Royal Society of Chemistry ISSN 1758-6224 (Print) 2040-1469 (Online)

Environmental Chemistry Group www.rsc.org/ecg

Bulletin

In this issue

The shoreline in front of the Mace Head Atmospheric Research Station near Carna, County Galway, Ireland, with views northwards across Roundstone Bay. On pp 3-8 of this issue, ECG committee members **William Bloss** and **Stephen Ball** review aspects of iodine's chemistry in the marine atmosphere, with particular reference to some recent field observations conducted at Mace Head. Marine iodine sources include emissions of molecular iodine from coastal seaweeds exposed at low tides and alkyl iodides from phytoplankton in the open ocean.

Also

Two final-year UK PhD students describe the environmental concerns which prompted their research: for **Samantha Lawrence** (University of Hertfordshire), it was atmospheric particle pollution from traffic and especially the contribution of non-exhaust vehicle emissions to overall particulate levels. And for **Melanie J. Bottoms** (University of Reading), the chemical and biological fate of veterinary antibiotics in the terrestrial environment.

RSC | Advancing the Chemical Sciences

Contents

Bulletin

Published biannually by the Royal Society of Chemistry's (RSC) Environmental Chemistry Group (ECG), Burlington House, Piccadilly, London, W1J 0BA, UK

Environmental Chemistry Group

www.rsc.org/ecg

The RSC's Environmental Chemistry Group (ECG) considers all aspects of the complex relationships between chemistry and the environment. The ECG aims to understand the behaviour of chemical species in the water, soil and atmospheric environments; exploring their sources, reactions, transport and in particular their effects on each of these environments.

This and previous issues of the *Bulletin* are available without charge online at www.rsc.org/ecg. Each member of the Environmental Chemistry Group also receives two issues per year of the printed ECG *Bulletin*. For membership details visit www.rsc.org/Membership.

Iodine chemistry in the coastal marine atmosphere

The sources, abundance and impacts of halogen compounds have been widely studied in atmospheric chemistry for several decades, with much attention previously focussed upon the involvement of man-made chlorine and bromine species in stratospheric ozone depletion. In this article, ECG committee members **William Bloss** and **Stephen Ball** consider a different angle on atmospheric halogen chemistry, looking at the role of naturally occurring iodine species in the marine boundary layer (the lowermost layer of the atmosphere over the oceans). The focus is on mid-latitude coastal regions, where a number of recent field measurements have elucidated aspects of iodine's sources, its behaviour and the impacts of its chemistry on the atmospheric environment.

Iodine sources and atmospheric chemistry in the marine environment

The primary sources of iodine species to the marine atmosphere are iodocarbons (RI) such as CH_2I_2, CH_2IBr and CH_3I, and molecular iodine, I_2 [see for example the reviews by Carpenter (2003) and von Glasow & Crutzen (2007)]. Iodocarbons are released by various marine organisms, including macroalgae (seaweeds), which live in coastal regions, and phytoplankton living in the surface waters of the ocean. Atmospheric mixing ratios of iodocarbons are typically around the pptv level, although they can be significantly higher in regions of high biological productivity (pptv = parts per trillion by volume: 1 part in 10^{12}). The major source of I_2 is seaweeds, particularly species of kelps such as *Laminaria digitata* which can have an iodine content as high as 1 % of their dry mass (Verhaeghe *et al*., 2008). As we will see below, in coastal regions I_2 release from seaweeds can be overwhelming and can dominate other iodine sources.

The biological drivers for halogen release remain unclear. Studies on seaweeds indicate that iodine species are released as a stress response to factors such as desiccation and exposure to UV light or ozone. Iodine may also be involved in the physiological protection of the plant from toxic active oxygen species such as hydrogen peroxide. Haloperoxidase enzymes are thought to catalyse the reaction of hydrogen peroxide with halide anions, leading to the formation of hypoiodous acid, HOI (Palmer *et al*., 2005). Subsequent production of iodocarbons may occur *via* the haloform reaction, which involves the substitution of hydrogen atoms adjacent to a carbonyl group for halogen atoms, either within the plant cells, or in organic matter suspended in seawater. It is also possible that iodine is produced in seawater by inorganic reactions involving dissolved ozone, iodide ($I^-_{(aq)}$) and HOI.

Once released to the atmosphere, molecular iodine and most iodocarbons undergo solar photolysis on timescales ranging from seconds (I_2) to minutes (*e.g.* CH_2I_2) to a few days (*e.g.* CH_3I), leading to the release of constituent iodine atoms into the lower atmosphere.

$$I_2, RI + h\nu \rightarrow I$$

It is worth noting that the timescales for liberating free iodine atoms are very much faster than the timescales for the release of chlorine or bromine atoms from long-lived anthropogenic chlorofluorocarbons which only undergo significant photolysis in the stratosphere (typical lifetime = tens of years). Thus iodine compounds simply do not persist long enough in the atmosphere to be mixed upwards and affect stratospheric ozone chemistry. However, iodine atoms do react with ozone close to the surface, leading to

