A lifetime of dedication to wild swimming led to seeking and discovering places all over the world. The sum of this work is contained within the volume *2000 Wild Swims*. At the ECG's 2023 Distinguished Guest Lecture Event, **Rob Fryer** shared the history of this passion, the source of it in his own life and some of the wonders he experienced whilst searching for places to enjoy. This highlights the importance of protecting our wild waters to keep them safe from pollution so that the environment and the people enjoying it can be healthy and happy.

When looking at the programme for the Environmental Chemistry Group's Distinguished Guest Lecture, I realised that I was the eldest speaker by a few decades. I also felt that this gave me the advantage of first-hand experience of life in "the olden days". I know people who have learned to swim on their own, without instruction and, whilst I am not as old as my first reference, I do have access to a rubbing of a 1757 engraving which depicts people swimming in a river in times past, though perhaps a minority, showing that people have been swimming in nature for centuries.



Rubbing of a 1757 engraving depicting people swimming in a river.

Wild Swimming in the 1950s – 1990s.

I actually learned to swim in a river – the River Cherwell at Oxford – when I attended school in the area. Swimming in the river was the normal thing to do, and the locals would start swimming when the river

temperature reached 60°F, yes Fahrenheit (or 15.5°C: at the time, Celsius was known as Centigrade, but nobody used it for measuring the temperature). Swimming would continue for the rest of the summer term, whether the water temperature went up or down.

At this time, it was just "swimming". The term "wild swimming" would not come about for forty years. It was as natural as going for a walk in the countryside. There were only a few concrete pools and, before the 1960s, they were expensive, so most leisure swimming took place in rivers or the sea. Then, throughout the 1960's, a large number of concrete swimming pools were built by councils all over the country. They were cheap and warm, but never my first choice. Of course, in cold weather, it is the preference of many to swim in a heated pool, and it is definitely easier to learn to swim in warmer water. However, in my opinion it is never such fun as swimming in natural water, and there is no communion with nature.

You are actually immersing yourself in nature when you swim in the wild. Having learned to swim in a river, rivers have always been my first choice. I swim for the beauty of a site. I am not a particularly good swimmer and can only swim breast-stroke, but I feel that that is the only way to be able to see where you are going and truly take in the visual pleasure of the surroundings.

However, with the advent of so many concrete pools, wild swimming came to be frowned upon. So much so that the Royal Society for the Prevention of Accidents (RoSPA) issued a policy that swimming in rivers and lakes in England was to be discouraged on the basis that the water was persistently too cold and, therefore, dangerous. RoSPA advised numerous councils, public bodies, and the media of this, and the British public adopted the anti-wild swimming message.

I remember being told off if a person saw me swimming in a river. At the time, I just kept quiet. Reflecting on this anti-wild swimming campaign, I now feel that it was a very serious attack on part of our culture. Swimming in rivers has always been "normal". Walking in the Snowdonia (Eryri) National Park has always been normal, too – but it is also dangerous. I understand that an average of 8 people die walking in Snowdonia every year, yet I cannot imagine that the public would tolerate a policy to actively discourage or ban walking on Snowdon (Yr Wyddfa).

I have come to believe that the difference lay in the commercial interest that exists as a result of people walking and hiking in Snowdonia, which is not so easy to draw from river swimming. River swimming was an easy target for banning. I noted, however, that sea swimming



Members of Farleigh and District Swimming Club enjoying a swim and paddle in the river.

has never been banned nor discouraged. There are far too many seaside towns dependent upon tourism based around beaches. River and lake swimming suffered a downturn from the 1960s onwards such that, whilst it was never illegal, a person would often feel furtive when swimming in rivers or lakes, especially in public view.

1999 publication: Waterlog

After nearly 40 years of repression, relief came in 1999. This was the year that Roger Deakin published his book *Waterlog*. The book was a record of his swims across the British Isles and shone a new light on swimming in natural waters. He coined the phrase “Wild swimming”, which then referred to all swimming in rivers and lakes in the UK, i.e., all of the swimming that RoSPA was seeking to restrict.

Roger Deakin made wild swimming not only acceptable but desirable. Having been unofficially banned and officially discouraged from the activity for so long, the public took to wild swimming with great enthusiasm. “Wild swimming” was a new name and it seemed to be a new idea, though it wasn’t new at all. This turned the clock back to what people had been doing for centuries – paddling and swimming in rivers and lakes for pleasure. Foreign visitors asked me, “Isn’t it just swimming in rivers?” because they had not suffered under decades of a restrictive policy.

Today, “wild swimming” includes swimming in the sea, as well as river and lake swimming in the UK and globally. However, many regard it as swimming in very wild, secluded locations. There is now a huge demand for wild swimming, and it is no longer left largely to “local lads”: people from all social backgrounds now practice swimming, and the bounce back to popularity has been enormous, like the release of a long pent-up spring. However, there is the expectation that our rivers should be clean, just as the air we breathe should be clean. In the face of the overwhelming support for the activity, RoSPA dropped its policy against what had become “wild swimming”.

Wild swimming seems to be a rather green recreation with a low carbon footprint. I cannot, therefore, see any reason to object to it. In fact, I feel that we should be encouraging this practice and ensuring that it is safe.

