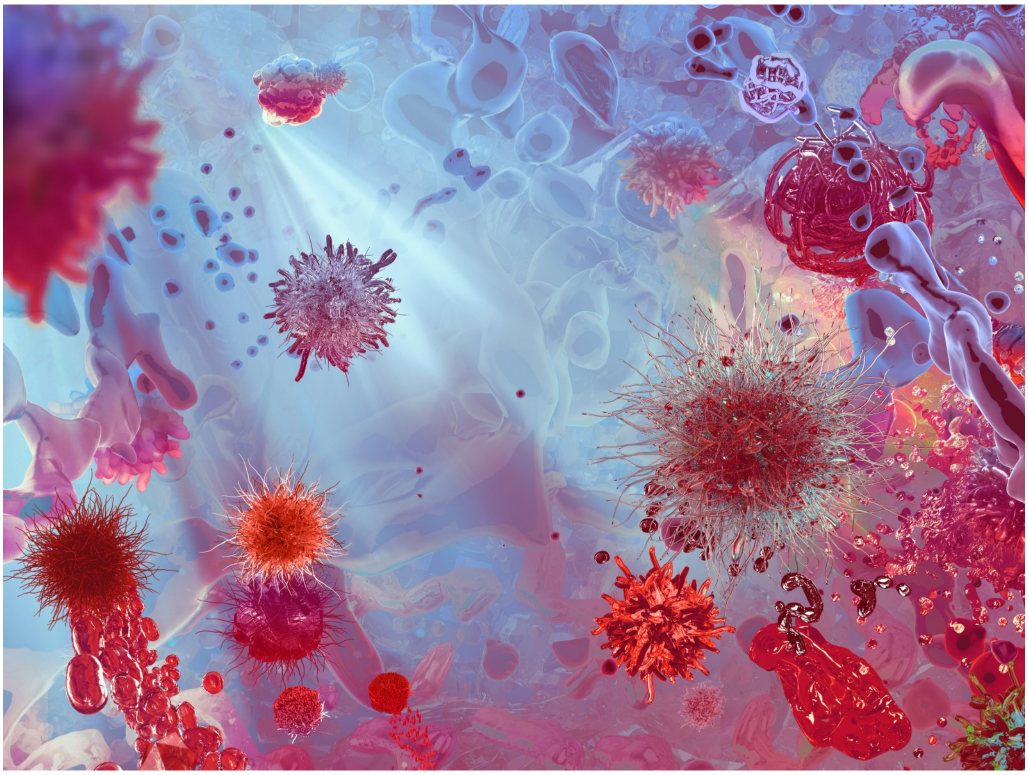
ROYAL SOCIETY OF CHEMISTRY | ENVIRONMENTAL CHEMISTRY GROUP

July 2018

ECG *Bulletin*



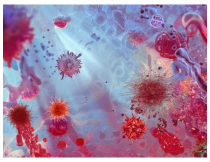
Biopollution: Antimicrobial Resistance in the Environment. This edition features Roger Reeve's meeting report from our annual Distinguished Guest Lecture and symposium (*pp. 9–10*), and articles from two of the speakers (*pp. 11–16)*.

Farewell. Following the departure of several committee members, Zoe Fleming and Tom Sizmur reflect on their time on the committee and their contributions to the ECG (*pp. 3–4*).

Environmental Briefs. Teresa Jones and Marc Mohajer examine the chemistry and regulation of poly- and perfluoroalkyl substances and glyphosate, respectively.

Also in this issue. ECG member Glynn Skerratt tells us about his career in the water industry (*p. 5)*; David Owen discusses the challenges and motivations of starting or joining small environmental chemistry enterprises (*pp. 17–18*); Tom Sizmur and Clare Topping review two new books (*pp. 6–7)*; Valerio Ferracci provides an update on the WMO Greenhouse Gas Bulletin and monitoring of CO_2 levels (*p. 19*); and Rowena Fletcher-Wood writes a guideline for a public engagement activity with microplastics.

Contents



Cover image:
The topic for the 2018 ECG DGL was the global problem of bacterial resistance to drugs (illustrated here at a cellular level) and the importance of understanding the role that the environment plays Credit: Tsvetkov Maxim/Shutterstock

ECG *Bulletin*

ISSN 1758-6224 (Print) 2040-1469 (Online). Published by the Royal Society of Chemistry's (RSC) Environmental Chemistry Group (ECG), Burlington House, Piccadilly, London W1J 0BA, UK.

See www.envchemgroup.com for articles published in the ECG *Bulletin* since 2007.

Environmental Chemistry Group

Website: www.envchemgroup.com
Twitter: @RSC_ECG
Facebook: RSCEnvironmentalChemistryGroup
Membership details: www.rsc.org/ecg

This and previous issues of the ECG *Bulletin* are available without charge at www.envchemgroup.com and www.rsc.org/ecg

The ECG *Bulletin* is printed on paper made from wood pulp sourced from sustainable forests, and is suitable for archival storage. This issue of the ECG *Bulletin* was printed by Prizmatic Print Solutions, www.prizmatic.co.uk; 01444 239000.

Article

A farewell to departing members of the ECG Committee

Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk) and Zoë Fleming (NCAS, University of Leicester, zf5@leicester.ac.uk)

At our March 2018 Annual General Meeting, we bid farewell to six members of the Environmental Chemistry Group (ECG) committee (Dr Rupert Purchase, Dr Julia Fahrenkamp-Uppenbrink, Professor William Bloss, Professor Martin King, Mr Ian Forber and Mr Brian Graham) and welcomed four new members (Dr Valerio Ferracci, Professor Dominik Weiss, Dr Clare Topping and Dr David Owen). Here in this article we pay tribute to the contributions that our departing members made during their time serving on the committee.

Dr Rupert Purchase joined RSC's Environment Group (renamed the Environmental Chemistry Group in 1993) as a committee member in 1986. He was instrumental in establishing the ECG *Bulletin*; in 1995 and he initiated and co-edited the first issue of the ECG Newsletter (renamed the ECG *Bulletin* in 2002). The first issue contained an article written by a long-standing former committee member, Geoff Dickes, on the history of the Environment Group since its inception in 1972. During his time as a committee member, Rupert contributed to the organisation of a number of symposia, whose proceedings were published by the RSC including:

- Aluminium in Food and the Environment, eds. R. C. Massey and D. Taylor, Royal Society of Chemistry, Cambridge, 1988.
- Food Contaminants: Sources and Surveillance, eds. C. S. Creaser and R. Purchase, Royal Society of Chemistry, Cambridge, 1991.
- The Laboratory Environment, ed. R. Purchase, Royal Society of Chemistry, Cambridge, 1994.
- Environmental Impact of Chemicals: Assessment and Control, eds. M. D. Quint, D. Taylor, and R. Purchase, Royal Society of Chemistry, Cambridge, 1996.

Together with colleagues from the ECG committee, Rupert produced over 15 issues of the ECG *Bulletin*. These pioneering actions by Rupert laid the groundwork

Figure 1. *From back left to front right: Ian Forber, Rupert Purchase, Martin King, Brian Graham, Jamie Harrower, Tom Sizmur, Zoë Fleming, Steve Leharne, Rowena Fletcher-Wood, Julia Fahrenkamp-Uppenbrink, Roger Reeve.*

for the committee members that followed, and set the standards which we, as current committee members, hope to uphold.

Dr Julia Fahrenkamp-Uppenbrink joined the committee in 2011 and assumed overall responsibility for the editorship of the ECG *Bulletin* between 2011 and 2017. During this time, she was chiefly responsible for sourcing articles, editing them, and producing the ECG *Bulletin* with help from several ECG committee members. Julia, as a professional editor, brought a new skill set to the committee, and spearheaded innovation in the design of the ECG *Bulletin* to make it easier to produce and read. Successful aspects of the redesign were to define clear article types, to publish shorter pieces and to streamline the production process. Julia also wrote several pieces for the ECG *Bulletin* herself and elevated the rigour of the editorial process to ensure that all the articles followed a consistent style. The work that Julia did in transforming the ECG *Bulletin* has substantially helped the ECG committee in going forward, as the well-defined steps and the simplified production process have made it easier for several people to assemble the ECG *Bulletin* today.

Professor William Bloss joined the ECG Committee in 2008 as the Atmospheric Chemistry Representative and, in this role, organised several scientific meetings, including a new event for early career atmospheric chemists that combined scientific presentations with a careers panel advising them on future career directions. Bill was elected as the Chair of the ECG from 2012 to 2014, and held the position of Vice Chair both before and afterwards (2010 to 2012, and 2014 to 2016). He also served as the ECG representative on the Environment, Sustainability and Energy Division from 2011 to 2015, representing the views of the ECG committee at a higher level within the RSC. In March 2018, as Bill was stepping down from the committee, he was awarded a commemorative plate in recognition of 10 years of service to the ECG committee.

Figure 2. *From back left to front right: Steve Leharne, Ian Forber, Rupert Purchase, Roger Reeve, James Lymer, Jo Barnes, Tom Sizmur, Bill Bloss, Martin King, Zoë Fleming, Rowena Fletcher-Wood, Julia Fahrenkamp-Uppenbrink.*

Professor Martin King joined the ECG committee in 2012 and established a series of 'Environmental Briefs' which have been published in the ECG *Bulletin* since 2013. These two page articles, all of a similar style, aim to bring concise but authoritative information about aspects of the environmental sciences to members of the Environmental Chemistry Group and to all those with an interest in chemistry of the environment. At least two Environmental Briefs have been included in each ECG *Bulletin* edition since their conception. Martin also served as Honorary Secretary from 2013 to 2015, as Chair from 2015 to 2016 and as Vice Chair from 2016 to 2018. He served as the ECG representative on the Environment, Sustainability and Energy Division, and joined their prize panel between 2015 and 2017.

Mr Ian Forber joined the ECG committee in 2013. Soon afterwards he took on the task of updating the ECG web pages on the RSC website. This project developed into a long-term technical role until he left the committee in 2018. Ian served as the ECG treasurer from 2015 to 2018, during which he navigated the committee through some major changes to the way in which RSC interest groups are funded, and established new funding policies. Ian also helped organise several scientific meetings, including the 2015 Analysis of Complex Matrices meeting.

Mr Brian Graham joined the committee in 2015 and contributed to the organisation and delivery of several events and scientific meetings, including our early career researcher conferences in 2016 and 2017. He also wrote and edited several ECG *Bulletin* articles.

We thank our departing members for their outstanding service to the ECG committee and wish them all the best in their future endeavours.

The ECG Interview: Glynn Skerratt

Dr Glynn Skerratt is the Secretary of the Environmental Chemistry Group. He has worked in the UK water industry and in higher education over the years and is now a freelance environmental consultant.

What inspired you to become a scientist? Fascination and curiosity were all part of it. I always enjoyed chemistry at school — the colours, the shapes of the crystals and, of course, the smells. Graduating from the then Royal Institute of Chemistry trained me to think like a scientist, a skill that has been invaluable throughout the rest of my life. The simple beauty of 'the scientific method' is such an elegant, common-sensed and reasoned way of approaching things.

How did you come to specialise in water? I wish I could say that it was because I was driven to improve our environment from childhood but, in truth, it all began with a job for the local water authority. My immersion in the water and sewage industry lasted almost 15 years, and I did my PhD part-time during that period. It focused on the hydrolysis kinetics of a class of organophosphorus compounds called ylids, and it taught me a lot about how to carry out research and the need for effective time management. I then spent 23 fulfilling years as a university lecturer teaching all kinds of analytical and environmental chemistry courses. Over the years, my teaching covered water and wastewater treatment technologies so my links with the water sector stayed strong.