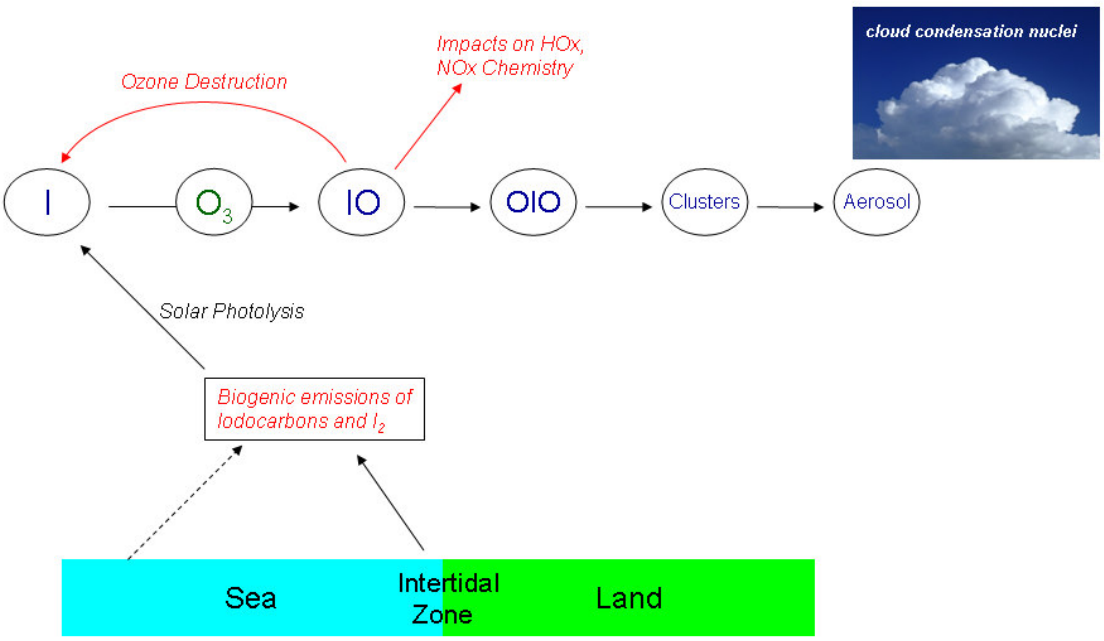


Figure 1: *The atmospheric chemistry of inorganic iodine species in the marine boundary layer.*

the formation of the gas-phase IO radical which lies at the centre of marine boundary layer iodine chemistry (**Figure 1**). Subsequent reactions of IO can regenerate iodine atoms leading to catalytic ozone destruction cycles, for example *via* some channels of the IO self-reaction:

2 x $I + O_3 \rightarrow IO + O_2$

$IO + IO \rightarrow I + I + O_2$

Net $2\,O_3 \rightarrow 3\,O_2$

(All reactions refer to gas-phase species unless otherwise indicated). Ozone acts as a greenhouse gas in the troposphere, and is a pollutant harmful to human health, vegetation and certain materials, for example some plastics and rubber. Consequently, processes that affect ozone concentrations are of considerable interest to atmospheric chemists. Tropospheric ozone also acts as the precursor to the key atmospheric oxidant, the hydroxyl radical (OH). The OH radical acts as a natural cleansing agent for the atmosphere. The reaction with OH initiates (and is usually the rate-determining step in) the degradation of many organic compounds, pollutants and greenhouse gases such as methane emitted into the atmosphere from both natural and anthropogenic sources. Processes which affect ozone and/or OH abundance can therefore affect atmospheric oxidising capacity.

The IO radical also interacts with other atmospheric radicals, including HO_x ($OH + HO_2$), for example *via* the sequence:

$IO + HO_2 \rightarrow HOI + O_2$

$HOI + h\nu \rightarrow OH + I$

$I + O_3 \rightarrow IO + O_2$

Net $HO_2 + O_3 + h\nu \rightarrow OH + 2O_2$

The formation and photolysis of HOI therefore converts HO_2 to OH, again affecting atmospheric oxidising capacity. A further effect of this reaction follows from the heterogeneous loss of HOI (*i.e.* removal of HOI from the gas phase to aerosol particles). This leads to a reduction in OH and HO_2 levels, as HO_x is removed from the gas-phase system. Concomitantly, the halogens can be returned to the gas-phase, or even undergo an amplification in concentration, through acid-catalysed aqueous phase reactions within aerosol particles (below; X,Y = Cl / Br / I) which liberate the (lower solubility) di-halogen / inter-

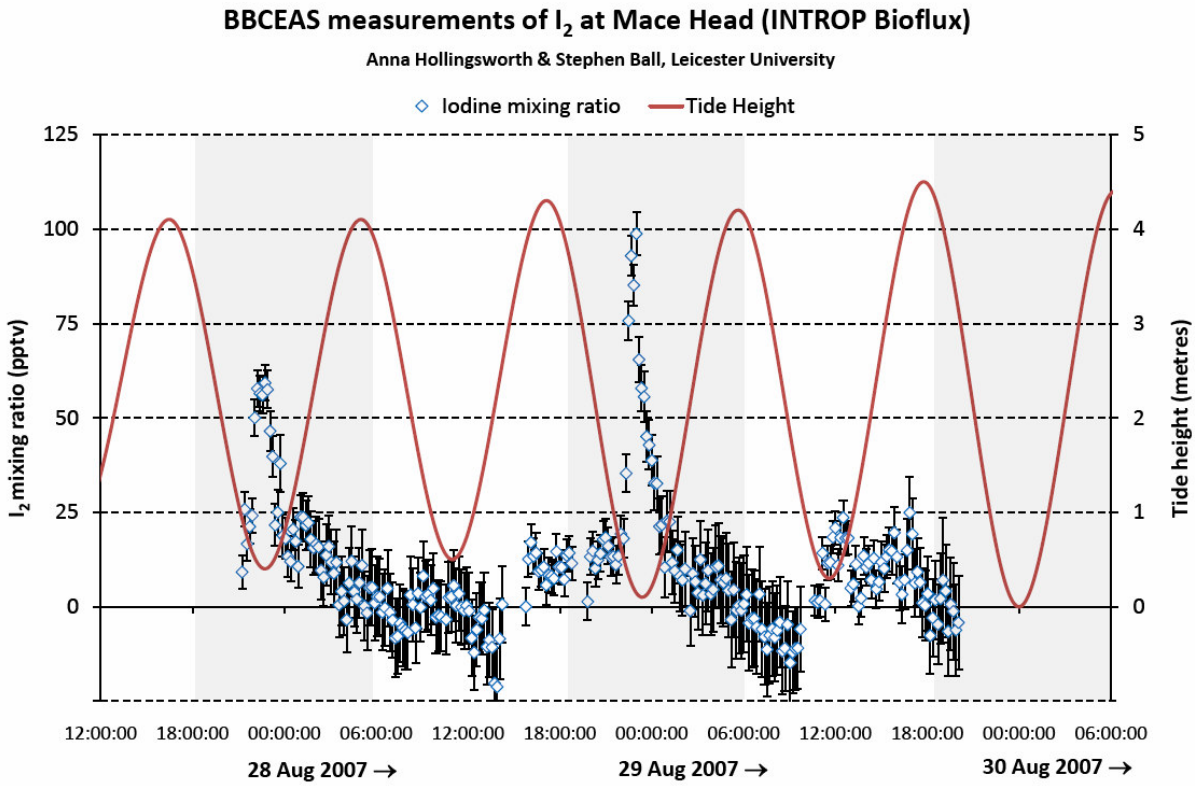


Figure 2: *Molecular iodine, I_2, measured on the shoreline at Mace Head, Ireland, using broadband cavity-enhanced absorption spectroscopy (BBCEAS) (a photo of the instrument appears below in* ***Figure 4****). I_2 levels peak at low tide, at night (shaded regions).*