The wild swimming environment

Recent years have seen significant publication in mass media about sewage and farm pollution of our natural waterways, which is serious because it is so frequent. The sheer volume of pollution makes it a major concern.

Whilst I have not studied significantly the numbers and details of the science of the pollution, I am able to draw upon history. 60 years ago, if you ever drove through the



I utilised the stack of old wine crates to climb over the locked gate, whilst my partner Susan Burrow waits to follow.

countryside, you needed to stop every 20 miles or so to clean the windscreen, which by that point had been coated with the bodies of numerous dead insects. A device was invented to reduce the number of insects impacting and obscuring the windscreen, but the stops were still required. I admit that I didn't like having to stop and clean the windscreen, but I am concerned that the complete lack of this problem today does suggest that enormous quantities of insecticide are being sprayed onto the countryside, which must be leaching into our rivers. I'd rather clean my windscreen than swim in insecticide. The contrast with the past is vast and concerning.

With industry, there are flows of pollution and ever-growing populations. The financial pressure on water companies from providing services at minimal cost has seen the demand for wastewater treatment exceed the capacity. This has led to flows of untreated sewage being introduced to our rivers. It is now a major problem, which the other speakers at the DGL event would shed more light upon.

Industrial pollution is not new. It particularly increased during the 18th and 19th century, and the industrial revolution, when many rivers became badly polluted. For instance, the River Biss, near my own home in Trowbridge, was once known for pollution with industrial dyes being flushed into it. My research indicates that swimming there would stain the skin, so bathers emerged a different hue than when they entered during the industrial revolution. For this reason, Trowbridge wild swimmers of the 1930s set up a swimming club on the River Frome 5 miles away at Farleigh Hungerford.

Farleigh and District Swimming Club

Before World War II, there were many river swimming clubs. Many supported water polo teams, races, and diving competitions. After the war and, with the advent of the 1960s concrete pools, all of these clubs except for Farleigh Hungerford opted to "go soft", as it were. A major factor was that the sport governing bodies made the use of concrete pools compulsory for competitions.

Farleigh Hungerford were set apart, giving up their water polo team and opting to continue as an entirely recreational club. This was possibly the only club to do so and is one of the longest standing river swimming clubs in the world. It now has approximately 5,000 members – that is 5,000 people enjoying a river.

I have chaired this club – the Farleigh and District Swimming Club – for 20 years, and am proud that it is, at last, financially strong. Of course, a club is not required to facilitate swimming in a river. However, a club can allow access to the river without encountering cattle in the adjacent field or angry fishers on the bank, whilst offering steps to the water, as well as showers and toilets when required. The Farleigh and District Swimming Club is now thriving with strong support, and has even repaired its weir.

2000 Wild Swims

I believe a factor in the reason that I was asked to speak at the ECG's 2023 DGL event is that I have written what may be the most comprehensive wild swimming guide available – 2000 Wild Swims. This has taken me 20 years to achieve, during which time, I had a lot of fun. Based on this experience, I seem to have developed a natural ability for finding new wild swimming locations. It has also been interesting to me to learn how some nations make substantial efforts to accommodate wild swimmers.

For example, on the A-138 road between Ainsa and Bielsa, along the edge of Rio Cinca in Spain, there are 7 lay-bys for parking. Each lay-by has a wooden staircase leading down to the stoney riverbank beside the road, from where people are able to access the river and swim during the summer. I cannot envisage any UK council ever building 7 lay-bys for wild swimmers, let alone a staircase from each one to allow access for wild swimming. However, I do hope that such provision will be made for wild swimming in the UK during my lifetime – and that I am able to find it. This is a superb example of what can be done and, of course, the river does not see significant pollution exposure.

Wild swimming is associated to quality of life, and I don't imagine that anyone is against improving that. I passionately believe that quality of life is connected to water quality and evidence would support this.

Then there's the fun of finding new locations. Until around 2018, the best method available was to utilise Google Earth, which indicated places with small photographs on the interactive, online globe. This has all been integrated into Google Maps, but even with these fantastic tools, I still needed to actually find the swims to write about them. Usually, people would give me rose-tinted descriptions of fantastic swims, together with rather optimistic distance estimates to walk there. This all contributes to making hunting for a new swim more fun – and challenging.

Perhaps the most thrilling moment is upon first hearing the sound of water and catching a glimpse of a pool

through the trees. One such place where I experienced this is “Il Fantastico”, in the Benedetto Alps in Italy. With such a name, it doesn’t need much description. It is a double pool at the end of a potentially risky path, and it definitely is “fantastico”.

There is a swimming location in Sardinia with an enchanting signpost consisting of paint on a rock with an arrow pointing the way to go. There are also places with misleading signs – the very popular Lagetti pools in Sicily, which are very scenic and popular and, to my knowledge, without much pollution. The main gate is locked, but beside the notice to state access prohibition, a stack of old wine crates has been left in position to act as a style over the fence. Officially no but, actually, yes, it says. My Italian friends tell me that the word for this is “No-sì”: No-yes.

Another little-known swim in Italy, with a huge rock on the far side, seems to have been sculpted by nature into a spiral twist. The sight is stunning! I never realised that the Italians’ sense of fashion actually extended to natural rocks in the countryside (though, perhaps the influence works the other way around, with the countryside influencing the Italians’ sense of fashion).