What advice would you give to anyone considering a career in environmental chemistry? Society has a nasty habit of leaving things until the last minute before dealing with them. We will rely on our educators and technologists to face the unprecedented environmental challenges ahead. If you care about our future and environment, enjoy chemistry and want us to live our best lives in the best circumstances, then become an environmental chemist. It'll put you in a great place to help mankind prosper in a responsible and sustainable way.

Could you describe your current job? Since leaving academia I have been working as a freelance consultant, developing and delivering online training courses, writing expert witness reports and reviewing and assessing funding proposals for the European Commission. I also sit on some committees at the Royal Society of Chemistry and occasionally chair licence reviews for The Science Council. It's nice to be able to put something back into the profession that has served me so well.

What are some of the challenges facing the environmental chemistry community? Now, more than ever, environmental chemists can help counter the trivial way in which science is often presented in the mainstream media and to challenge any journalistic attempt to strive for balance when objectivity should be the target, given an overwhelming weight of current scientific evidence favouring one side of an argument. Helping to explain the concepts of risk and the balance of probability, and counter-balancing society's morbid fascination with pseudoscience are also high on the agenda.

What is the most rewarding aspect of your career so far? When a student thanks me for helping them achieve something they didn't think or believe they were capable of, well, that's just the best feeling ever. Almost as good as watching a beaming PhD student I've been supervising walk proudly across the stage to collect their doctorate.

If you weren't a scientist what would you do? If I weren't a scientist, I'd be struggling hard to make any sense of the natural world in which we live… so I guess that's the answer: I'd struggle. As for paying the rent, maybe I'd be trying to take half-decent photographs for a living.

And what do you do when you are not working? I enjoy filling my days by taking quite poor photographs (see above), reading anything I can lay my hands on, walking slowly around the Lake District or the South Tyrol, and vaguely following recipes to see what turns out.

Book Review

Trace Elements in Abiotic and Biotic Environments

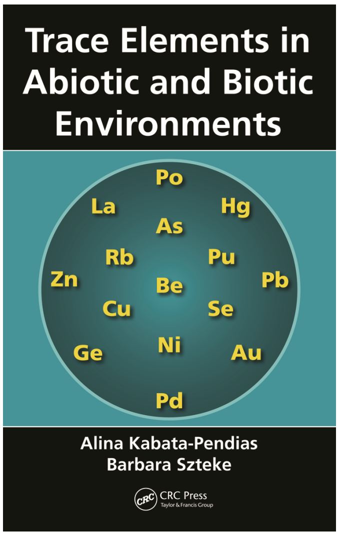
Tom Sizmur (University of Reading, t.sizmur@reading.ac.uk)

An interdisciplinary examination of how trace elements behave in the environment and how they interact with human biochemistry.

This volume takes a similar format to previous publications by Alina Kabata-Pendias, author of 'Trace Elements in Soils and Plants', now a reference point of choice for introductory material on trace element biogeochemistry in the terrestrial environment. This is not the sort of book that one reads from cover to cover. Rather, it is a useful place to gain background information on an element that can be used as a starting point to guide further exploration. This is particularly useful for a student or researcher embarking on a new project. In this spirit, I dipped into a few chapters to learn more about a few elements that I am unfamiliar with, to find out about their behaviour in the environment, and their role in human physiology.

The chapter on gallium begins by outlining how gallium is chemically similar to aluminium and is thus produced mainly as a by-product from bauxite mining. Due to its low melting temperature (~30 °C), it is used to make low melting point alloys (e.g. as a replacement for mercury in a thermometer). It is relatively stable in soils, a property that makes it a good marker for the characterisation of soil pedogenesis. Although not an essential element, there is some evidence for it being beneficial in some microorganisms, particularly fungi. Radioactive gallium-67 salts (e.g. gallium citrate) can be injected intravenously – whereby they dissociate into Ga^{3+} ions – which are then used for medical diagnostics.

Rhodium, the least abundant of the platinum group elements, is primarily used as an alloying agent with platinum and palladium in catalytic converters. Due to its extensive use in the automobile industry, rhodium concentrations in urban and roadside soils are slowly increasing. Rhodium is not known to play any biological role or to be particularly toxic. However, due to its increasing abundance in the environment, there is considerable interest in quantifying human exposure from the ingestion of food contaminated by aerial deposition.



The chapter on yttrium starts by comparing it with the lanthanides, and remarks that it is often classified as a 'rare earth element' due to its chemical similarity. It is found in the 3+ oxidation state in uranium or rare earth element ores, and used (as Y_2O_3) for luminescence or semiconductor materials in electronic devices. Environmentally, yttrium is found in greater concentrations in mosses and lichens than vascular plants, indicating that atmospheric deposition is its main source. Similar concentrations in Poland and Alaska imply that yttrium is globally well-mixed in the atmosphere, rather than deposited close to emission sources. It is not known to play any biological role and is considered mildly toxic because it can cause lung disease if inhaled in large quantities. The mechanisms of toxicity include enzyme inhibition and substitution for essential elements, resulting in imbalance. A radioisotope of yttrium, yttrium-90, is used in radioimmunotherapy drugs for the treatment of various cancers, including leukaemia and lymphoma.

Overall, 'Trace Elements in Abiotic and Biotic Environments' provides a large breadth of information for the environmental scientist or (eco)toxicologist and is an excellent starting point for anyone wanting to know a little more about some of the more exotic trace elements. In my view, it is missing an introduction and/or conclusion which could serve to bring together the information and define its scope, or to highlight opportunities to drive forward the future of the discipline.

Reference

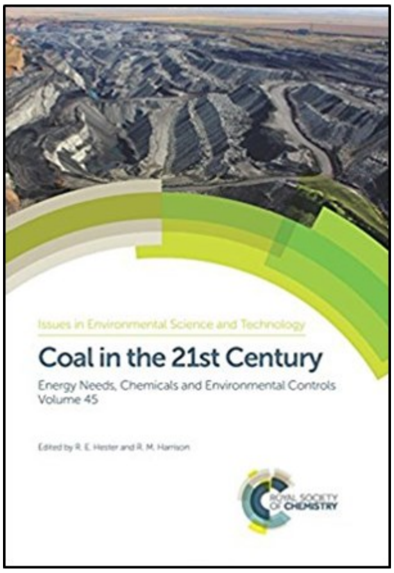
Kabata-Pendias, A. and Szteke, B. (2015) Trace Elements in Abiotic and Biotic Environments. CRC Press, Boca Raton, FL, USA.

Book Review

Coal in the 21st Century

Clare Topping (clare.topping@gmail.com)

From reports of extreme weather events to America's withdrawal from the Paris agreement, climate change has rarely been out of the news in the last year. As much of the historical rise in carbon dioxide levels has been attributed to the burning of coal, particularly in Europe and the USA, and a large proportion of future emissions, particularly in China and India, are expected to come from coal fired power stations, Coal in the 21st Century is a timely publication. Covering a wide variety of topics, it is a combination of papers from authors based in the US and UK edited by R. E. Hester and R. M Harrison.



The opening chapter by Liam McHugh from the World Coal Association discusses the likely future of coal within the wider context of power generation. Included is an overview of improvements in efficiency and emissions from newer coal fired power stations that incorporate carbon capture and storage (CCS) technology. The role of coal in lifting developing countries out of poverty is emphasised, although the author's optimism about the likelihood of emissions reductions even with coal included in the energy mix is not repeated in the following chapters.

The elemental nature of toxins from coal waste means that they persist in the environment for decades

The next two chapters discuss the process of mining and the technologies in coal fired power stations in more detail. Chapter two describes the different types of mine, the equipment used for extraction and transportation and the associated environmental impacts. A short section about novel methods of extraction was interesting, but overall this chapter would have benefitted from some better editing and more details about the economic and environmental impacts of coal production around the world. The third chapter focuses on power station equipment and includes some illuminating examples of the trade-offs required with newer, more efficient technologies. For example, India's supercritical and ultra-supercritical coal fired power stations are unable to consume its domestic coal, and will therefore have to rely on increasing coal imports despite an increasing domestic supply. According to the authors of this chapter, in order meet the requirements of the Paris agreement and limit warming to 2°C over the course of the 21st century, both existing and new build coal fired power stations will become stranded assets before the end of their expected operational lifetimes.

The chapters on health and regulation are mainly drawn from examples from the US, but they do contain a lot of information. The health impacts from all aspects of the process, including mining, processing, transportation and burning, are all considered. Of particular note was the longevity of some of the pollution and the size of the issue. Waste from mining and coal fired power stations are the two largest US industrial wastes; the elemental nature of toxins from coal waste means that they persist in the environment indefinitely. Both these facets combine to cause significant health problem in areas where there is an economic reliance on coal.

The Clean Power Plan, SO_2 cap and trade and mercury regulation are discussed in chapter five. Disappointingly, given the amount of coal being burned in India and China, there was only a short section on regulation in these two countries— cap and trade in China and taxes in India— but there was no follow up in the chapter as to whether these are successful and sustainable.

The final two chapters of the book cover more technical aspects of coal use, including direct and indirect liquefaction and the holy grail of Carbon Capture and Storage (CCS). The impact of catalysts, solvent and the structure of coal itself on the efficiency of the liquefaction processes are discussed. The use of coal to provide feedstocks and fuels is currently commercialised using gasification and the Fischer Tropsch process, but only in a couple of countries. As the authors note, it is only security of supply that will drive investment in these processes whilst the oil prices remain low. The chapter on CCS is surprisingly short considering the high value placed on its role in reducing emissions by the Intergovernmental Panel on Climate Change (IPCC). The three basic strategies for CCS are discussed, with the emphasis on capture rather than utilisation of the captured CO_2. This chapter also briefly covers biomass with CO_2 combustion and bio-CCS technology along with direct air removal of CO_2, CO_2 utilisation and enhanced oil recovery. The opportunities and problems for scale-up are considered but the technologies are currently lacking credible demonstration plants at scale, whilst governments have generally been pulling support from investing in research in these areas.

Coal Mining Credit : Shutterstock

This book is a timely addition to the Issues in Environmental Science and Technology series, particularly with the changes in the administration in the US.

This book is a timely addition to the Issues in Environmental Science and Technology series, particularly with the changes in the administration in the US. It includes chapters on all the main themes—mining, burning, health, regulation and carbon capture and storage. However, whilst some chapters are excellent and comprehensive without being dull, others would benefit from some severe editing as they are poorly written.

There is also, in my opinion, too much emphasis on the US, with most of the focus of health, regulation and mining predominantly written with a US bias. With the increasing use of coal in India and China, a more balanced, global review would have been more fitting to the title. 'Coal in the 21st Century' is a slightly misleading title, as it is as much about coal in the 20th as 21st century. A recommended read though for anyone wanting a primer on coal as a source of energy, particularly those reviewing the potential of sustainable energies and IPCC emissions scenarios.

Whilst coal is expected to be a part of the 21st Century energy supply mix, it would appear that the majority of the authors in the book think that this path comes with a high environmental price that is unlikely to be mitigated.

Reference

Hester, R.E. and Harrison, R.M. (Eds) Coal in the 21st Century: Energy Needs, Chemicals and Environmental Controls. Issues in Environmental Science and Technology Volume 45. Published by Royal Society of Chemistry, Cambridge 2018

Meeting Report

Biopollution: antimicrobial resistance in the environment

Roger Reeve (Durham, rgrreeve@gmail.com)

The topic for the 2018 Distinguished Guest Lecture and Symposium, held on March 28 2018, was the global problem of developing resistance to drugs and the importance of understanding the role that the environment plays in its control. Much of the popular media publicity has been centred on the over-use of antibiotics for medical prescriptions, but resolving the problem will be more complex.