halogen compounds back into the gas phase:

$$HOX + aerosol \rightarrow HOX_{(aq)}$$

$$HOX_{(aq)} + Y^-_{(aq)} + H^+_{(aq)} \rightarrow H_2O_{(l)} + XY$$

A further, and rather different, effect of iodine chemistry is to drive the formation of new particles in the atmosphere (or the growth of pre-existing ones). Laboratory studies of gas-phase iodine reactions have long been afflicted by the formation of white deposits upon optical surfaces when appreciable levels of iodine oxides are produced in the presence of ozone. Recently chamber experiments and atmospheric observations have shown that polymerisation reactions, thought to involve the combination of OIO monomers (formed through the self-reaction of IO radicals), can form clusters and ultimately solid-phase particles of bulk formula I_2O_5 and/or I_4O_9 (McFiggans *et al*., 2004; Saunders & Plane, 2005).

$$IO + IO \rightarrow OIO + I$$

$$n\ OIO\ (+ m\ O_3\ ?) \rightarrow \rightarrow (I_2O_5)_{x\ (s)}$$

$$\rightarrow \rightarrow \text{bulk-phase iodate } (IO_3^-)$$

Hence the biogenic release of iodine source gases could amplify the number, concentration and/or the size of marine aerosol particles. If an aerosol particle can then grow sufficiently by the condensation of ambient water vapour, it may act as a cloud condensation nucleus (CCN). Particles that contain a high fraction of soluble inorganic salts (here, iodate) are thought to be particularly efficient cloud condensation nuclei. Higher CCN concentrations lead to the formation of clouds composed of more, but smaller, water droplets which are brighter (reflecting more solar radiation) and which persist for longer. Thus, the contribution of iodine species to the marine particle population could have a significant climate influence (O'Dowd *et al*., 2002). Understanding the details and quantifying the magnitude of these effects are key issues, which recent laboratory and field measurements have begun to unravel.

Measurements of iodine chemistry

The atmospheric science community's expanding interest in iodine chemistry in recent years is being driven both by a desire to understand some interesting science and, more practically, by substantial advances achieved in analytical instrumentation, which now make it possible to detect iodine compounds at the very high dilutions found in the ambient atmosphere. For instance, an automated GC-MS instrument has been developed for iodocarbons, with impressive detection limits down to around 0.05 pptv (Carpenter *et al*.,

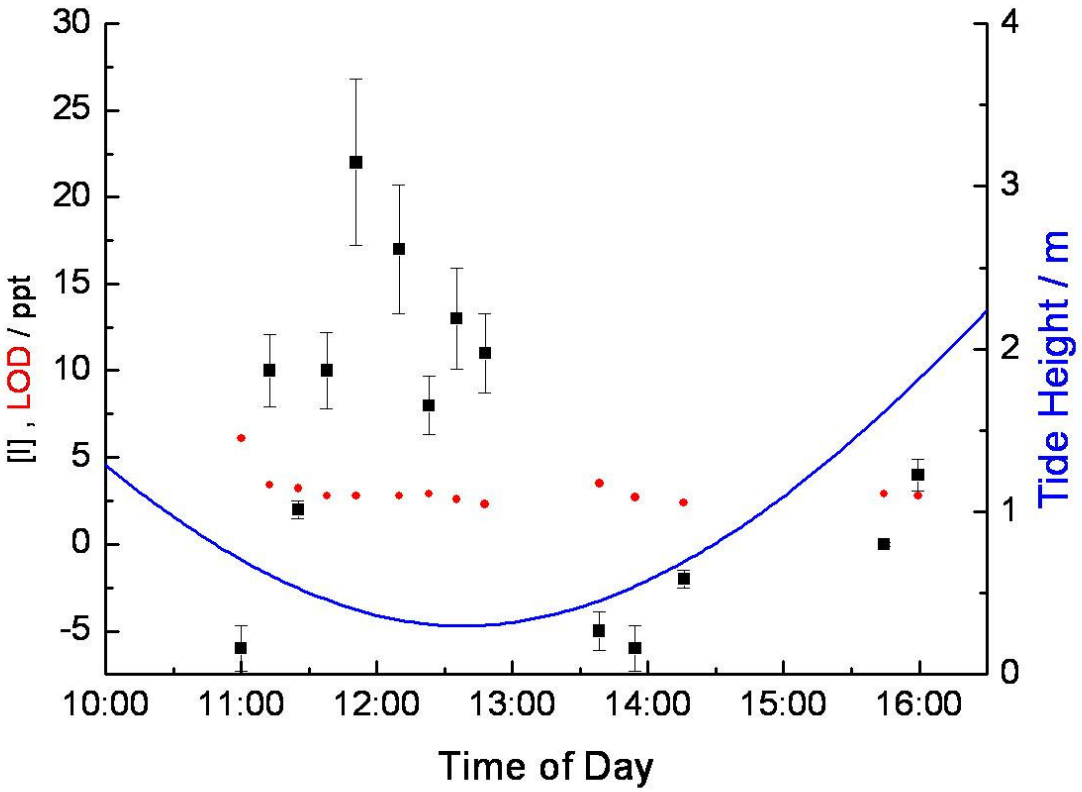


Figure 3: *Iodine atoms measured on the shoreline at Mace Head, Ireland, using resonance fluorescence detection (see also Figure 4 and Bale et al., 2008). Figure shows observed I mixing ratios (black points), detection limit (red circles) and local tide height (blue line; right hand axis). Iodine levels peak at low tide, at midday, when I_2 emission and photolysis are both maximised.*