In my exploration, I have come across interesting pieces of wild swimming art. In Riomagno, a photograph has been cunningly placed behind the waterfall, to make it appear as if a woman is trying to escape a hungry crocodile that is emerging from the water. At Puente de Genave in Spain, there is a statue of two children jumping into the river. There are no wild swimming statues in the UK that I am aware of, but these examples do provide evidence that it has formed a part of the local culture elsewhere in the world.

There are beautiful swims in the UK, such as Llangynidr, in Wales. It presents such a stunning scene, where taking a photograph can result in an image that appears more like a painting. The waterfall, its island, the deeps, the shallows, and the wonderful old oak tree stretching



Statue of 2 children jumping into the river at Puente de Genave, Spain.

overhead, not to mention the lesser island (to the right of the photograph), where people bask in the sun all contribute to the beauty of this spot.

This is not to suggest that wild swimming does not take place in less stunning situations. Wild swimming also – indeed, usually – takes place much nearer to the residential areas where people live. These are the areas where we really need to concentrate on reducing pollution. Let’s clean up our waters now that we can enjoy what is really a very basic and simple need to just enjoy them.



Wild swimming spot at Llangynidr, Wales.

Article

Monitoring pollution and its impact on water quality using innovative tools

Fiona Regan (Dublin City University, Fiona.regan@dcu.ie)

Water quality monitoring traditionally relied on spot sampling and standard analytical techniques. But with engineering design, additive manufacturing, and multidisciplinary research teams, we can see the potential to move from the lab into the field. However, this takes time and requires testing and scaling prototypes to prove new technologies in areas of chemical and biosensing. We are at a critical time for investment in sensor development to improve and indeed change how we monitor water into the future and make better decisions on aquatic system protection.

Monitoring water quality is driven by legislation, such as the Water Framework Directive (WFD)¹ in Europe, the Clean Water Act² in Canada, the Australian Water Act³ and the US Clean Water Act⁴ in the United States. To obtain more information about water quality, monitoring and sampling must be carried out frequently. Continuous monitoring can overcome the problem of frequency by providing long-term measurement, sampling and collection of data⁵.

A number of aquatic systems are dependent on the quality of the water for survival⁶. A wide range of sensors exist for water monitoring which allow both *in situ* and on site operation. Portable test units or instruments can complement or validate data for *in situ* sensors or are used to provide spatial resolution. Such instruments can provide information on pollution source tracking and screening of water samples, and are available for biological or chemical parameters^{7,8}. However, they fail in terms of being able to provide data at sufficient temporal frequency.

Autonomous sensors can provide real-time or near-real-time data (**Figure 1**) at good temporal frequency, facilitating decision support in a timely fashion.

Sensors can provide extensive baseline data and an improved understanding of water quality changes and trends over time and space. These, what we call, off-the-shelf sensors can provide valuable data but are generally non-specific for target analytes of interest.

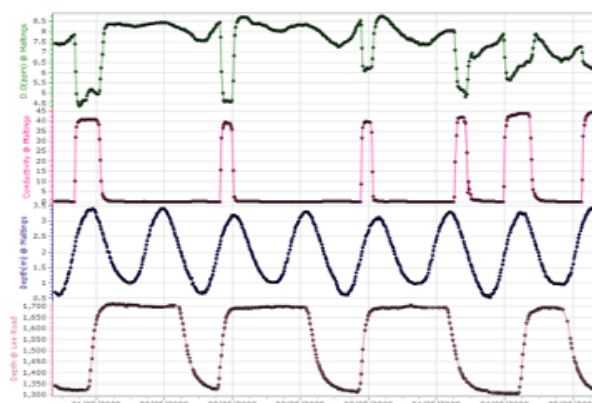


Figure 1. A real-time dataset from autonomous sensors measuring turbidity, temperature, salinity and water depth.

Taking an assay from the laboratory to the field requires years of development and rigorous validation.

There are some great examples in the literature of chemical assays used in portable or hand-held sensors technologies. **Figure 2** shows an example of a phosphate analyser based on the blue method, developed for phosphate determination in a catchment in an agricultural area.

Future digital challenge for water

With *in situ* – autonomous sensing becoming increasingly used, technological development in the field is moving forward swiftly with a growth in optical sensors. These sensors work on principles of fluorescence, scatter and absorption with low to affordable capital and operational costs, extended life-time, and increasing availability for a wide range of parameters.

Wet-chemistry based sensors are used traditionally where analytical precision and accuracy is required and currently where no alternative sensors exist (i.e. nutrient or metal speciation) while multiparameter sensors still remain the go-to for environmental applications. The trend is likely where we will see lower cost sensors, increasingly specialised and easier to integrate and maintain.

In this time of data-driven models, increased volumes of data and its availability from *in situ* and remote sensors is needed for the development of novel artificial

There are many challenges when taking an assay from the laboratory to the field - it requires years of development and rigorous validation



Figure 2. Demonstrating the portable phosphate analyser which uses centrifugal microfluidics, in a

intelligence (AI) and machine learning (ML) methods, which in turn will provide novel models and data treatment algorithms.

Growing climate-related events

With increasing environmental pressure due to global climate change, increases in global population and the need for sustainable obtained resources, water resources management is critical.

Water monitoring networks and their designs are fundamental to the management of catchment/watershed systems and are the first step in providing decision support to stakeholders.