Antimicrobial compounds can enter the water supply from hospitals and from domestic use via sewage treatment plants, and antimicrobial resistant organisms can therefore build up in the environment. From here, antibiotic-resistant genes can be transferred through the ecosystem and ultimately back to human pathogens with severe implications for healthcare. Of particular concern is the major use of antibiotics in the farming industry, often with similar compounds to those used in human healthcare. And, finally, the environment itself contains reservoirs of antibiotic resistant genes which also could be transmitted back to affect human healthcare.

> **There is concern that the environment contains reservoirs of antibiotic resistant genes which could be transmitted back to affect human healthcare**

The morning session was convened by Dr Zoë Fleming, chair of the ECG. The first presentation was by **Dr Andrew Singer** (Natural Environmental Research, Centre for Ecology and Hydrology) and gave 'An Environmental Chemist's Introduction to the Global Crisis of Antibiotic Resistance'. After an introduction to the different types of antimicrobials (chemicals that kill or inhibit viruses, bacteria, fungi, protists and worms), the talk concentrated on the specific problems of antibiotics. Different classes of antibiotics were introduced as well as the four main mechanisms by which resistance occurs. In the west, antibiotics from human use largely enter the environment through waste water treatment plants. Farming is an additional input into the environment. A gap in current knowledge is the relative contribution of waste water treatment plants and farm run-off to antimicrobial resistance. In order to bridge this gap, Dr Singer's group researches aquatic reservoirs of antibiotic resistant bacteria at the catchment scale. Monitoring around some sewage work outfalls has shown hotspots of resistance. Modelling is used to predict resistance build up, based on the antibiotic usage within the catchment and the impact of future reductions in usage. The importance of co-selectives, including metals and biocides, in resistance pathways is becoming apparent. Reductions in all uses of antimicrobials may be required to achieve sustainable reduction of drug-resistant infections in humans.

Professor Célia Manaia (Universidade Catolica Portuguesa) followed with a talk entitled 'Antibiotic Resistance — from Nature to Environmental Contaminants'. Antibiotic resistance in the environment can be natural as well as anthropogenic. Entry to the environment following human use can occur via hospital effluent or waste water treatment plants. Waste water treatment plants are important resistance reservoirs in the urban environment. Improving waste water treatment needs to establish a compromise between chemical and biological control. Any disinfection such as ozonation or UV treatment must not be too aggressive towards the treatment plant microbiota. There is also an additional input to the environment from farm use of antibiotics. Mitigations suggested are the identification of critical control points and action at these points. Continual surveillance on an international scale is also necessary, and three current projects were mentioned. A question was asked concerning possible modification of sewage treatment plants. All options are expensive, so a cost benefit analysis is necessary during the selection. There are also some locations in the world where the agricultural input may be more important to control.

After a short break, the meeting continued chaired by the Distinguished Guest Lecture organiser, Dr Rowena Fletcher-Wood. **Dr Lee Slater** (Dept of the Environment, Food and Rural affairs) continued with 'Anthropogenic

Source Antimicrobial Resistance in the Environment—Implications to Policy and Environmental Management Practice'. By its nature, policy formulation takes many years. Development is within a continuous cycle—definition of issue, understanding the problem, control options, engagement with stakeholders, evidence and analysis, returning to a redefinition. Control of antimicrobial resistance is at the first 'understanding the problem' stage. Care has to be taken that a decision is not made to promote one direction that, with hindsight, proves to not be the most important action. This does not mean that there should be complacency – several examples were given of compounds which had unexpected consequences. The precautionary principle should be borne in mind, but this should only be on the basis of firm scientific principles. We can all help to formulate policy, as individuals, as leaders or future leaders, or as educators or as an industry. One delegate questioned the timescale involved in comparison with the proven need for action— no new antibiotics are in the pipeline and the lifetime of antibiotics before resistance is developed is only a few years. The response was encouraging that, although policy may take many years, it was an evolutionary process and interim guidance could be produced as evidence grows.

The Distinguished Guest Lecturer was **Professor Joackim Larsson** (University of Gothenburg). He is currently the Director of the Centre of Antibiotic Resistance involving more than 100 researchers from six faculties. The presentation started by giving the reasons to consider the importance of the environment in antibiotic resistance. Understanding environmental antibiotic resistance gives a possible indication of regional clinical resistance, defines transmission routes for resistant bacteria (human/animal to environment to human/animal) and could also have importance as an evolutionary arena for the emergence of new forms of resistance (favoured by a selection pressure from presence of antibiotics). There is evidence developing from studies in European counties showing a correlation between *E. coli* resistance in untreated sewage to resistance in clinical blood stream infections. Antibiotic resistance in the environment is ancient. Conditions to promote resistance build-up can happen anywhere and at any time. This may occur in the gut, but evidence is building that this also occurs in the environment due to background low concentrations of antibiotics.

Entry of waste water in the environment in the west is usually via sewage treatment plants. Determining the relative contribution of antibiotic concentrations and transfer of resistance is difficult as they have a common source. The overall effect of the treatment plants is complex and dependent on plant design and operation. One study of a plant with and without ozonation tertiary treatment showed that ozonation reduced antibiotics in effluents and downstream sediment to non-detectable levels, but the presence of resistant genes in downstream sediment was not affected.

Figure 1. *Professor Joakim Larsson with his 2018 Distinguished Guest Lecture medal presented by Dr Rowena Fletcher-Wood. Photographed at the Royal Society of Chemistry Centre, Burlington House*

Another inputs of antibiotics into the environment includes farming. In locations such as India or China, discharge from antibiotic production plants is important. High concentrations are found in surface, ground and drinking water and wildlife. India has produced a national action plan which includes setting antibiotic discharge limits from industry, farms, healthcare and veterinary care but is the only country so far to do so. This is also a recommendation in the recent O'Neil UK report.

A question followed defining the resistance issue – which area is of most concern within this highly complex problem? The most important areas may differ in different geographical locations. In the west, municipal waste treatment may be the most important, whereas in the east, more diverse environmental considerations may take priority.

The meeting concluded with the presentation of the 2018 Distinguished Guest Lecture medal to Professor Larsson.

The delegates left the meeting appreciating both the complexity of the problems and also the research currently underway to define areas of greatest importance as a step-forward to control of resistance.

Article

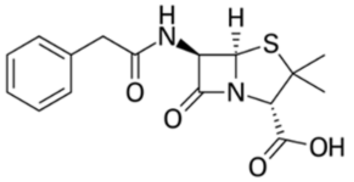
An introduction to the global crisis of antimicrobial resistance

Andrew C Singer (NERC Centre for Ecology & Hydrology, Wallingford, UK, acsi@ceh.ac.uk)

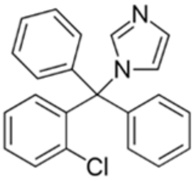
Antimicrobials are chemicals that are used to kill or inhibit the growth of microorganisms. Their use in medicine has spanned over 80 years, during which time their overuse and misuse in humans and animals, and their reckless release into the environment, has nurtured a global crisis of drug-resistant pathogens.

The term ‘antimicrobials’ includes a wide range of chemicals antagonistic towards five categories of organisms: 1) antivirals, inhibitors of viral replication; 2) antibacterials, which kill or inhibit the replication of bacteria; 3) antifungals, which kill or inhibit fungi; 4) antiprotozoals, which kill or inhibit the replication of protists; and 5) anthelmintics, which kill or inhibit worms. A typical example of an antimicrobial in each category is shown in Figure 1. The global movement to combat antimicrobial resistance (AMR) includes efforts to tackle infections resistant to drugs from each of these five categories. However, the main focus of most AMR Action Plans is on antibacterials.

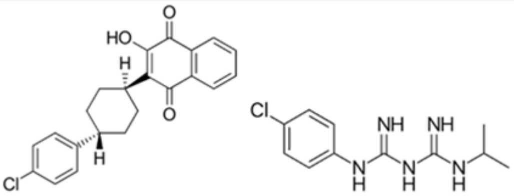
Alexander Fleming’s characterisation of the antibacterial properties of the culture broth of *Penicillium chrysogenum* was the catalyst for modern antibacterials (*1*) . However, it is less widely known that the motivation behind this original finding was to improve the culture conditions for *Bacillus influenzae* growth in the laboratory (now known as *Haemophilus influnezae*). At the time of Fleming’s research in the late 1920s, *B. influenzae* was presumed to be the infective agent behind the Spanish Influenza Pandemic of 1918 — a pandemic responsible for infecting 500 million people worldwide, and killing between 5 to 10% of those infected (*2*). Fleming felt that the antibacterial properties of the *P. chrysogenum* would be useful in producing pure cultures of the bacterial pathogen, thereby aiding the drive towards the discovery of a vaccine against this bacterium. The first evidence of the viral origin of influenza was published around the time of Fleming’s Nobel Prize-winning paper, in 1929.



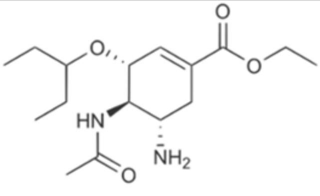
Antibacterial: benylpenicillin



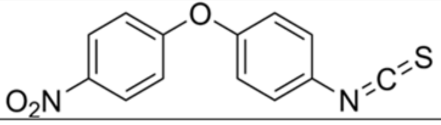
Antifungal: clotrimazole



Antiprotozoal: atovaquone and proguanil



Antiviral: oseltamivir (Tamiflu)



Anthelmintic: nitroscanate

Figure 1. *Exemplar antimicrobials within each of the five pathogen categories*

Fleming never fully characterised nor isolated the active ingredient in the fungal broth; this was completed by a team led by Ernst Chain and Howard Florey (*3*). Chain and Florey shared the Nobel Prize in Medicine with Fleming in 1945, the same year that a pioneering x-ray crystallographer in the Florey team, Dorothy Hodgkin, proposed the first 3D structure of penicillin. Hodgkin's achievement earned her membership in the Royal Society in 1947. In 1964, she won the Nobel Prize for her 'X-ray Analysis of Complicated Molecules' including benzylpenicillin, cephalosporin and vitamin B_{12} (*4*).

In the years following the research from the Florey group, hundreds of antibiotics were discovered from bacteria and fungi, or developed as a modified form of existing antibiotics (*5*). Concurrent with each newly marketed antibiotic was the observation of resistant microorganisms. Until recently, it was commonly believed that the emergence of an antibiotic resistance gene was the direct result of natural selection *in vivo*. Although many clinicians still hold on to this belief, it is now clear that most of the resistance mechanisms currently relied upon by microorganisms have been in the resistome (the pool of all resistance genes in a habitat) for thousands or perhaps millions of years. This means that nearly every antibiotic resistance gene first evolved in a microbe found in the environment. The rare but inevitable event of human pathogens acquiring this gene was facilitated by much of humanity's poor hygiene practices, including the lack of sanitation and the ubiquitous release of pollutants into our environment (*6*, *7*).

It is a fundamental law of nature that any chemical that results in the reduction in growth or the killing of a microbe will ultimately drive natural selection towards 'solutions.' A conservative estimate suggests that 13% of all biomass on earth are microbes (*8*). Their short generation time, relative to macroorganisms, helps ensure their adaptation to any chemical challenge. Microbial adaptation to chemical antagonism applies not only to antibiotics, but also to 'natural' pollutants such as metals (*e.g.* Zn, Cd, Ni, Cu) and plant secondary metabolites (*9, 10*).