1999). Here atmospheric samples are drawn through an adsorbent trap to pre-concentrate the iodocarbons; the trap is then heated to drive off adsorbed molecules, which are separated by gas chromatography and detected by mass spectrometry. A pre-concentration methodology (but with a different detector) has been used for denuder sampling atmospheric I_2 into starch solutions (*e.g.* Saiz-Lopez *et al.*, 2006). However, I_2 and, conveniently, also its oxides IO and OIO, absorb light at visible wavelengths, and their structured absorption spectra make them particularly amenable to *in situ* spectroscopic detection. Thus any of these three iodine compounds can be identified unambiguously in an atmospheric sample's absorption spectrum *via* the molecule's characteristic absorption bands and, provided the molecular absorption cross sections are known accurately from lab measurements, the absorption bands' intensities provide a direct measure of ambient concentration (without the need for further calibrations). The disadvantage of deploying an absorption measurement for atmospheric sampling is that the low ambient concentrations of the target species means that observations need to be conducted over a very long absorption path through the atmosphere in order to produce a detectable signal. Long-path differential optical absorption spectroscopy (DOAS) achieves path lengths of ≈10 km by reflecting its light beam off a distant retro-reflector (a mirror). Indeed atmospheric IO and OIO were first observed by DOAS instruments (*e.g.* Alicke *et al.*, 1999), and now such methods also routinely detect I_2.

DOAS's typical 5-km-out-5-km-back sampling geometry means that the concentrations inferred from such a measurement represent the average concentration of a given molecule over the entire light path. This presents a problem when looking at molecular iodine chemistry because I_2 emissions from seaweeds tend to be localised on the shoreline, and because the I_2 atmospheric lifetime is extremely short, these emissions are not evenly mixed along the DOAS light path. A "point measurement" analogue of DOAS is provided by newly-developed cavity-based methods such as broadband cavity ringdown spectroscopy (Ball & Jones, 2003) and broadband cavity enhanced absorption spectroscopy (Langridge *et al.*, 2008) which achieve multi-kilometre absorption paths by repeated reflections of a light beam inside a high finesse optical cavity composed of extremely efficient mirrors (> 99.99% reflection efficiency). Certain species can also be quantified by fluorescence spectroscopy, again as localised point

Figure 4: *Novel instruments for in situ measurements of reactive iodine species deployed at the Mace Head site. Left panel: A dual channel broadband Cavity-Enhanced Absorption Spectrometer for observations of IO, OIO and I_2 – photograph courtesy of Anna Hollingsworth. Right panel: Resonance Fluorescence instrument for the detection of iodine atoms and photolabile iodine species.*

measurements. Thus atmospheric IO has been detected using laser-induced fluorescence (Whalley *et al*., 2007) using an instrument originally developed to detect the even-less abundant OH radical, and a resonance fluorescence instrument has been deployed to measure the ambient iodine atoms, with a trial deployment showing a strong correlation between iodine activity and daytime low tide (Bale *et al*., 2008).

A consistent observational picture is beginning to emerge from field studies, particular those conducted at costal sites with abundant seaweed populations (*e.g.* Mace Head, Galway, Ireland; Roscoff, Brittany, France). Generally the concentration of iodine compounds peaks around low tide when the seaweed beds are exposed to the atmosphere. IO and I atom concentrations peak sharply at daytime low tides because their source is atmospheric photochemistry; conversely, I_2 concentrations peak at night-time low tides because during the day a substantial fraction of the emitted I_2 is probably photolysed during its short wind-borne journey from seaweed source to the instruments located on dry land (see **Figures 2 and 3**). However, all three species are more abundant for the very lowest low tides, again suggesting that the source is from seaweed and particularly the deeper-water seaweeds that are exposed only rarely by unusually low tides. The more elusive OIO radical remains something of an enigma – some observations correlate with tide, but others do not. However, the rapid production of large numbers of very small iodine-rich aerosol particles in "nucleation bursts" do strongly correlate with low tides and their elevated I_2 levels (Saiz-Lopez *et al*., 2006).

Outlook

While recent field, laboratory and theoretical studies have led to significant advances in our understanding of the role of iodine species in the troposphere, a number of major uncertainties remain.

The discussion above has focused upon observations at mid-latitude coastal sites, but these represent a small fraction of the global marine environment. Is iodine activity also found in the open ocean at significant levels? Recent observations from the Cape Verde observatory, located in the tropical mid-Atlantic remote from coastal influences, have measured IO at levels of 2 pptv (Read *et al*., 2008) with associated ozone destruction rates of 1.8 ppb day^{-1}. The latter may be compared with a total (boundary layer) ozone level of 30 - 35 ppbv, *i.e.* the halogen-driven ozone destruction is significant (ppbv = parts per billion, by volume). Again these observations were only from a single location. However, the first satellite retrievals of IO (Saiz-Lopez *et al*., 2007; Schönhardt *et al*., 2008) have shown substantial iodine columns over the Southern Ocean (associated with sea-ice coverage) and in lower latitude regions such as the Eastern Pacific. The satellite data cannot accurately determine the altitude distribution of the IO *column density* retrieved, so the concentrations at specific altitudes cannot be determined, and further ground-based field observations will be required to assess the global marine boundary layer impact of iodine chemistry.

A second issue is our understanding of the fundamental photochemical and kinetic parameters describing the behaviour of iodine species in the atmosphere. A number of

these are uncertain or simply not known (for example, the absorption cross-sections of various iodine reservoir compounds, and the mechanism and kinetics of the route from OIO through I_2O_4 and on to formation of clusters and hence new particles). These uncertainties hamper our ability to quantitatively model the impact of a given iodine-loading upon the atmosphere, and will require further laboratory studies for their resolution.

Finally, the biological mechanism for the production of iodine species and their physiological function within the plant remains unclear – and consequently so does our understanding of any response the system might have to changing conditions, such as climate or ocean acidity, which may affect the marine biota ultimately responsible for much of the atmospheric iodine production. Addressing these and other questions is the subject of ongoing research activity within the atmospheric chemistry community, which will improve our understanding of the behaviour of this intriguing species in our atmosphere.

WILLIAM BLOSS

School of Geography, Earth & Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

E-mail: w.j.bloss@bham.ac.uk

STEPHEN BALL

Department of Chemistry, University of Leicester, Leicester LE1 7RH, UK

E-mail: sb263@leicester.ac.uk

References

Alicke, B.; Hebestreit, K.; Stutz, J.; Platt, U. (1999), Iodine oxide in the marine boundary layer, *Nature*, **397**, 572.