In the era of data driven models, increased data collection and its availability from *in situ* and remote sensors is needed for the development of novel AI and ML methods treatment

To be fit-for-purpose, monitoring has to be carried out in a cost-effective way and allow implementation at larger spatial scales.

Rapid developments of *in situ* water quality monitoring instrumentation and remote sensing (aerial and satellite) have the potential to drive progress towards more cost-effective sensor networks at catchment scale. However, a significant expansion in research and development in chemical and biosensing capability is needed before we see the transformation needed in moving from the laboratory to the field. This kind of transformation is needed if we are to meet a Zero Pollution goal in this decade.

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Article

PFAS – an overview of an emerging chemical of concern and the UK’s approach to monitoring and managing the risks

Alun James (Environment Agency, alun.james@environment-agency.gov.uk), Russell Robertson (Environment Agency), Bojana Nanic (Environment Agency), John Collins (Environment Agency)

Per- and polyfluoroalkyl substances (PFAS) are a group of widely used synthetic substances. They are extremely persistent in the environment and as a result, they have been dubbed the “forever chemicals”. This along with their widespread use means many are now ubiquitous in our environment. Recent monitoring undertaken across England has shown how PFAS are detected in >65% of surface water samples, > 20 % of groundwaters and in all saline and freshwater fish analysed. Despite their widespread use and occurrence very little is known about the toxicity of most PFAS. Many countries are moving towards increased regulation of some or all PFAS potentially through grouping strategies and/or considering mixture risk assessments.

Very little is known about the majority of PFAS as most have not been subject to extensive testing

What are PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a group of synthetic substances widely used in many consumer products and industrial applications. They have unique water, oil, heat and stain-resistant properties meaning they have a broad application and can be found in a range of products including cosmetics, paper, coatings, electronics, ammunition, textiles, and artificial turf. Due to their unique and diverse molecular structure, PFAS can play an important and sometimes essential role in improving performance, quality, and longevity of a product. Some of the most documented uses include

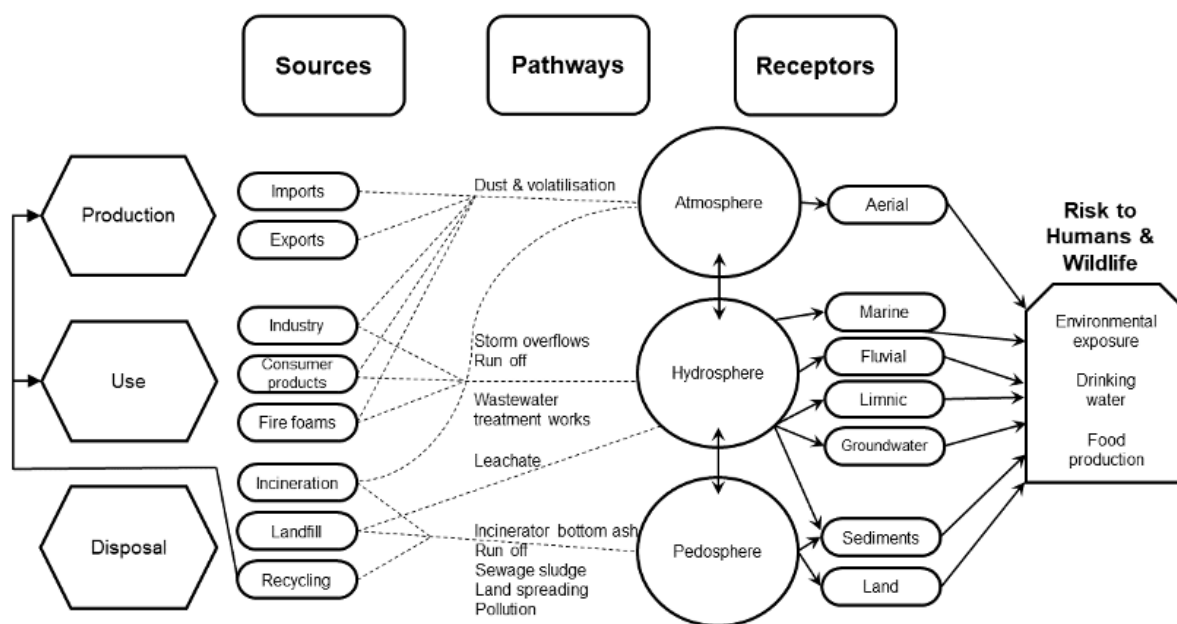
the production of the fluoropolymer Teflon, the stain-resistant coating Scotchgard¹ and the use in Aqueous Film Forming Foam (AFFF) used as a fire suppressant. AFFFs are made from fluoro- and hydrocarbon surfactants, they are thermally stable and able to form thin films and foam blankets making them effective at extinguishing flammable liquid fires², however, due to the amount and nature of the release, they are important sources of PFAS globally. The types of PFAS comprise several different families and sub-families which have been recently defined by The Organisation for Economic Co-operation and Development³.

What is the issue?

The same properties of PFAS that are so desired in products and industrial applications also make them extremely resistant to degradation under natural conditions, as a result, they have been dubbed the ‘forever chemicals’ due to their environmental persistence. Two of the most well-studied PFAS are perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), which were manufactured in significant quantities between 1950 and 2006.