All microorganisms harbour resistance genes, without which they would have no 'immune system'. Some of the resistance genes are clinically important, while most afford a basic level of protection. The problem arises when clinically-relevant resistance genes are shared. Microorganisms acquire resistance genes through a range of genetic mechanisms termed mobile genetic elements. Without mobile genetic elements, the challenge of tackling AMR would be considerably easier.

River Thames near Iffley Lock, Oxfordshire. Credit : Shutterstock

However, this feature not only allows for the sharing of solutions to chemical challenges among bacteria, but it also allows these solutions to be clustered together in tightly packed mobile genetic units called plasmids (*11*). Plasmids can be shared, allowing previously susceptible micro-organism to acquire resistance to the immediate chemical threat and, critically, simultaneously to acquire solutions to numerous other chemical threats found on the plasmid. It is a bit like seeking travel insurance to cover an unadventurous trip to the beach and being offered, at the same cost, worldwide travel insurance that covers ski trips, cancelled airlines and lost luggage. The term for this in the clinical setting is 'multi-drug resistance' (MDR).

MDR is maintained in environmental microbes through the release of pollutant mixtures. Once a chemical's concentration is above the threshold that inhibits the growth of a microbe, this pollutant becomes ecologically important as it will be driving the selection of resistance genes. The lower the selection threshold, the more significant the effect of the pollutant, whereupon even trace amounts of these chemicals can select for resistance. Importantly, the resistance genes do not necessarily disappear once the threshold is no longer met. Resistance genes found on a plasmid, for example, will be retained as long as one of the genes found on the plasmid offers a selective advantage (*12*). So, if a plasmid with an antibiotic resistance gene is no longer in use, it can remain present in a population of microbes if they inhabit an environment where, for example, zinc is abundant, and the zinc resistance gene is co-located on the same plasmid as the aforementioned antibiotic resistance gene. To use a metaphor, you still have ski insurance even if you don't go skiing, as it comes 'free' with the insurance package. Importantly, it is the problem of the co-selecting potential of pollution mixtures, not just antibiotics, that must be overcome to achieve significant gains in combatting global antimicrobial resistance.

The future utility of antibiotics will be reliant on our ability to address the contaminantion we release into the environment. The challenge of combating contaminants is a global one and it must coincide with improvements in hygiene and sanitation to be sustainable.

References

1. Fleming, A. (1929) On the Antibacterial Action of Cultures of a Penicillium, with Special Reference to their Use in the Isolation of B. influenzæ. *Br. J. Exp. Pathol.*, **10**, 226-236

2. Taubenberger, J.K. and Morens, D.M. (2008) The pathology of influenza virus infections. *Annu. Rev. Pathol.* **3**: 499–522.

3. Chain, E., Florey, H.W., Gardner, A.D., Heatley, N.G., Jennings, M.A., Orr-Ewing, J., and Sanders, A.G. (1940) Penicillin as a Chemotherapeutic Agent. *The Lancet* **236**: 226–228.

4. Hodgkin, D.C. (1965) The x-ray analysis of complicated molecules. *Science.* **150**: 979–988.

5. Aminov, R.I. (2010) A brief history of the antibiotic era: lessons learned and challenges for the future. *Front. Microbiol.* **1**: 134.

6. United Nations Environment Programme (2017) UNEA 3 Report: Towards a Pollution-Free Planet - Background Repor (c) United Nations Environment Programme, 2017, ISBN: 978-92-807-3669-4

7. Chief Medical Officer Annual Report 2017: Health impacts of all pollution – What do we know? (2018) https://www.gov.uk/government/publications/chief-medical-officer-annual-report-2017-health-impacts-of-all-pollution-what-do-we-know

8. Bar-On, Y.M., Phillips, R., and Milo, R. (2018) The biomass distribution on Earth. *Proc. Natl. Acad. Sci. USA* 201711842, published ahead of print May 21 2018.

9. Singer, A.C., Crowley, D.E., and Thompson, I.P. (2003) Secondary plant metabolites in phytoremediation and biotransformation. *Trends Biotechnol.* **21**: 123–130.

10. Singer, A.C., Thompson, I.P., and Bailey, M.J. (2004) The tritrophic trinity: a source of pollutant-degrading enzymes and its implications for phytoremediation. *Curr. Opin. Microbiol.* **7**: 239–244.

11. Salto, I.P., Torres Tejerizo, G., Wibberg, D., Pühler, A., Schlüter, A., and Pistorio, M. (2018) Comparative genomic analysis of *Acinetobacter spp.* plasmids originating from clinical settings and environmental habitats. *Sci. Rep.* **8**: 7783.

12. Lopatkin, A.J., Meredith, H.R., Srimani, J.K., Pfeiffer, C., Durrett, R., and You, L. (2017) Persistence and reversal of plasmid-mediated antibiotic resistance. *Nat Comm* **8**: 1689.

Article

Antibiotic resistance — from nature to environmental contaminant

Célia M. Manaia (Universidade Católica Portuguesa, CBQF – Centro de Biotecnologia e Química Fina – Laboratório Associado, Escola Superior de Biotecnologia, Porto, Portugal, cmanaia@porto.ucp.pt)

Antibiotic resistance is a human health issue, the consequence of our failure to treat simple bacterial infections. Antibiotic resistance has been disseminated into the environment, and is now a source of biological pollution. Current state-of-the-art research has revealed the most important sources of antibiotic resistance contamination, and provides some suggestions of how it can be controlled.

There are still important uncertainties regarding the human health risks associated with antibiotic resistance. These are due to the complexity of the problem and may be addressed with further research and worldwide surveillance. Until then, it is recommended that the precautionary principle is applied to any activity or source that may contribute to the environmental propagation of antibiotic resistance.

The clinical definition of antibiotic resistance is the failure to treat infections caused by bacteria that were once susceptible to a specific antibiotic or class of antibiotics. Multidrug resistance is due to the accumulation of resistance to different classes of antibiotics in the same bacterial strain. Multidrug resistance leaves, in some cases, very limited therapeutic options. Antibiotic resistance is now a global problem with serious implications for human health and major economic impacts. Worldwide, the number of deaths per year that are attributed to antibiotic resistant bacterial infections is 25,000 in the European Union, 23,000 in the United States of America and 38,000 in Thailand; not only this, but in India in one year more than 58,000 babies died due to infection with resistant bacteria (*1*). In addition, there are a number of other effects with important economic and health impacts such as extensions to hospitalisation periods and sick leave, and an increase in unsuccessful medical interventions. Antibiotic resistance is not only an issue affecting already diseased persons: it can also affect healthy individuals exposed to antibiotic resistant bacteria, either in healthcare facilities or in any other place where antibiotic resistant bacteria can be found, such as contaminated air or water bodies (*2–4*).

Although antibiotic resistance is a human health problem handled in healthcare facilities, it did not originate in hospitals. To find the ancestors of clinically relevant antibiotic resistance, it is necessary to investigate the natural environment, where the capacity to specifically resist each class of antibiotics is one of the multiple mechanisms used by bacteria to cope with external stimuli. Therefore, antibiotic resistance somehow escaped from the natural environment, and now exists in human pathogens (*5,6*). How, why and when this transfer happens is, except in a very few cases, unknown (*7, 8*).

Over the last 80 years of regular and intensive antibiotic use, antibiotic resistance has been delivered back to the natural environment, and is now a contaminant of great concern. Instead of just being found in strictly environmental bacteria, contaminant antibiotic resistance has become a property of new bacterial hosts, mainly human and animal commensal bacteria and pathogens. These antibiotic resistant bacteria can now be found everywhere, not only in healthy human and animal microbiomes (the whole set of microorganisms inhabiting a given place), but also in the environment, mainly in areas subjected to human activities. The primary sources of antibiotic resistant bacteria are hospital and household sewage and animal production facilities, where antibiotics can be used to promote growth (a practice banned in the European Union in 2006) or to treat infections (*9*). The impact of these sources on the dissemination of antibiotic resistance varies according to the degree to which good-practices and sanitation are implemented, among other factors (*10, 11*). Ensuring the availability and sustainable management of water and sanitation is the 6th Sustainable Development Goal proposed by the United Nations (*12*). In 2015, only 39% of the global population (2.9 billion) used a safely managed sanitation service (*13*).

Sewage collection and treatment in waste water treatment plants is unquestionably important for human health and environmental protection. However, multiple studies have shown that state-of-the-art treatment processes are not able to avoid the dissemination of antibiotic resistant bacteria into the environment (*14–16*). Therefore, even in regions where adequate waste water treatment processes are implemented, the contamination of streams, lakes, rivers, and soils with antibiotic resistant bacteria may be unavoidable (*15–18*). This problem is aggravated by the fact that, as for many other environmental contaminants, water is a privileged transport route and a preferential bacterial habitat. The generalised distribution of antibiotic resistance in the environment can also result in the contamination of wildlife, the human food chain, or leisure areas (*19*). The cycle of antibiotic resistance in the environment and the paths of human exposure are extremely complex and still poorly understood (*15, 16, 20*) (**Figure 1**).

However, the current knowledge in the field paves the way to propose important measures that may contribute to mitigation and control of antibiotic resistance propagation. A first step is the identification of critical antibiotic resistance sources. Two clear examples can be given. Firstly, hospital effluents which may contain high doses of antibiotic resistant bacteria of clinical relevance, and often resistance types that are emerging in the clinical setting but not previously found in the environment. These can be discharged into municipal waste water treatment plants without prior treatment. Clinical antibiotic resistance genes released in hospital effluents can in this way be further disseminated to the environment (*18, 21, 22*). Secondly, waste water treatment sludge and animal manure, known to be impregnated with antibiotic resistance determinants, can be used as natural fertilisers in soils with serious implications for soil contamination (*23, 24*). The dedicated treatment of hospital effluents before discharging in the municipal collector, the improvement of municipal waste water treatment to optimise simultaneous removal of antibiotic resistance with the myriad of contaminants that occur in waste water, and the implementation of stewardship measures to minimise antibiotic use in humans and animals are all part of a long list of possible control strategies (*10, 14, 16, 24*).