Bale, C. S. E.; Ingham, T.; Commane, R.; Heard, D. E.; Bloss, W. J. (2008), Novel measurements of atmospheric iodine species by resonance fluorescence, *J. Atmos. Chem.*, **60**, 51.

Ball, S. M.; Jones R. L. (2003), Broadband cavity ringdown spectroscopy, *Chem. Rev.*, **103**, 5239.

Carpenter, L. J.; Sturges, W. T.; Liss, P. S.; Penkett, S. A.; Alicke B.; Hebestreit, K.; Platt, U. (1999), Short-lived alkyl-iodides and bromides at Mace Head: Links to macroalgal emission and halogen oxide formation, *J. Geophys. Res.*, **104** (D1), 1679.

Carpenter, L. J. (2003), Iodine in the marine boundary layer, *Chem. Rev.*, **103**, 4953.

Langridge, J. M.; Ball, S. M.; Shillings, A. J. L.; Jones, R. L. (2008), A broadband absorption spectrometer using light emitting diodes for ultrasensitive *in situ* trace gas detection, *Rev. Sci. Instr.*, **79**, 123110.

McFiggans, G. *et al*. (2004), Direct evidence for coastal iodine particles from *Laminaria* macroalgae – linkage to emissions of molecular iodine, *Atmos. Chem. Phys.*, **4**, 701.

O'Dowd, C. D.; Jimenez, J. L.; Bahreini, R.; Flagan, R. C.; Seinfeld, J. H.; Hämeri, K.; Pirjola, L.; Kulmala, M.; Jennings, S. G.; Hoffmann, T. (2002), Marine particle formation by biogenic iodine emissions, *Nature*, **417**, 632.

Palmer, C. J.; Anders, T. L.; Carpenter, L. J.; Küpper, F. C.; McFiggans, G. B. (2005), Iodine and halocarbon response of *Laminaria digitata* to oxidative stress and links to atmospheric new particle production, *Environ. Chem.*, **2**, 282.

Read, K.A. *et al*. (2008), Extensive halogen-mediated ozone destruction over the tropical Atlantic Ocean, *Nature*, **453**, 1232.

Saiz-Lopez, A.; Plane, J. M. C.; McFiggans, G.; Williams, P. I.; Ball, S. M.; Bitter, M.; Jones, R. L.; Hongwei, C.; Hoffmann, T. (2006), Modelling molecular iodine emissions in a coastal marine environment: the link to new particle formation, *Atmos. Chem. Phys.*, **6**, 883.

Saiz-Lopez, A.; Chance, K.; Liu, X.; Kurosu, T. P.; Sander, S. P. (2007), First observations of iodine oxide from space, *Geophys. Res. Lett.*, **34**, doi:10.1029/2007GL030111.

Saunders, R. W.; Plane, J. M. C. (2005), Formation pathways and composition of iodine oxide ultra-fine particles, *Environ. Chem.*, **2**, 299.

Schönhardt, A.; Richter, A.; Wittrock, F.; Kirk, H.; Oetjen, H.; Roscoe, H. K.; Burrows, J. P. (2008), Observations of iodine monoxide columns from satellite, *Atmos. Chem. Phys.*, **8**, 637.

Verhaeghe, E. F.; Fraysse, A.; Guerquin-Kern, J-C.; Wu, T.-D.; Deves, G.; Mioskowski, C.; LeBlanc, C.; Ortega, R.; Ambroise, Y.; Potin, P. (2008), Microchemical imaging of iodine distribution in the brown alga *Laminaria digitata* suggests a new mechanism for its accumulation, *J. Biol. Inorg. Chem.*, **13**, 257.

von Glasow, R.; Crutzen, P. J. (2007), Tropospheric halogen chemistry, In *Treatise on Geochemistry*, **4**, 1.

Whalley, L. K.; Furneaux, K. L.; Gravestock, T.; Atkinson, H. M.; Bale, C. S. E.; Ingham, T.; Bloss, W. J.; Heard, D. E. (2007), Detection of iodine monoxide radicals in the marine boundary layer using laser induced fluorescence spectroscopy, *J. Atmos. Chem.*, **58**, 19.

Web link: The Mace Head Research Facility http://macehead.nuigalway.ie/mace1.html

Non-exhaust particle emission sources

In addition to the by-products of fuel combustion, there are other ways that vehicles can contribute to particulate air pollution. As part of her PhD studies, completed in 2009, **Samantha Lawrence** from the University of Hertfordshire investigated the sources and measurement of non-exhaust vehicle pollution.

Atmospheric particle pollution

Atmospheric pollution is a global problem and the links between poor air quality and adverse health effects are well documented (e.g. Dockery and Pope, 1994; Miguel *et al*., 1999). Air pollution is thought to be directly responsible for a reduction in the life expectancy of a person living in the UK by an average of 7-8 months. This corresponds to additional health costs of up to £20 billion each year (Defra, 2007). As part of a number of measures to improve air quality, the European Union (EU) issued the 'First Air Quality Daughter Directive' in 1999 (1999/30/EC) (http://europa.eu/legislation_summaries/index_en.htm) followed by a number of amendments, with the latest directive (2008/50/EC) published in May 2008.

Road transport is a major source of air pollution, and particulate matter (PM_{10}) emissions from vehicles account for 20% of primary emissions nationally and ~70% of the total PM_{10} emissions in London (PM_{10} is particulate matter with an aerodynamic diameter of up to 10 µm) (Fuller and Green, 2006; Mattai and Hutchinson, 2006). Although particulate *exhaust* emissions from vehicles are regulated, *non-exhaust* vehicle emissions are not at present subject to regulatory scrutiny. This article describes the sources and measurement of non-exhaust particulate emissions.

Road transport emissions

Recent studies have shown an increase in the number of UK registered vehicles; almost 34 million vehicles were registered in the UK during 2007, an increase of 2% compared to the previous year (DfT, 2008). As vehicle numbers increase, road transport is expected to continue to be the largest emission source of particles into the atmosphere for the foreseeable future. Legislation and policies have focused on reducing the impact of vehicle exhaust emissions and, as a result, annual concentrations have actually decreased. **Figure 1** shows the average annual concentrations of PM_{10} in London at three different types of monitoring station: outer London background; inner London background; and a central London roadside (Fuller and Green, 2006). There is a clear difference between the background and the central London roadside site, highlighting the impact of traffic emissions. A reduction in PM_{10} concentrations from 1996 – 2001 can be seen. After this time, concentrations appear to level off with a slight increase during 2003 owing to a number of particle episodes caused by secondary PM_{10} from distant sources and photochemistry.