Due to their high bioaccumulation and biomagnification potential and associated health impacts, regulatory pressures increased on PFOA and PFOS during the mid-2000s. In response to this pressure, the sector turned to structurally similar replacements, including homologues with fewer fluorinated carbons (short-chain PFAS) or other less well-known PFAS. While most of these replacement PFAS do not bioaccumulate to the same degree, they are just as persistent and often more water soluble and mobile.

As a result, these PFAS are capable of travelling significant distances from their source, and many are now ubiquitous in environmental compartments globally⁴.



A recent report by the Environment Agency has summarised the current understanding of PFAS from a UK context⁵.

Health impacts associated with the exposure of some PFAS include cancer, immune system dysfunction, liver damage, developmental and reproductive harm, and hormone disruption^{6,7}. Field studies have shown how many PFAS are able to bioaccumulate and biomagnify, being found at increasing concentrations at higher trophic level. In addition, uptake into plant tissues has been shown to be significant.

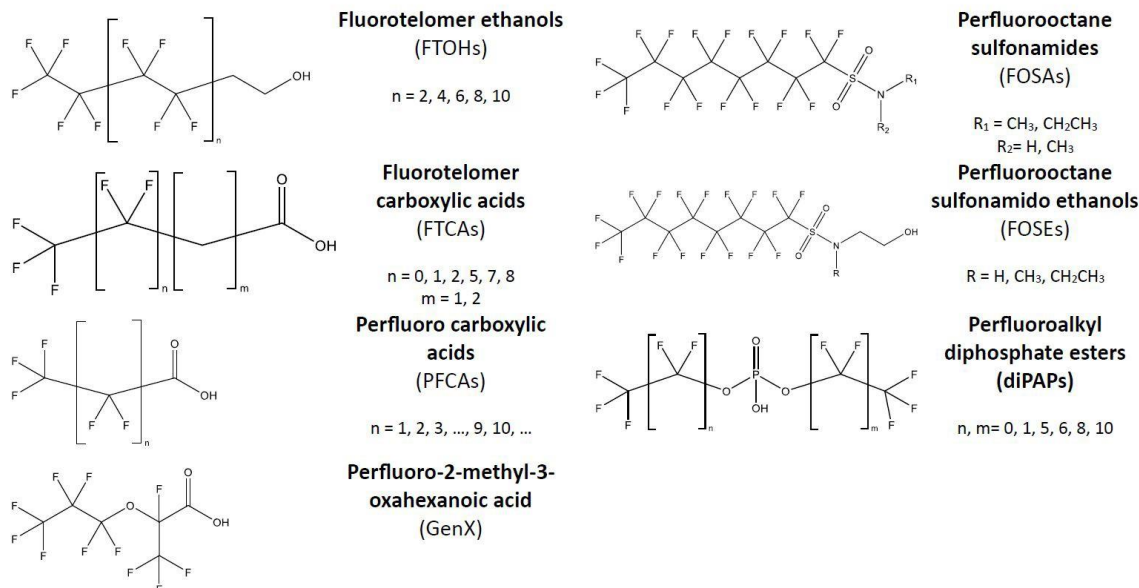
While a small number of PFAS have proven impacts on human and environmental health, despite their widespread use, very little is known about the toxicity of thousands of PFAS. This is because most have not been subject to extensive testing, so information about their hazardous properties is unknown. It is also recognised that assessing the hazard for PFAS on a substance-by-substance basis is neither possible nor practical. Despite this uncertainty, many countries are moving towards increased regulation of some or all PFAS. Due to the complexity of the PFAS family, there are growing calls for their management through grouping strategies⁸ and/or considering mixture risk assessments⁹.

How PFAS risks are being managed

Due to robust toxicological evidence, PFOA and perfluorohexanesulfonic acid (PFHxS) are already listed under Annex A of the Stockholm Convention and PFOS is listed under Annex B. A fourth PFAS, perfluorononanoic acid (PFNA) is also being increasingly linked to negative health impacts¹⁰. In the UK, PFOS is a designated priority hazardous substance and classified as a ubiquitous, persistent, bioaccumulative and toxic (uPBTs) compound under the Water Framework Directive

(WFD) (2000/60/EC), now superseded by the Water Environment (Water Framework Directive) (England and Wales) Regulations 2017. Ongoing developments in the EU include the submission of a draft Environmental Quality Standard (EQS) dossier for the risk assessment of 24 PFAS¹¹ which is currently being monitored and reviewed in England, by the Environment Agency and the UK Health & Safety Executive (UK HSE). In October 2021 the UK Drinking Water Inspectorate (DWI) issued guidance and recommended trigger values for water suppliers that cover 47 PFAS. At an international level, both PFOS and PFOA are the subject of an upcoming review in 2023 by the International Agency for Research on Cancer (IARC).

Up until now the management of PFAS has mainly focused on use restrictions. Recently the UK HSE published the PFAS regulatory management option analysis (RMOA) which is a key (non-legally binding) tool to inform policy and support the authorities in their regulatory decision making¹². This was published alongside the government's Plan for Water and focused on UK REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) registered PFAS and employed a grouping approach based on structural similarity as an analogue for similarity in hazard profile. The recommendations outlined the need for dossiers under UK REACH to restrict the use and disposal of AFFF where non-PFAS alternatives are available and on other wide dispersive uses such as coatings, cleaning agents, textiles, etc. Other recommendations from the RMOA include "to bring together work on PFAS strategically", including a review of the UK Fluorinated Greenhouse Gases Regulations (2015) to determine whether additional PFAS registered under UK REACH should be brought within scope.