Although the scientific community has already identified critical control points (such as those mentioned above), it remains difficult to devise global strategic interventions. It is important to recognise that antibiotic resistance is spread between different environmental compartments, is often present in very high abundance, and represents the most serious clinical threats (e.g. carbapenem and colistin resistance). It is necessary to recognise the paths by which resistance moves from the environment to humans and animals (*20*). Only some of the wide diversity of antibiotic resistant bacteria in the environment will be able to colonise and eventually infect humans (*25*). Priorities include the elucidation of important antibiotic resistant vectors that are able to simultaneously thrive in the environment and colonise and/or infect humans. In addition, it is essential to identify the major paths through which antibiotic resistance vectors spread. Another key question refers to the number of cells and associated circumstances that will be needed to cause any harm in the human body. This value corresponds to the designated "infectious dose", which is not known and is not trivial to determine for most environmental antibiotic resistant bacteria. If

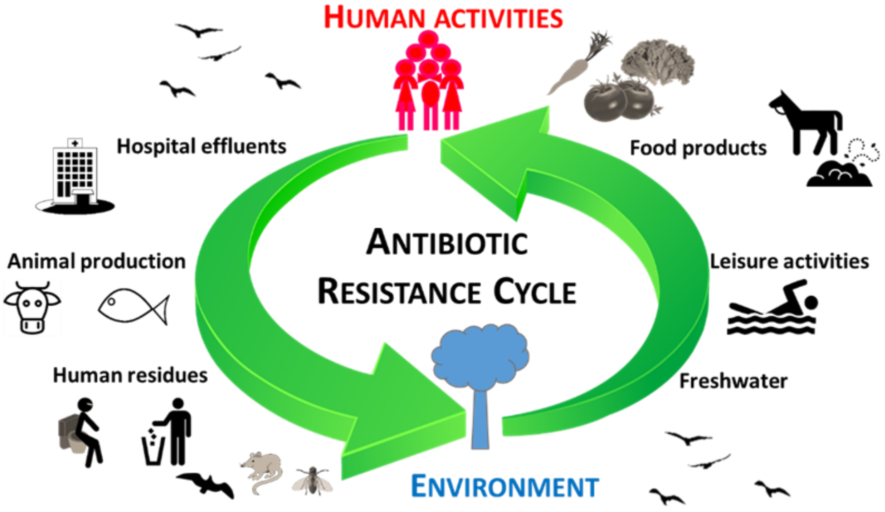


Figure 1. *Schematic representation of the antibiotic resistance cycle, where humans and the environment are linked by different processes and players, of which some examples are given.*

known, this value could be used as a reference to determine the maximum admissible load of antibiotic resistant bacteria in a given environment that does not represent a risk to humans. However, the calculation of an "infectious dose" presents other challenges, such as the capacity for bacteria to self-replicate. Another challenge is that the limits of quantification of antibiotic resistance achieved by state-of-the-art techniques, like quantitative PCR, may be too high to enforce reliable environmental safety guidelines. These arguments show that while it may be difficult to provide clear evidence that antibiotic resistance can be transmitted from environmental sources to humans, or to define objective thresholds of maximum admissible values, the application of the precautionary principle to contain the environmental spread and human transmission of antibiotic resistance is urgently needed.

References

1. Centers for Disease Prevention and Control (CDC). (2017). Infographic: Antibiotic Resistance The Global Threat. https://www.cdc.gov/globalhealth/infographics/default.html
2. Vaz-Moreira, I., Nunes, O. C., & Manaia, C. M. (2014). Bacterial diversity and antibiotic resistance in water habitats: searching the links with the human microbiome. *FEMS Microbiology Reviews*, **38**, 761-778.
3. Pal, C. et al. (2016). The structure and diversity of human, animal and environmental resistomes. *Microbiome*, **4**, 54.
4. Bengtsson-Palme, J. et al. (2017). Environmental factors influencing the development and spread of antibiotic resistance. *FEMS Microbiology Reviews*, **42**, fux053.
5. Allen, H. K. et al. (2010). Call of the wild: antibiotic resistance genes in natural environments. *Nature Reviews Microbiology*, **8**, 251.
6. Van Goethem, M. W. et al. (2018). A reservoir of 'historical'antibiotic resistance genes in remote pristine Antarctic soils. *Microbiome*, **6**, 40.
7. D'Andrea, M. M. et al. (2013). CTX-M-type β-lactamases: a successful story of antibiotic resistance. *International Journal of Medical Microbiology*, **303**(6-7), 305-317.
8. Nordmann, P., & Poirel, L. (2005). Emergence of plasmid-mediated resistance to quinolones in Enterobacteriaceae. *Journal of Antimicrobial Chemotherapy*, **56**, 463-469.
9. Davies, J., & Davies, D. (2010). Origins and evolution of antibiotic resistance. *Microbiology and Molecular Biology Reviews*, **74**, 417-433.
10. Berendonk, T. U. et al. (2015). Tackling antibiotic resistance: the environmental framework. *Nature Reviews Microbiology*, **13**, 310.
11. Wuijts, S. et al. (2017). Towards a research agenda for water, sanitation and antimicrobial resistance. *Journal of Water and Health*, **15**, 175-184.
12. United Nations (UN). Transforming our world: the 2030 agenda for sustainable development. (2015) A/RES/70/1. sustainabledevelopment.un.org
13. World Health Organization (WHO) (2015). News Rooms – facts sheet. Sanitation.
14. Bürgmann, H, et al. (2018). Water & Sanitation: An Essential Battlefront in the War on Antimicrobial Resistance *FEMS Microbiology Ecology* (In press)
15. Manaia, C. M. et al. (2016). Antibiotic resistance in urban aquatic environments: can it be controlled?. *Applied Microbiology and Biotechnology*, **100**, 1543-1557.
16. Vikesland, P. J. et al. (2017). Toward a comprehensive strategy to mitigate dissemination of environmental sources of antibiotic resistance, *Environmental Science & Technology*, **51**, 13061-13069.
17. Czekalski, N., Díez, E. G., & Bürgmann, H. (2014). Wastewater as a point source of antibiotic-resistance genes in the sediment of a freshwater lake. *The ISME Journal*, **8**, 1381.
18. Vaz-Moreira, I. et al. (2016). Multidrug resistance in quinolone-resistant gram-negative bacteria isolated from hospital effluent and the municipal wastewater treatment plant. *Microbial Drug Resistance*, **22**, 155-163.
19. Marti, E. et al. (2018). Abundance of antibiotic resistance genes and bacterial community composition in wild freshwater fish species. *Chemosphere*, **196**, 115-119.
20. Larsson, D.G.J. et al. (2018). Critical knowledge gaps and research needs related to the environmental dimensions of antibiotic resistance. *Environment International* (in press).
21. Narciso-da-Rocha, C. et al. (2014). blaTEM and vanA as indicator genes of antibiotic resistance contamination in a hospital–urban wastewater treatment plant system. *Journal of Global Antimicrobial Resistance*, **2**, 309-315.
22. Varela, A. R. et al. (2015). Molecular evidence of the close relatedness of clinical, gull and wastewater isolates of quinolone-resistant Escherichia coli. *Journal of Global Antimicrobial Resistance*, **3**, 286-289.
23. McKinney, C. W. et al. (2018). Occurrence and abundance of antibiotic resistance genes in agricultural soil receiving dairy manure. *FEMS Microbiology Ecology.*
24. Topp E. et al. (2018). Antimicrobial resistance and the environment: assessment of advances, gaps and recommendations for agriculture, aquaculture and pharmaceutical manufacturing. *FEMS Microbiology Ecology,* **1**, 94. doi: 10.1093/femsec/fix185.
25. Manaia, C. M. (2017). Assessing the risk of antibiotic resistance transmission from the environment to humans: non-direct proportionality between abundance and risk. *Trends in Microbiology*, **25**, 173-181.

Meeting Report

The geochemistry and mineralogy of contaminated environments

Steve Leharne (Greenwich University, s.a.leharne@greenwich.ac.uk)

6th June 2018, Royal Society of Chemistry, Burlington House, London

The contaminated sub-surface continues to be an important area of environmental concern. This area of research shows increasing maturity from an initial focus on levels of contaminant metals and organics in soils to an examination of the physical and chemical interactions of contaminants with soil and rock minerals; how these interactions control bioaccessibility and may help in contaminant removal/remediation is also of interest. The purpose of this meeting, jointly organised by the RSC's Environmental Chemistry Group and the Mineralogical Society's Environmental Mineralogy Group, was to survey recent advances in our understanding of biogeochemical processes affecting contaminants in the soil environment.

The first session was primarily concerned with organic contaminants. Two presentations from Newcastle University (**Jim Entwistle** and **Katherine Rothwell**) looked at redox systems based upon Fe(II)/Fe(III) couples and clay minerals. **Entwistle** looked at the formation of electron doped clay minerals which might then be used to degrade trichloroethene and tetrachloroethene. The systems showed little ability to reduce these exemplar chlorinated ethenes, though he was able to identify the formation of a green-rust like phase. **Rothwell,** on the other hand, showed that the presence of redox mediators could aid in the degradation of exemplar nitro-aromatic compounds. **Mohammed Alyami** (Bangor University) was interested in the analytical challenges presented by the extraction of crude oil from Saudi Arabian sands. He further examined the challenges to plant growth in oil contaminated media. **Ian Ross** (Arcadis) was also concerned with analytical and interpretive challenges. In this case, his focus was on perfluoroalkyl substances (PFAS) present in a contaminated land site. He focussed upon the use of advanced analytical tools that could be used to identify a range of PFA molecules.

Sul Mulroy (Manchester University) was concerned with the extraction of Co and Ni containing ores from various mines in Africa and their environmental impact. Data show that proximity to extraction locations leads to high exposure rates for human and other biotic receptors. Using Extended X-ray Absorption Fine Structure (EXAFS) spectroscopy he was able to show that Ni and Co were associated with Mn(III/IV) oxides. Furthermore, Ni was located as an inner-sphere complex over hexagonal vacancies in the phyllomanganate layers of lithiophorite, whilst Co typically replaces Mn in lithiophorite phyllomanganate layers. **Malama Chissanga** (Manchester University) examined the use of Raman Spectroscopy and reverse isotopic labelling to establish whether microorganisms were able to degrade a target contaminant. In this case, *Pseudomonas putida* and *Escherichia coli* were grown in ^{13}C enriched glucose and then exposed to ^{12}C enriched phenol. A wavenumber shift in key vibrational bands shows the metabolisation of the target compound by *P. putida*.

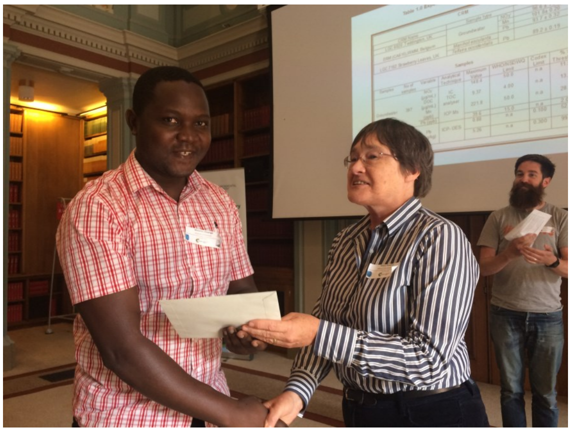
Bio-monitoring was the subject of the next presentation from **Daniel Niepsch** (Manchester Metropolitan University). Using lichens taken from various locations in central Manchester, he examined the take up of N, C and S. Moreover, through the determination of isotopic enrichment factors, he was able to tentatively ascribe elemental uptake from various anthropogenic sources. Biological intervention, using fungi to remediate a site contaminated with Pb and PAHs, was the focus of **Felipe Sepulveda's** (University of Glasgow) presentation. Culture experiments indicated that *Paecilomyces javanicus* could grow in the presence of Pb and PAHs. After 10 days of exposure *P. javanicus* grew around the PAH particles, indicating that they could act as a potential carbon source and reduce the Pb concentration.

Sequential extraction, using acid solutions of varying concentration, was used by **Joanna Wragg** (BGS) to help identify the mineralogical sources of bioaccessible As. The dissolution of a predominantly Fe-As mineral phase and a Ca-Fe-As phase seemed to be responsible for the release of bioaccessible As as measured using a gut model.

The keynote lecture was presented by **Tom Sizmur** (University of Reading and Chair of the ECG). His subject was the biogeochemistry of mercury in the intertidal mudflats in the Bay of Fundy in Nova Scotia, Canada. Low concentrations of mercury in sediments leads to enrichment in *in situ* invertebrates including polychaete worms and ultimately semipalmated sandpipers. Studies have shown that sandpipers migrating from northern Canada to South America present significantly increased mercury body burdens due to their consumption of large quantities of polychaete worms prior to their migration south. His work demonstrated that the worms could alter the redox conditions of their sediment environment – oxidizing S to SO_4^{2-} – which had the effect of increasing the bioavailability of Hg. Some extremely interesting and well-made measurements showed that solar radiation and the concomitant rise in temperature could lead to increased rates of Hg reduction to the elemental state and volatilisation of Hg from the sediment environments.