So why, after the introduction of strategies to decrease PM_{10} emissions including the introduction of exhaust emission limits and the installation of particle traps in new diesel vehicles, have PM_{10} concentrations remained relatively stable? One suggestion is that car manufacturers have adjusted the engine's emission map. This adjustment may result in lower emissions when vehicles are driven under the conditions of the standard test-cycles (Harrison *et al*., 2008). However, when driven in normal circumstances, vehicle particle emissions could be much higher, resulting in an underestimation of exhaust emissions. Another possibility is that the legislation only focuses on reducing emissions from the *exhaust* pipe of the vehicle and ignores other vehicle-related emissions. As traffic volumes increase, the problems associated with *non-exhaust* emissions will become more apparent.

Why are non-exhaust emissions important?

Studies have shown that non-exhaust emissions can equal or surpass those from the exhaust pipe. In Berlin, vehicular emissions increased PM_{10} concentrations by up to 40% (Lenschow *et al*., 2001). Over half of this increment was assigned to non-exhaust emissions. In some parts of the USA, 90% of PM_{10} levels come from non-exhaust emissions (Abu-Allaban *et al*., 2003). Jones *et al*., (2008) found weekday non-exhaust emissions at a roadside site in Birmingham, UK contributed *ca*. 20% of PM_{10} emissions. Even with mounting evidence regarding their significance, there is still

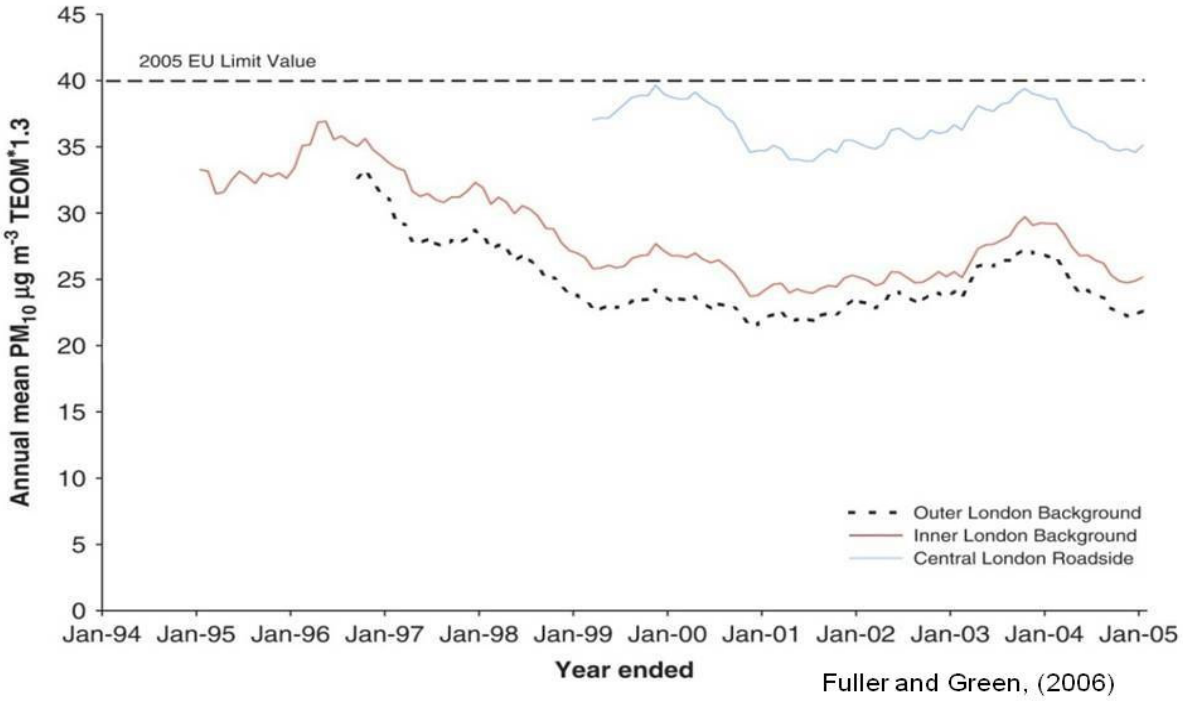


Figure 1: *Annual mean PM_{10} concentrations in London, 1994-2004.*

insufficient legislation to reduce non-exhaust particulates – partly due to the limited amount of information about their origins and concentrations.

What are non-exhaust emissions?

Non-exhaust vehicle emissions are released through processes unrelated to fuel combustion and not emitted from the exhaust pipe of the vehicle. Non-exhaust emissions are generated:

- during the mechanical processes associated with driving such as **brake**, clutch or **tyre wear**;
- through **road surface wear** or **the resuspension of road dust** as the vehicle travels over the road surface; and
- from the corrosion of vehicle components.

Brake wear. Brakes reduce vehicle speeds by using friction to convert kinetic energy to thermal energy, producing debris and particles through the abrasion of the brake linings, rotors, pad or discs. During a lifetime, 80% of the brake's friction material will wear away (Garg *et al*., 2000). **Figure 2** clearly shows brake dust collected on a vehicle wheel; this is either released into the atmosphere or deposited onto the road surface ready to be resuspended by other vehicles. A number of factors can contribute to differences in wear rates, including the brake pad's chemical composition and its microstructure, rate of wheel rotation, pressure, rubbing speed, the metallic counter face, contact surface temperature and the resistance of the weight being stopped (Ingo *et al*., 2004). Brake materials are a mixture of modifiers, binders, fillers, lubricants and carbon material. Brake dust contains high concentrations of Al, Ba, Ca, Cu, Fe, K, Mg, Sb, Ti and Zn (Hildemann *et al*., 1991; Kennedy and Gadd, 2003). Researchers have found that during braking, an average of 35%

Figure 2: *Brake dust collected on a vehicle wheel*

Figure 3: *Worn tyre particles on a road surface.*

of the brake wear material is lost and emitted as airborne particulate matter (Garg *et al*., 2000). Researchers have shown that brake wear may account for 14% of the total PM_{10} mass (Stocker and Carruthers, 2007).