With thanks to Franziska Türk for the figure.

While these approaches can restrict ongoing PFAS uses and manufacturing, the discharge of PFAS into the environment from legacy sources remains significant. As the awareness of issues has become apparent, the UK has allocated resources to develop, expand and improve capabilities and expertise in PFAS science. This includes specialists in regulation, permitting, monitoring and contaminated land to support bodies including the Environment Agency, Drinking Water Inspectorate, Local Authorities, Food Standards Agency, UK Health and Safety Executive, and Defra.

How we monitor PFAS in England

The Environment Agency is leading a number of investigations, R&D projects and innovative monitoring programmes to better understand the occurrence and behaviour of PFAS in different environmental compartments. This involves the research and development of analytical capabilities that are now delivering a number of internationally significant programmes.

Currently 43 individual PFAS are being routinely monitored by the Environment Agency in surface and groundwater. To complement this, investigations that include PFAS Total Oxidisable Precursor Assay analysis (PFAS Top assays) and ultra-short chain PFAS such as trifluoroacetic acid (TFA) are being undertaken to better understand the environmental PFAS burden. These monitoring campaigns are demonstrating how perfluorobutanoic acid (PFBA), perfluoropentanoic Acid (PFPeA), perfluoroheptanoic acid (PFHpA), PFOA, perfluorobutanesulfonic acid (PFBS), and PFOS are

detected in >65% of surface water samples and PFBA, PFOA and 6:2 Fluorotelomer sulfonic acid (6:2 FTS) are detected in >20% of our groundwaters.

Across the UK there are also number of monitoring programmes that look for PFAS in biota including fish, otters, predatory birds, and marine mammals. As with similar monitoring campaigns globally^{13,14}, these data are demonstrating the ubiquity of PFAS in the environment. Freshwater fish monitored by the Environment Agency demonstrate how longer chain perfluoroalkyl carboxylic acids (PFCA); perfluorodecanoate (PFDCa), perfluoroundecanoate (PFUnA), perfluorododecanoate (PFDDA), perfluorotridecanoate (PFTrDA), perfluorotetradecanoate (PFTeDA) and perfluoroalkyl sulfonic acids (PFSA); PFOS, PFHxS and the perfluoroalkane sulfonamides (FASA); and

PFBA are detected in all samples.

The Environment Agency is also working closely with Water companies to investigate PFAS through the Chemicals Investigation Programmes and undertake targeted monitoring for PFAS in effluents, receiving waters, and sewage sludges. In an attempt to limit emissions, UK regulators are currently reviewing a number of permitted discharges to water from high-risk sources such as airports, PFAS manufacturing facilities and Waste Water Treatment Works (WwTW).

Analytical challenges

Measuring PFAS is difficult and there are numerous methods and approaches available. Fully quantitative analysis using mass spectrometry is one of the most applied, however, due to the chemical diversity of the

Understanding the PFAS true burden of a sample often requires different methodologies for sample collection, preparation, and analysis.

group and corporate secrecy surrounding their manufacturing, formulation and structure; analytical standards are only available for around 50 substances. While these analyses have demonstrated the occurrence of PFASs and PFCAs in many publications, the presence of less stable precursors and intermediates are less understood. These precursors can undergo abiotic or biotic transformation to the more stable PFASs and PFCAs and are likely to have different physical, chemical and toxicological properties from their breakdown products¹⁵.

Understanding the PFAS' true burden of a sample often requires different methodologies for sample collection, preparation, and analysis. While techniques such as fluorine nuclear magnetic resonance, suspect screening and nontarget analysis offer a broader insight into unknown PFAS, there is an ongoing need for better suspect lists and new identification tools to broaden our analytical scope.

Environmental challenges

PFAS pollution is a critical worldwide issue, and their toxic and persistent properties are present significant and tangible risks to health of humans and wildlife. From a risk management perspective, one of the biggest challenges we have stems from how little we know about the majority of PFAS. Across England, recent risk screening work reviewing potential source sites has identified over 20,000 locations across England. Addressing the issues will often require collaboration between multiple regulators and stakeholders who may lack the resource and expertise.

PFAS are currently one of the most significant environmental pollutants globally, and the Nordic Council of Ministers estimates that the direct healthcare costs from exposure to PFAS in Europe alone are €52-84 billion annually¹⁶. Once released into the environment PFAS are extremely difficult to remove and remediate. The societal cost is often shouldered by governments typically forced to fund the clean-up of pollution and individuals who suffer from health consequences¹⁷.

In summary

Even with tighter PFAS regulation, the legacy of these "forever chemicals" will be around for decades to come. To implement effective management regimes better insights into the contributions from different pollutants is needed. While so much is still unknown about the fate, transport, toxicity and environmental burden of thousands of PFAS, as a society we need to manage these uncertainties. While measures and actions need to be underpinned by the best available science, the lack of information should not prevent justifiable action being taken.