The causal risk pathway of hazard-pathway-receptor can be broken by intervention in the pathway process. Two presentations (**Ian Ross**, (Arcadis and **Adrian Cleary**, University of Manchester) examined the use of phosphates to reduce elemental mobility at contaminated land sites. **Ross** looked at the addition of soluble phosphate to reduce the mobility of U(VI). Reduction to U(IV) can lead to immobilisation but is potentially reversible. The formation of insoluble and surface passivated U(VI) phosphate can be a more sustainable solution. **Cleary** focussed upon the use of glycerol phosphate to immobilise the radioactive nuclides ^{90}Sr, ^{99}Tc, and U. The breakup of glycerol phosphate to its glycerol and phosphate moieties provided remedial opportunities for nuclear facilities. It was shown that glycerol, as an electron donor, can immobilise Tc and U through reduction. On the other hand, the presence of phosphate and calcium can lead to Sr mineralisation. Of course P can also be a potential pollutant. **Sam Bingham** (University of Bristol) examined the role of the Upper Greensand aquifer as a sink and source of phosphate in the Hampshire Avon catchment. Changes in physico-chemical conditions such as changes in pH, Ca^{2+} and PO_4^{3-} concentration were shown to impact the precipitation or release of phosphate. Finally, **Joseph Nwackukwu** examined the impact that urbanisation in SE Nigeria and changing land use had on human exposure to $NO_3^-$and Pb.

The meeting ended with prizes awarded to **Agustín Solano Arguedas**, (University of Manchester) for his poster, "Natural biogeochemistry of Co, Ni and Cr in Costa Rican lateritic soils" and to **Malama Chisanga** (University of Manchester) for his presentation "Raman spectroscopy and reverse isotopic probing: novel method for identifying microbes associated with degradation of environmental pollutants".



Article

Motivations to start or join a small enterprise in environmental chemistry

David Owen (TreatChem, david.owen@treatchem.co.uk)

For every environmental chemist who has put a foot on the first rung of a career ladder, there comes a pivotal moment when they reflect on their position and decide whether that career is acceptable to them or not. Some will decide that security is their main priority, others will decide to leave and seek out fresh opportunities. Ultimately, the specific circumstances and the personality of the individual will decide their path. Depending upon their skill base, unique insights, and exposure to market opportunities, a small number of environmental chemists will decide to be their own master and start up a small business of their own. This decision will be a life changing one.

Business with environmental concern. Credit: Shutterstock

The challenge for anybody considering a career in environmental chemistry is to understand the potential pathways that allow either partial or full deployment of the expertise they gathered before, during, or after their formal education. Historically, many chemistry graduates have found places in the chemical industry (usually in petrochemical, inorganic and pharmaceutical companies). These sectors previously provided a stable, long term career in research and development, production, regulatory compliance or management, but as the chemistry industry has evolved to be more competitive and specialised, many of the 'peripheral' areas such as process improvement or innovation have been outsourced to smaller companies that can deliver state-of-the-art customised solutions. The result of these changes has been an overall narrowing of the traditional chemist's role and a diversification of the roles available in small- and medium-sized enterprises (SMEs), particularly roles requiring environmental chemistry expertise. Combined with the emergence of new, interdisciplinary industries based on digital, electronic or genetic technologies, the options for environmental chemists have become bewilderingly diverse. This diversification, however, does not mean that chemists, biochemists, microbiologists, ecologists, and toxicologists are no longer in demand: the basic science of chemistry remains a key a foundation to several emerging industries. As such, a good career within this increasingly multidisciplinary field requires the ability to change with circumstance and learn continuously: a single area of expertise no longer ensures a career for life. Change will be the ever present constant, and those willing to embrace it will be the winners.

> **"Choosing to work for an SME or establish an entrepreneurial career is a matter of personal preference, skill base, and attitude to risk."**

Successful start-ups foster great opportunities for individual expression and recognition, but also engender risk; ventures may fail for various commercial, intellectual or competitive reasons. For some, this offers an exciting, adventurous and fast-moving career. Others prefer the comparatively more sedate pace in an established SME, perhaps after gaining experience at a larger company. Choosing to work for an SME or establish an entrepreneurial career is a matter of personal preference, skill base, and attitude to risk. All these factors contribute to future economic growth and innovation.

The problem of experience (or rather the lack of it), is probably the main barrier graduates find when entering a career in SMEs. SMEs often prefer employees who have received industrial training and experience at a larger company, since they are often small and have limited capacity for training. However, because of the pace of progress in some notable fields of science, such as genetics and biochemistry, lack of experience can be overcome by up-to-date knowledge in specific technologies. This is probably more true for the SME start up companies spun out from academic research. The massive increase in high tech companies in the Oxford Cambridge corridor is testament to the need for very specific qualifications. This demand for qualified personnel is similar to the demand for highly qualified IT graduates in Silicon Valley.

> **“a small number of environmental chemists will decide to be their own master and start up a small business of their own. This decision will be a life changing one”**

A graduate who finds an initial placement in one of the larger companies and progresses from there to an SME is likely to find it a somewhat different environment, primarily because they will move to an organisation that is involved in all stages of development. In successful SMEs, the company trains the individual in the core skills, services and management systems of the organisation. The net effect is that the individual has the opportunity to see the result of their efforts and accrue more robust and transferable skills.

For those attempting entrepreneurial careers by starting their own company, there is even greater risk. According to Small Business (business.co.uk) and other industry sources, the failure rate of start-ups within five years can be as high as 40%, often the requirement for careful financial management is underestimated. Generally, the finances required, even for a small business, are much higher than most individuals anticipate. This often means that more time is spent organising the cash reserves of the business than actually conducting the day to day operations. A business plan is critical for building achievable goals and assessing how far ahead or behind target the business is, even if the target is revised. The business plan also provides transparency for potential investors. These less exciting (but necessary) activities are core to a successful business, but do not always fulfil the ambitions of the environmental chemist at the helm.

Some organisations and charities (such as The Oxford Trust) provide intermediary support for incubator companies, helping them to establish themselves with lower rents and mentoring. For the novice, good mentoring and support is invaluable.

The RSC provides career support to members at all stages, including bespoke one-to-one consultations. Additionally, the RSC Consultancy Group is an interest group that runs a regular programme of networking and professional development events, and hosts an online discussion forum. Chemistry World, the RSC's flagship magazine, administers an award for 'Entrepreneur of the Year' that recognises individuals who demonstrate creativity and vision, driving chemistry innovation to commercial success for their business.

The amount of effort and understanding required to start a business is typically much greater than ever anticipated and, significantly, falls outside the expertise in environmental science that the entrepreneur typically possesses. But, for those that choose to go down this path, the rewards will usually be deemed worth the effort.

References and Further Information

- RSC Careers Support (http://www.rsc.org/careers/)
- Chemistry World Entrepreneur of the Year (http://www.rsc.org/ScienceAndTechnology/Awards/EntrepreneuroftheYear/)
- RSC Consultancy Group (http://www.rsc.org/Membership/Networking/InterestGroups/Consultancy/)
- Small Business (http://business.co.uk)
- The Oxford Trust (http://theoxfordtrust.co.uk/)
- Department for Business, Energy and Industrial Strategy (https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy)

Update

WMO Greenhouse Gas Bulletin No 13

Valerio Ferracci (Cranfield University, v.ferracci@cranfield.ac.uk)

As scientists shine new light on the relationship between atmospheric composition and past climates, the concentration of greenhouse gases in the atmosphere continues to rise.

The World Meteorological Organisation (WMO) issues annual bulletins summarising the latest measurements of the concentrations of greenhouse gases in the Earth's atmosphere. The latest bulletin (WMO Bulletin No. 13, 2017), which is freely available online along with those from previous years (*1*), reports on the observations gathered up until (and including) 2016 from a number of monitoring stations scattered across the planet.

The global average atmospheric CO_2 concentration in 2016 was 403.3 ppm, a 45% increase from pre-industrial levels of ~278 ppm. This was accompanied by the largest year-on-year increase in CO_2 concentration to date (3.3 ppm $year^{-1}$) attributed to both record levels of anthropogenic CO_2 emissions and the influence of the 2015-16 El Niño event, which led to enhanced natural CO_2 emissions (as described in the WMO Bulletin No. 12, 2016). While anthropogenic CO_2 emissions were generally thought to have slowed down (or even reached a plateau) during the period 2013-16, 2017 witnessed a significant increase (*2*). It will be interesting to see what effect this will have on the CO_2 levels reported in next year's WMO bulletin.

Updates on the two other major greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), are also reported. Their concentrations in 2016 were respectively 1.853 ppm and 328.9 ppb, 157% and 22% higher than pre-industrial levels in each case. The annual increase in CH_4 concentration (9 ppb $year^{-1}$), was one of the largest in the last decade, following a period of effectively zero growth in the early 2000s. The rate of increase in N_2O concentration (0.9 ppb $year^{-1}$) was slightly lower than the average growth rate during the last decade.

Power Plant with a big chimney with smoke. Credit Shutterstock

In addition, each year the WMO bulletin focuses on a particular aspect of climate science. Previous editions have addressed topics such as ocean acidification (WMO Bulletin No. 10, 2014) and the effects of El Niño events on greenhouse gas emissions (WMO Bulletin No. 12, 2016). The latest edition contains an introduction to ice-core analysis and other proxy techniques used to quantify historic atmospheric CO_2 levels. These studies corroborate our understanding of the relationship between greenhouse gases and the Earth's temperature and climate. They show, for example, that changes in global temperatures during glacial and inter-glacial periods were always accompanied by variations in atmospheric CO_2 concentration. Additionally, data obtained from ice cores indicates that current CO_2 abundances far exceed the natural variability observed in CO_2 concentrations over the last few hundreds of thousands of years (typically in the range 180-280 ppm). Proxy data suggests that elevated levels similar to those currently measured were last encountered in the mid Pliocene period (3-5 million years ago). Then, global mean surface temperatures were 2-3 °C higher than today, causing the ice sheets in Greenland and West Antarctica to melt and leading to sea levels 10-20 m higher than at present.

The 2016 Paris Agreement is seeking to keep temperature increases by the end of the century to well below 2 °C relative to pre-industrial values. The WMO bulletins are an effective way to keep up-to-date with the latest developments in the field of greenhouse gas monitoring, and they also provide very useful insights on climate science as a whole.

References

1. https://public.wmo.int/en/resources/library/wmo-greenhouse-gas-bulletin

2. http://www.globalcarbonproject.org/carbonbudget/17/files/GCP_CarbonBudget_2017.pdf

Public Engagement How To:

Microplastics

Rowena Fletcher-Wood (Science Oxford, rowena.fletcherwood@gmail.com)

An amazing attention-grabber – with this simple exhibit, kids can spend hours and hours digging out tiny fragments of torn plastic straw with a pair of tweezers from a pile of dirt. **This exhibition guideline explains how to set up and introduce microplastics to the public.**

Theory

Plastics are essential to modern life, but we dispose of them too readily, dumping them in landfill sites, releasing them into the wild, and flushing them down our drains. Many pieces of plastic enter the environment, where they cause harm and eventually break down into very, very small pieces, including microplastics.