Tyre wear. During rotation, tyres abrade against the road surface and the abrasion of the tyre tread generates particles of dust and debris. Tyre wear is a growing problem owing to the ever increasing number of tyres in use. In Britain, over 47 million tyres were discarded during 2005 – about 100,000 worn tyres a day (Used Tyre Group, 2007). **Figure 3** shows tyre wear particles deposited on a road surface. As vehicle numbers increase, the number of tyres in use could be as much as 200 million by 2021 (Environment Agency, 1999). Tyres are a complex mixture of very different materials, including steel cord, several types of rubber, carbon black and other organic materials and inorganic compounds. During braking, the majority of the weight of a front-wheel drive vehicle is shifted onto the front wheels of the vehicle. Also, the engine is normally positioned at the front of the vehicle, so additional weight is loaded here. This explains why the tyre wear from the front wheels of a front-wheel drive car accounts for 69-85% of the total tyre material lost per vehicle per km (Luhana *et al*., 2004). Tyre wear particles contain high concentrations of Al, Ca, Fe, Na and Zn, and organic compounds such as styrene butadiene rubber, benzothiazole and polycyclic aromatic hydrocarbons (Hildemann *et al*., 1991; Rogge *et al*., 1993; Kennedy and Gadd, 2003). It is calculated that tyres contribute 11% of the total PM_{10} mass (Stocker and Carruthers, 2007).

Road surface wear. Road surface wear particles are produced as a result of the shear forces caused by the relative movement of the surfaces during the interaction between the road surface and a vehicle's tyre. Studded tyres and traction material used in Nordic countries, northern parts of the USA, Japan, and Canada increase road surface wear. Within Europe, concrete and asphalt based road surface materials are commonly used. Concrete surfaces are composed of sand, cement and small rocks/stones, whereas asphalt surfaces consist mainly of bitumen. Concentration of constituents can vary widely between different countries, although general concentrations of stone and bituminous binders are 90-95% and 5-10% respectively (Luhana *et al*., 2004). Road surface wear particles contain concentrations of Al, Ca, Cr, Fe, K, Ni, Si, V and Zn, which are all present in road surface materials (Kennedy and Gadd, 2003). Road surface wear can contribute as much as 10% of the PM_{10} mass (Stocker and Carruthers, 2007).

Resuspension of road dust. Road dust undergoes a cycle of suspension in the atmosphere and deposition on the ground as a result of turbulence from passing vehicles and the effects of the wind. Resuspended road dust is a complex mixture of particles which originate from natural and anthropogenic sources, and the composition of road dust correlates strongly with local particle emissions. Resuspension of road dust is thought to be the largest contributor to non-exhaust particle emissions. However, there are several problems with sampling and analysing road dust emissions and these have led to uncertainties in calculations of the contribution of resuspended road dust to PM_{10} concentrations: estimates range from 10-90% (Abu-Allaban *et al*., 2003; Stocker and Carruthers, 2007). Emission factors also vary considerably; emission factors for resuspension vary from 40 mg/vkm (NAEI, 2008) for the UK to 10,000 mg/vkm, calculated for a mixed fleet using a dispersion model in the USA, where road surfaces are very different compared with the UK (Venkatram *et al*. (1999). Road transport emission factors estimate the relationship between the amount of pollution produced and the number of vehicle miles travelled (NAEI, 2008). Emission factors are used by atmospheric dispersion modellers and others to determine the amount of air pollutants being emitted in certain areas; this helps to implement air quality strategies. The UK resuspension emission factor

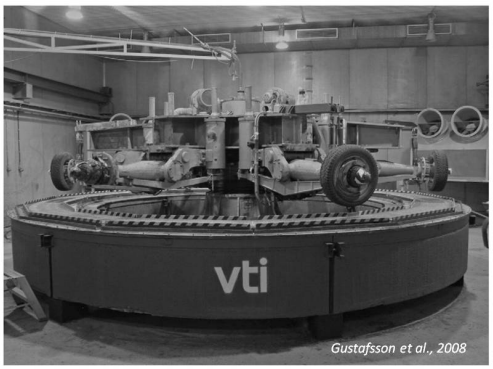


Figure 4: *A road simulator used in Sweden to generate wear particles from tyres and different road surfaces.*

is relatively crude because it does not account for variations in vehicle speed or weight and road or weather conditions. Further research on non-exhaust vehicle emissions in the UK is urgently needed.

Measuring non-exhaust emissions

Quantification of non-exhaust emissions is a difficult task owing to the number of uncertainties associated with these pollutants (Lawrence *et al*., 2009). Concentrations of non-exhaust emissions can vary considerably depending on their origins, which means emission factors can be quite site specific. Currently there are two different approaches for the calculation of non-exhaust emission factors for atmospheric dispersion models: **direct measurements** (laboratory and dynamometer tests) and **receptor modelling** (source apportionment studies) (Lawrence *et al*., 2009).

Direct measurements. Dynamometer and laboratory tests are direct methods for measuring vehicle emissions and have been used by several researchers including Dannis, (1974); Cadle & Williams (1978), Garg *et al*. (2000), and Gustafsson *et al*., (2008). **Figure 4** shows the road simulator used by the Swedish National Road and Transport Research Institute, Linköping to generate particles from tyre and road surface wear (Gustafsson *et al*., 2008). Emission factors are determined by operating a vehicle for a selected period of time over simulated driving conditions, usually on a dynamometer or on an engine bed. Although these tests provide a valuable insight into the processes associated with non-exhaust emissions, they are expensive and time-consuming and do not accurately represent actual driving conditions, where weather conditions, road surface and other factors influence emissions.

Receptor modelling. Receptor modelling (also known as source apportionment studies) is another method for studying emission factors. Receptor modelling techniques have been developed to identify and apportion the various source contributions to particulate matter concentrations in real world situations. This technique is based on the theory that a given source can be distinguished by the particles it produces, their size, density, and chemical characteristics (Hopke *et al*., 1980; see also Hopke, 1989 and 1991).
Researchers in the UK have used receptor modelling techniques to reduce the uncertainties related to non-exhaust emissions. In a Defra-funded project, the Transport Research Laboratory undertook a literature review of non-exhaust emissions and developed the ADMS-Urban dispersion model to improve the prediction of non-exhaust emissions (Stocker and Carruthers, 2007). Further information may be found on Defra's web site (Science and Research Projects: Road Vehicle Non-exhaust Particulate Matter: Report on Emission Modelling: Project No. AQ05511).