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Reactive nanoadsorbents for environmental cleanup: testing disposal sustainability

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Nano-enabled solutions are continuously being explored as an efficient and sustainable option for water clean up. Laboratory-synthesised nano-adsorbents efficiently remove heavy metal cations and oxyanions from water. However, their high contaminant sorption capacity questions their safe disposal and long-term environmental fate after disposal. We have explored different nanocomposites with varying contaminant removal mechanisms for their possible fate in soils and landfill conditions.

Ongoing research efforts are dedicated to finding strong candidates for sorption-assisted techniques in the treatment of contaminated waters. Several conventional and advanced adsorbents satisfy the bottom line sustainability criteria of being scalable, efficient, economic, and environmentally friendly. Most of the conventional and advanced adsorbents are being continuously explored for real world deployment ranging from activated carbon filters in home reverse osmosis (RO) purifiers, granulated activated carbon beds in water treatment plants, to recently deployed nano-adsorbents such as iron oxyhydroxides (FeOOH) for arsenic, nano

alumina fibres for particulates, carbon nanotube-(CNT)based membranes for desalination, zeolites for removal of ammonia and heavy metals etc¹.

High surface area and reactivity of nano-adsorbents lead to their high contaminant removal capacities, suggesting huge contaminant loads at their saturation level. This further leads to the next environmental concern, *i.e.* the fate of contaminant-sorbed adsorbent wastes in the environment and possible sustainable disposal pathways. Concerns regarding the disposal include:

(i) desorption of sorbed contaminants, (ii) dissolution of the adsorbent, (iii) release of constituent metal ions from the adsorbents, and (iv) migration of toxicants in the subsurface environment.

Disposal of nano-adsorbents in soils and landfills leads to their interaction with sunlight, air and water, including slightly acidic rainwater, and organic acids-rich soil pore water or landfill leachate waters. Organic compounds can form complexes with toxic metals, leading to their increased solubility and migration in the subsurface environment². At the same time, organic acids released by plants can also dissolve and leach contaminants from the adsorbent wastes posing the risk of their plant uptake³. Surface characteristics, composition, nature of adsorbent-adsorbate interaction, binding strength, and mechanisms are some of the factors that can play a crucial role in deciding the environmental fate of these

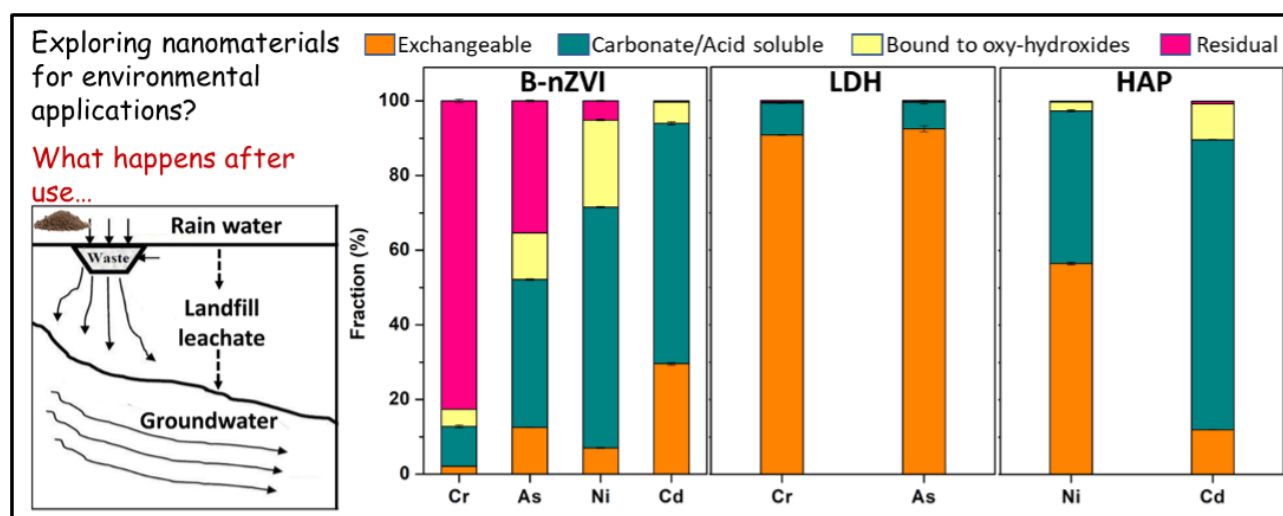


Figure 1. Sequential extraction of sorbed contaminants on different nanoadsorbents .

adsorbent wastes⁴. Current research in the field includes assessment of toxicity of various nano-adsorbents before and after the sorption of contaminants, transport of graphene or other nanomaterials in saturated porous media, and life cycle assessment (LCA) of some of the nano-adsorbents. LCA considers the use of energy and water in the processing of various raw materials to synthesise nano-adsorbents to final applications, considering the total energy utilisation in terms of equivalent CO₂ emissions and climate change⁵.