Set up

Fill an A4 sized tray with dry earth or soil, chop or grate 2 or 3 coloured straws as small as possible and distribute the pieces through the soil. A bendable desk light and phone-attachable microscope make great technical additions if you have a power source or battery light. We also had a facewash containing microplastic beads for visitors to look at and touch.

Challenge

Find the plastic contaminants!

Kit List

Robust A4 sized tray
Dry soil
4 pairs of plastic tweezers
Coloured straws
Scissors or grater
Bendable desk light
Phone with a camera
Clip-on microscope
Microplastic examples

Exhibition Cost

About £40 (excluding phone), but all components except straws will be reusable; costs are mainly for the “extras”, especially the clip-on microscopes (£20 for 3) and desk lamp (about £10).

Exhibition weight

Less than 5kg

Exhibition size

Would fit into a printer paper box

Resources required

Electrical power for the desk lamp

Things to look out for

After a few enthusiastic visitors, this exhibit will need resetting. Ensure the soil used is dry as there will be mess because some children find it hard to distinguish soil debris from plastic. Lying a piece of paper beside the tray allows them to collect plastics and examine them through the microscope. Also beware that you might get several children round the exhibit, so provide at least four pairs of plastic tweezers and place it, if possible, on a small table or corner of a larger table to give them more space to get round. Larger and heavier trays will be more stable, especially on tables with other exhibits!

Article

RSC careers events and opportunities

RSC Careers Team (careers@rsc.org)

Early Career Symposium – Liverpool

Hosted by the Royal Society of Chemistry's Early Career Network, the 5th Early Careers Symposium 30-31st August 2018, in Liverpool, will bring together early career chemists from all sectors. It offers an excellent opportunity for both industrial and academic researchers to attend panel discussions and to listen to parallel talks and keynote speeches from world renowned experts. There are travel grants available, and the event will enable participants to:

- Hear about the latest developments in three broad areas of chemistry: organic and biochemistry; physical and analytical; inorganic and materials
- Present poster submissions
- Develop communication skills and gain confidence when presenting research
- Meet the next generation of leaders in the chemical sciences

Mentoring

We run a Member to Member mentoring scheme and currently have nearly 80 active mentoring partnerships.

Why become a mentor? Mentoring is valuable to both mentees and mentors. Mentors find the experience of helping another member rewarding as they help them to grow – addressing their own challenges, considering their relationships at work and thinking of the future.

> **"It's always useful to think about my goals and setting myself objectives. 'Everyday life' often prevents me from doing this, and so this has given me an opportunity to do so."**

The benefits of mentoring: Being mentored has helped our members to:

- achieve greater clarity around their career goals and how to achieve them
- gain greater self-confidence and self-belief
- pursue personal and professional development and practical learning
- improve relationships with their colleagues and their performance in their current role

One member described how having a mentor has given him the opportunity to think about his career: "It's always useful to think about my goals and setting myself objectives. 'Everyday life' often prevents me from doing this and so this has given me an opportunity to do so."

We are running a specific training course for mentors who work in academia on the 18th October at Burlington House. If anyone is interested in attending please email careers@rsc.org for the details. Mentors must be either Members (MRSC) or Fellows (FRSC).

Career Consultants

The Royal Society of Chemistry's Team of qualified careers specialists offer free 1-to-1 confidential consultations on any aspect of running your career. This could include:

- A review of your career so far and planning your next steps
- Updating your CV
- Maximising your LinkedIn profile
- Job search strategies
- Preparing for interviews
- How to effectively use Continuous Professional Development tools

These sessions are available to our Associate members (AMRSC), Members and Fellows

Consultations can take place by telephone, Skype and email as well as face to face in London or Cambridge. We will also be visiting the following cities in 2018:

- Liverpool (18-20 Sept)
- Glasgow (1-3 October)
- Manchester (22-24 October)
- Newcastle (13-15 November)
- Coventry (19 November)
- Bristol (27-29 November)

Eligible members will receive an email invitation to book an appointment nearer the date.

Contact: If you'd like to speak to a Careers Specialist before then, email careers@rsc.org to book a telephone consultation.

ECG Early Careers Environmental Brief (ECGECEB No 3)

Adverse effects and control legislation of poly- and perfluoroalkyl substances

Teresa Jones (University of Reading BSc Environmental Science student, teresaj93@hotmail.co.uk)

Poly- and perfluoroalkyl substances (PFASs) are a group of anthropogenic chemicals used globally as emulsifiers or surface protectors in many industrial and consumer applications. They are used, for example, in food packaging and cooking products, carpets, clothes, mattresses, and fire extinguishers (*1*). These substances are also widely known as perfluorinated chemicals (PFCs) but should not be confused with perfluorocarbons, which are potent greenhouse gases. PFASs consist of a partly (poly) or fully (per) fluorinated carbon chain that is connected to functional groups containing, for example, oxygen, sulfur and/or nitrogen atoms. Their potential to be bioaccumulative, toxic **(Table 1)**, and highly persistent has been increasingly recognised (*1*).

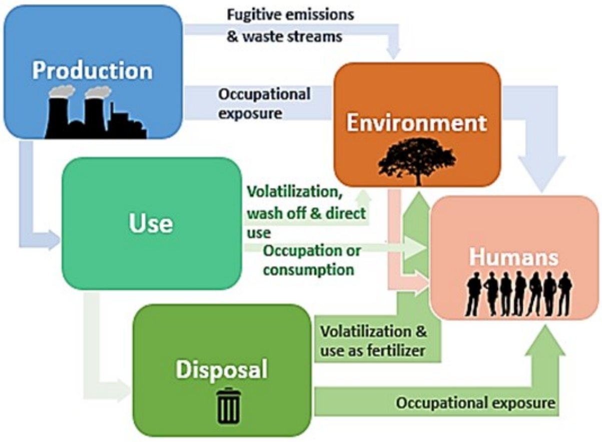


Figure 1. *Routes by which PFASs may be potentially released to the environment and exposure to humans, Adapted from: (2), with added data from (3).*

PFASs are a group of over 3000 compounds, typically subdividided into long and short chain compound groups, depending on the length of the carbon chains in their structure. The environmental and human health response varies, but long chain PFASs (containing 6 or more carbon atoms) are more potent. In recent years, efforts have been made to limit exposure of humans and the environment to perfluoroalkyl acids (PFAAs), such as PFOA and PFOS **(Table 1)** (*2*).

Class	**Sub-class**	**Com-pound**	**Guidance level**
Perfluoro-alkyl acids (PFAAs)	Perfluoro-carboxylic acid (PFCA)	Perfluoro-octanoic acid (PFOA)	0.3 µg/L
	Perfluoro-alkane-sulfonic acid (PFSA)	Perfluoro-octane-sulfonate (PFOS)	0.3 µg/L
PFAA pre-cursors	Perfluoroalkane sulfonyl fluoride (PASF) based substances		Variable
	Fluorotelometer-based substances		Variable
Others	Fluoropolymers		Variable
	Perfluoropolyethers (PFPE)		Variable

Table 1. *Simplified classification of PFASs, and guidance levels above which pose risk to human health. Adapted from: (1) and (2).*

Effect on the Natural Environment

PFASs can enter the environment in solid, gas, or liquid form during manufacturing, use, or disposal **(Figure 1)**. Pathways include fugitive emissions or wastewater streams during production, volatilisation during use, and use of sewage sludge as fertiliser during disposal. Through these pathways, natural ecosystems such as waterways, soils, and biota become polluted with PFASs. Although land is exposed to the largest amount (>200 tonnes globally on average per year), PFASs can be transported thousands of miles through water currents and through the atmosphere as aerosols (*2*). Oceans are the largest reservoir, where PFASs are mainly present as polyfluoroalkyl acids (PFAAs). Deep water and surface currents aid in global transportation. Studies have shown their presence as far as the arctic (*3*). PFASs are stable in the environment and are resistant to biodegradation, and physical degradation through exposure to air, water or sunlight. Long chain PFASs are often accumulated by organisms faster than the rate of expulsion, and thus are bioaccumulative. Biomagnification also occurs when concentrations are passed up the food-chain through consumption (*1*).

Effect on Human Health

Humans are exposed to PFASs through interaction with the environment, such as contaminated air, water, soils, and dust, as well as through use of PFAS-containing products. Occupational exposure occurs during the production and disposal stages. The main pathways are through consumption of food grown in contaminated soils and of contaminated drinking water. PFASs are found in the blood of the general population in small concentrations owing to their wide distribution, most commonly in the form of PFOA and PFOS (*2*). They have a long residence time and may remain in the blood stream for over 1000 days (*3*). High levels of PFASs have negative effects on reproduction and foetal development, resulting e.g. in reduced birth weight (*3*). They have also been shown to cause developmental, endocrine, neurobehavioral, and metabolic toxicity in animal experiments. Chronic toxicology testing has been carried out for PFAO and PFOS; both substances caused tumours in rats, suggesting carcinogenic properties (*1*).

Control Legislation

Between 2004 and 2009, the Organisation for Economic Co-operation and Development (OECD) carried out three studies to identify and quantify sources of PFAS. Organisations in participating countries were required to report all PFASs manufactured or imported into their jurisdiction (*4*).

Following this, the European Union set out regulations developed in association with advocacy groups, industry, and researchers. The use, production, import and export of PFOS and its derivatives have been prohibited/restricted under the EU Commission Regulation No 757/2010 of 24 August 2010. It is likely they will soon be recognised as a priority hazardous substance in Directive COM (2011) 876, amending the Directive on Environmental Quality Standards (Directive 2008/105/EC) and the Water Framework Directive (2000/60/EC). PFOA and certain perfluoro-carboxylic acids (PFCA) are listed as substances of very high concern (SVHC) under the EU Chemicals Regulation REACH, which obligates industries to register products containing these PFASs. The long-term goal is to completely substitute these harmful substances (*4*).

Further Research & Remediation

Current legislation focuses on phasing out long chain PFASs by prohibiting the sale of PFOA and related compounds as standalone substances, and limiting concentrations in various manufactured products between 2020 and 2032. The phase out process is slow to lessen economic challenges (*5*). However, as the substances may travel across country borders via fugitive emissions and water currents, commitment is required on a global level to reduce human and environmental exposure. In conjunction, *in situ* remediation technologies for contaminated land require further development; currently used pump-and-treat techniques are expensive and energy-intensive (*2*). Dilution and burial techniques should also be considered to remedy already contaminated environments and reduce the residence time in soils and waterways.

Substances that are structurally similar to the potent long chain PFASs are being used as alternatives in industry, but these remain unassessed and unregulated (*2*). This is a cost-effective solution but does not address the issue of PFAS accumulation. Further research needs to evaluate their potential risks related to human and environmental exposure.

References

1. Fulmer, A. (2016). Poly- and Perfluoroalkyl Substances: Background Technical Information. Water Research Foundation, pp. 2-4. Available at: http://www.waterrf.org/resources/StateOfTheScienceReports/PFCs_StateOfTheScience.pdf (Accessed 2 Nov. 2017).

2. Wang, Z., DeWitt, J., Higgins, C. and Cousins, I. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? Environmental Science & Technology, 51(5), pp.2508-2518.

3.OECD (2013). OECD/UNEP Global PFC Group, Synthesis paper on per- and polyfluorinated chemicals (PFCs), Environment, Health and Safety, Environment Directorate, OECD. Available at: https://www.oecd.org/env/ehs/risk-management/PFC_FINAL-Web.pdf (Accessed 13 Nov. 2017).

4. OECD. (2017). Country information - OECD Portal on Per and Poly Fluorinated Chemicals. Available at: http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/european-union.htm (Accessed 13 Nov. 2017).

5. Europa. (2017). Official Journal of the European Union - COMMISSION REGULATION (EU) 2017/1000 of 13 June 2017. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1000&from=EN (Accessed 13 Nov. 2017).

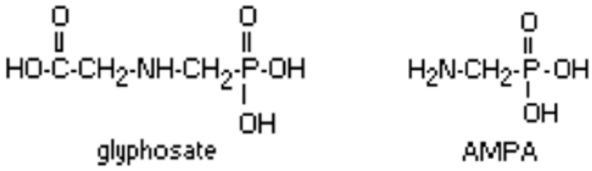
ECG Early Careers Environmental Brief (ECGECEB No 4)

Should the EU continue to use glyphosate?

Marc Mohajer (University of Reading BSc Environmental Science student, marcmohajer@gmail.com)

Glyphosate, N-(phosphonomethyl)-glycine, is the active substance in up to 750 glyphosate-based herbicides. They are the most widely used herbicides in the world, with 700,000 tons used worldwide in 2012 (*1*), particularly with genetically modified glyphosate-resistant crop plants such as soybeans (*2*). In December 2017, the European Union reapproved the use of glyphosate-based herbicides for another 5 years. This Brief discusses the effects of glyphosate-based herbicides on humans and plants and examines whether their use should be prohibited.

Glyphosate-based herbicides were introduced in 1974 by the Monsanto company. They inhibit the essential sixth enzyme of the shikimate pathway, 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS). They thereby prevent the development of amino acids and defence functions in plants and microorganisms, resulting in their death after a few days. Glyphosate-based herbicides also contain surfactants such as polyoxyethylene amine (POEA), which increases uptake by and movement through the plants (*1*). Glyphosate, due to its C-P linkage in the molecule, is resistant to decomposition. However, it is eventually broken down through decomposition and microorganisms, which frequently metabolise to aminomethyl phosphonic acid (AMPA) (**Figure 1**). Glyphosate can also decompose in the plant, creating glyphosate and AMPA residues in the soil. Recommended application levels are between 0.72 and 2.88 kg glyphosate per hectare, with a maximum annual application of 4.32 kg glyphosate per hectare (*2*).



$HO\text{-}C(=O)\text{-}CH_2\text{-}NH\text{-}CH_2\text{-}P(=O)(OH)\text{-}OH$ $\quad H_2N\text{-}CH_2\text{-}P(=O)(OH)\text{-}OH$

Figure 1. *Similar structure of glyphosate and AMPA*

The first glyphosate-based herbicide was Roundup Original, which contained around 15% glyphosate isopropylamine salt and POEA of the herbicide, the most toxic substance in the formula. The remaining 68.4% was made up of other substances, which are usually overlooked even though they can cause harm to the environment, animals, and humans. A study by Peixoto (*3*) showed that glyphosate formula reduced the activity of rat's liver, while glyphosate alone did not. Glyphosate has since been used in many different formulations, creating new blends that can be potentially more toxic and aggravate contamination (*4*).

What it is used for

Glyphosate use around the world has increased rapidly in the past two decades, rising 15-fold between 1994 and 2014. Glyphosate-based herbicides are generally used before the planting of genetically modified crops such as cotton, maize, canola and soybeans. In Europe, where genetically modified crops are not grown commercially, it is applied mainly to cereals and oilseeds as well as in vineyards and orchards (*4*). Smaller-scale uses include weed control in urban areas, e.g. along streets and parks, and in gardens. Glyphosate has also been directly applied to waterbodies to control seaweed levels or eliminate alien species.

Occurrence in Soil

The biggest factor affecting glyphosate occurrence in soil is the type and texture of the soil. Glyphosate is adsorbed by clay and organic matter, whereas it is quickly washed out of sandy soils. Thus, glyphosate and AMPA can build up and be present in some soils for up to a year before decomposing fully (*1*). In 2017, from 317 samples taken from around Europe, 45% contained measurable amounts of glyphosate or AMPA, with the latter being far more frequent. Concentrations of up to 2 mg kg^{-1} were measured (*2*).

Occurrence in water

Glyphosate-based herbicides can be found in a wide variety of freshwater bodies as a result of transport from soil to surface waters by rain and erosion. Here, the herbicide can remain as a particulate or be dissolved. As a particulate, it can travel to the bottom of the water body and join the sediment at the bottom, where it takes much longer to dissolve than whilst suspended in the water column. Glyphosate-based herbicide concentrations of up to 450 mgL^{-1} have been reported in water bodies, with concentrations in sediments of up to 470 mg kg^{-1} In Argentina, concentrations in water were only between 0.5 and 7.6 mg L^{-1}, but those in sediments were up to 200 mg kg^{-1}, with the highest concentrations measured in the vicinity of agricultural activities (*5*).

Effect on Plants

Glyphosate-based herbicides affect not only the target organisms, but also native species, reducing biodiversity. A study in Argentina recorded that, after use of a glyphosate-based herbicide for 21 days, 50% of species showed a phytotoxic response or death, with 75% showing growth reduction. This poses a severe problem for the use of glyphosate-based herbicides in forested areas (*6*). A growing concern is the rising incidence of plant resistance to glyphosate.

Effect on Animals and Humans

Glyphosate and AMPA are taken up by animals through consumption of water and plants and released again through excretion. Because they target EPSPS enzymes, which are only found in plants, glyphosate-based herbicides have a reduced direct effect on humans and animals. Nevertheless, they been shown to have a toxic effect on aquatic species. For example, Bridi et al. (*6*) have reported that glyphosate-based herbicide concentrations of 0.5 mg L^{-1} reduced the travel distance and mean speed of zebrafish during the study period (*7*). Another study, focusing on POEA, showed that exposure to Roundup reduced physiological attributes of damselfly larvae, reducing food intake and speed as well as muscle and sugar mass. POEA was not the only toxic variable. However, when the study was repeated for other glyphosate-based herbicides without POEA, similar, but reduced effects were seen (*8*).

To limit the exposure of humans to glyphosate-based herbicides, it is recommended that humans only enter fields 12 hours after application. However, this only restricts one path for the herbicide to travel: by inhalation. A 2014 study detected glyphosate residues in the urine of 44% of the general public of Europe, with an average concentration of 1 mg L^{-1} and even higher concentrations in farmers. In 2015, the WHO categorised glyphosate as a "2A Probable Carcinogenic". The report does admit to the "limited evidence" and also went against many other reports, including a subsequent report by the UN and WHO in 2016, which concluded that human health risk levels associated with glyphosate exposure from food, drinking water, and residential sources are below the agencies' levels of concern.

Conclusion

It would be challenging to implement a complete ban of glyphosate, given that it is used so widely. However, the negative effects of glyphosate-based herbicides have been well documented, and its use needs to be more carefully managed; for example, small-scale uses in urban areas should be curtailed.

References

1. A. H. C. Van Bruggen *et al.*, Environmental and health effects of the herbicide glyphosate, *Sci. Total Environ.*, **616–617**, pp. 255–268, Mar. 2018

2. V. Silva *et al.*, Distribution of glyphosate and aminomethylphosphonic acid (AMPA) in agricultural topsoils of the European Union, *Sci. Total Environ.*, Oct. 2017.

3. F. Peixoto, Comparative effects of the Roundup and glyphosate on mitochondrial oxidative phosphorylation, *Chemostphere,* **61**, pp1115-22, Dec 2005

4. R. Z. Rissoli, F. C. Abdalla, M. J. Costa, F. T. Rantin, D. J. McKenzie, and A. L. Kalinin, Effects of glyphosate and the glyphosate based herbicides Roundup Original ® and Roundup Transorb ® on respiratory morphophysiology of bullfrog tadpoles, *Chemosphere*, **156**, pp. 37–44, Aug. 2016.

5. D. J. Pérez, E. Okada, M. L. Menone, and J. L. Costa, Can an aquatic macrophyte bioaccumulate glyphosate? Development of a new method of glyphosate extraction in Ludwigia peploides and watershed scale validation, *Chemosphere*, **185**, pp. 975–982, Oct. 2017.

6. F. M. Florencia, T. Carolina, B. Enzo, and G. Leonardo, Effects of the herbicide glyphosate on non-target plant native species from Chaco forest (Argentina), *Ecotoxicol. Environ. Saf.*, **144**, no. Supplement C, pp. 360–368, Oct. 2017.

7. D. Bridi, S. Altenhofen, J. B. Gonzalez, G. K. Reolon, and C. D. Bonan, Glyphosate and Roundup ® alter morphology and behavior in zebrafish, *Toxicology*, **392**, pp. 32–39, Dec. 2017.

8. L. Janssens and R. Stoks, Stronger effects of Roundup than its active ingredient glyphosate in damselfly larvae, *Aquat. Toxicol.*, **193**, pp. 210–216, Dec. 2017.

Upcoming meetings

Future perspectives on environmental nanotechnology

A symposium by *Environmental Science: Nano* and the Environmental Chemistry Group

9.30am-5pm Monday 8th October 2018
Royal Society of Chemistry, Burlington House, Piccadilly, London, W1J 0BA

We are delighted to present a symposium showcasing the high impact research from *Environmental Science: Nano* Editorial Board members. Presentations will focus on future research directions from this international group of environmental nanotechnology experts.

Confirmed Speakers

Gregory Lowry, Carnegie Mellon University, USA
Jerome Rose, European Centre for Research and Teaching in Environmental Geosciences, France
Joel Pedersen, University of Wisconsin-Madison, USA
John Fortner, Washington University in St. Louis, USA
Nathalie Tufenkji, McGill University, Canada
Peter Vikesland, Virginia Polytechnic Institute and State University, USA
Zhang Lin, South China University of Technology, China
Wei-Guo Song, Institute of Chemistry, Chinese Academy of Sciences, China

The symposium will also include a short presentation on How to publish in *Environmental Science: Nano*, and a Q&A with the journal's Editors.

Registration

Students £22.50, early bird members £30, early bird non-members £40, members £40, non-members £50. Coffee and lunch is included in the registration price.

Early Bird deadline: 8th September
Online booking deadline: 27th September

Contact: Dr Sam Keltie, Executive Editor, *Environmental Science: Nano,* RSC, esnano-rsc@rsc.org.

Latest advances in the analysis of complex environmental matrices

A symposium by the Environmental Chemistry, Separation Science and Water Science Forum Groups

Friday 22nd February 2019
Royal Society of Chemistry, Burlington House, Piccadilly, London, W1J 0BA

This event is the fourth in the series of highly successful biennial meetings which have been jointly organised by the RSC's Environmental Chemistry Group and Separation Science Group (Analytical Division), and this year is joined by the Water Science Forum. The aim of the series of meetings is to highlight advances in the chemical analysis of complex environmental samples. The event will have talks covering the analysis of all three environmental matrices (soils and sediments, water, and air) by a wide range of instrumental techniques such as GC, HPLC, MS and NMR.

Reports from Previous Meetings

ECG *Bulletin*, July 2017
http://www.rsc.org/images/ECG%20Bulletin%20July%202017_tcm18-249545.pdf
ECG *Bulletin*, July 2015
http://www.rsc.org/images/ECG-Bulletin-July-2015-final_tcm18-246976.pdf
ECG *Bulletin*, July 2013
http://www.rsc.org/images/ECG-Bulletin-July-2013_tcm18-233368.pdf

Registration

Contact: Graham Mills, University of Portsmouth, graham.mills@port.ac.uk
Roger Reeve, Durham, rgrreeve@gmail.com
Lee Williams, University of Sunderland, lee.williams@sunderland.ac.uk