So far, knowledge is limited regarding the fate, dissolution and transport of the contaminant-sorbed nano-adsorbents in the environment. Therefore, we have focused on a variety of contaminant-loaded nanoadsorbents that can attach contaminants through distinct interaction mechanisms, *i.e.* anion-exchange (layered double hydroxides, LDHs)⁶, cation exchange, and crystal incorporation (hydroxyapatites,

HAPs)⁷ and complexation, redox transformation and coprecipitation (clay-supported nanoscale zerovalent iron composites, B-nZVIs)⁸. These collected adsorbent wastes were processed through sequential extraction procedure to probe their soil fractionation and to evaluate contaminant desorption and adsorbent dissolution in different stages (**Figure 1**). Different sorbed contaminants on B-nZVI displayed varying fractionation, with limited exchangeable fraction suggesting strong contaminant binding. Chromium showed minimal leachability with retention of > 80% in residual phase, suggesting minimal long-term leaching. LDH-sorbed contaminants exhibited over 90 % release as exchangeable fraction, emphasising disposal challenges, although research also suggests their potential in contaminant recovery and adsorbent reuse. In HAP, both nickel and cadmium showed considerable release dispersed over exchangeable and acid-soluble fractions with limited strongly-bound fractions, indicating potential soil contamination. These nuanced findings underscore the complex environmental implications, disposal considerations, and potential recovery strategies for B-nZVIs, LDHs, and HAPs in the context of contaminant interactions.

We have further explored contaminants release in simulated landfill conditions by reacting adsorbent wastes sequentially with rainwater, landfill leachate water, and groundwater in continuous column mode. The required amount of soil needed to dilute the wastes before disposal can be correlated with the total contaminant leaching in the simulated landfill environment. The safe dilution disposal factor (SDDF) was defined as total metal leaching through adsorbent waste columns in rainwater (RW), landfill leachate water (LW), and groundwater (GW) divided by the soil permissible limit (SPL) of different metals as defined by environmental protection agency⁹.

$$SDDF = (C_{RW} + C_{LW} + C_{GW}) / C_{SPL}$$

Results suggest that researchers should give equal importance to the long- and short-term environmental

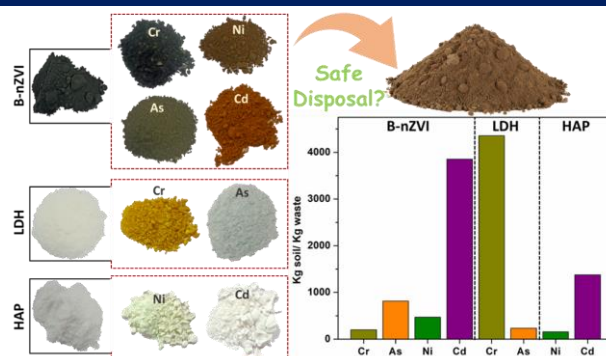


Figure 2. Contaminant-sorbed nanoadsorbent wastes and their respective soil dilution requirements .

fate of adsorbent wastes after contaminant removal. Combined understanding of their potential for soil fractionation and leaching of sorbed contaminants in landfill environment can help in defining different disposal pathways, and minimising environmental risks.

Redox-active nanoparticles like B-nZVIs lead to redox-transformation of contaminants and bind strongly, limiting their recyclability and reuse. Conversely, sorbed contaminants can be recovered from weak binders like LDHs, allowing reuse. Adsorbents showing very high contaminant removal capacities and low SDDF values or soil dilution requirements (**Figure 2**) are thus eco-friendlier compared to adsorbents with low capacity and high soil dilution requirement, while adsorbents with e-resource recovery-reuse potential should be our priority.

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Upcoming meeting

Killer threads! Fast fashion's impact on the environment.

Where: The Royal Society of Chemistry, Burlington House, London, W1J 0BA

When: 18th March 2024

This one-day **Distinguished Guest Lecture and Symposium** organised by the Environmental Chemistry Group of the Royal Society of Chemistry explores the impact that modern apparel manufacturing, consumption and disposal could have on the environment.

The 2024 DGL is available in hybrid format for those further afield or unable to travel to London for the specific date.

Registration: <http://tinyurl.com/77jxs7j4>

Chemical Impact of Climate Change

ECG is co-badging the Royal Society of Chemistry's Toxicology Group's series of free online lunchtime talks and discussions examining how climate change, and the way we adapt to it, will influence the nature and impact of chemicals in the environment. The first two webinars are available for registration.

Webinar One

30th January 2024 12.30-13.15 GMT

In the first talk, **Martin Rose** will be discussing the impact of a changing climate on food chemical safety covering topics such as food contaminants, mycotoxin exposure increases via flooding, and sea temperature impacts on arsenic and methyl mercury availability.

Registration: <http://tinyurl.com/mznau4pp>

Webinar Two

27th February 2024 12.30-13.15 GMT

Laura Thain from the Environment Agency's Chemicals Regulatory Development team in England with a talk about her work screening prioritised substances for the need for intervention and regulatory planning "Considering climate change in chemicals regulation".

Registration: <http://tinyurl.com/53uc5p3u>

Committee vacancy

ECG Committee vacancies

The Environmental Chemistry Group has three committee vacancies to fill.

The ECG committee currently has three vacancies and is looking for members to join and help us to organise events and produce our biannual Bulletin. The committee is open to all members of the Royal Society of Chemistry ECG, regardless of membership category or previous experience. Staff are on hand to support our volunteers and to offer guidance as required.

This is an opportunity to get involved, to support your community, to share your love of science and to develop professionally. Training is also available.

To nominate yourself, please contact Networks@rsc.org for more information.