Road tunnel sampling. Sampling in road tunnels together with statistical techniques such as principal component analysis (PCA) and multi-linear regression analysis (MLRA) have helped to identify non-exhaust emission sources and allowed the calculation of non-exhaust emission factors (Luhana *et al*., 2004).

In research funded by the National Environmental Research Council (NERC) and the BOC foundation, and undertaken as part of my PhD studies, we refined tunnel-sampling methodologies. Tunnel sampling was undertaken inside the Hatfield Tunnel, Hertfordshire, which is part of the A1(M) motorway between Junctions 3 and 4, 0.8 km west of Hatfield town centre. **Figure 5** shows the air sampling equipment

Figure 5: Sampling equipment installed inside a motorway tunnel.

used (Lawrence *et al*., 2009). Non-exhaust emissions were studied from traffic that used the tunnel in peak and off-peak times. Analytical data (metal ion and organic contaminants) and source apportionment techniques were used to calculate source specific emission factors (Lawrence *et al*., 2009). Although the results of this study (to be published in 2009) are related to a tunnel environment, they also provide an insight into the impact of non-exhaust emissions on roadside particle concentrations compared with the results from laboratory tests.

Public awareness of non-exhaust vehicle pollution

As well as trying to reduce the uncertainties associated with analysing non-exhaust emissions, we are also attempting to raise public awareness of this source of traffic pollution. There is a common misconception that vehicles only harm the environment through exhaust emissions. If we wish to reduce non-exhaust emissions, then a greater public understanding is needed. Through the creation of a web site (www.ies-uk.org.uk/non-exhaust) which explains how the general public can help to improve air quality in general, and moderate vehicle pollution in particular, we hope that awareness of non-exhaust sources of vehicle pollution will increase.

Summary

As engine vehicles evolve and alternative cleaner (non-hydrocarbon) fuels are developed, the impact of non-vehicle emissions will become more significant. Cars containing large batteries and/or heavy duty storage tanks are likely to be heavier, and consequently non-exhaust emissions will increase. Providing policy makers with improved scientific data on non-exhaust particulate emissions will help to meet EU objectives and standards, and will benefit both the quality of our air and public health.

Acknowledgements

I would like to thank the National Environmental Research Council (NERC) and BOC Foundation who provided the financial assistance, which made my PhD possible. Support and funding obtained from the Institute of Environmental Sciences' John Rose Award is also appreciated and has enabled the development of the non-exhaust pollution website (www.ies-uk.org.uk/non-exhaust). The guidance and advice obtained from my principal supervisor Professor Ranjeet Sokhi regarding this article is also acknowledged.

References

Abu-Allaban, M.; Gillies J. A.; Gertler, A. W.; Clayton, R.; Proffitt, D. (2003), 'Tailpipe, resuspended road dust, and brake-wear emission factors from on-road vehicles', *Atmospheric Environment*, **37**, 5283-5293.

Cadle, S. H.; Williams, R. L. (1978), 'Gas and particle emissions from automobile tires in laboratory and field studies', *Rubber Chemistry and Technology*, **52**, 146-158.

Dannis, M. L. (1974), 'Rubber dust from the normal wear of tires', *Rubber Chemistry and Technology*, **47**, 1011-1037.

Defra (2007), Department for Environment, Food and Rural Affairs, *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*, Volume 1. ISBN 978-0-10-171692-5

DfT (2008), Department for Transport: Transport Statistics Bulletin, Vehicle Licensing Statistics 2007: http://www.dft.gov.uk/pgr/statistics/datatablespublications/vehicles/licensing/vehiclelicensingstatistics2007

Dockery, D. W.; Pope, C. A, III, (1994), 'Acute respiratory effects of particulate air pollution', *Annual Review of Public Health*, **15**, 107-32.

Environment Agency (1999), 'Environment Agency News: Tyres in the Environment: Executive Summary', *The Science of the Total Environment*, **234**, 243-245.

Fuller, G. W; Green, D. (2006), 'Evidence for increasing concentrations of primary PM_{10} in London' *Atmospheric Environment*, **40**, 6134-6145.

Garg, B. D.; Cadle, S. H.; Mulawa, P. A.; Groblicki, P. J.; Laroo, C.; Parr, G. A. (2000), 'Brake wear particulate matter emissions', *Environmental Science and Technology*, **34**, 4463-4469.

Gustafsson, M.; Blomqvist, G.; Gudmundsson, A.; Dahl, A.; Swietlicki, E.; Bohgard, M.; Lindbom, J.; Ljungman, A. (2008), 'Properties and toxicological effects of particles from the interaction between tyres, road pavement and winter traction material' *Science of The Total Environment*, **393**, 226-240.

Harrison, R. M.; Jones, A. M.; Lawrence, R. G. (2004), 'Major component composition of PM_{10} and $PM_{2.5}$ from roadside and urban background sites', *Atmospheric Environment*, **38**, 4531-4538.

Harrison, R. M.; Stedman, J.; Derwent, D. (2008), 'New directions: Why are PM_{10} concentrations in Europe not falling?' *Atmospheric Environment*, **42**, 603-606.

Hildemann, L. M.; Markowski, G. R.; Cass, G. R. (1991), 'Chemical composition of emissions from urban sources of fine organic aerosol', *Environmental Science and Technology*, **25**, 744-759.

Hopke, P. K.; Lamb, R. E.; Natusch, D. F. S. (1980), 'Multielemental characterization of urban roadway dust', *Environmental Science and Technology*, **14**, 164-172.

Hopke, P. K. (1989), 'Target transformation factor analysis', *Chemometrics and Intelligent Laboratory Systems*, **6**, 7-19.

Hopke, P. K. (1991), 'An introduction to receptor modelling' *Chemometrics and Intelligent Laboratory Systems*, **10**, 21-43.

Ingo, G. M.; D'Uffizi, M.; Falso, G.; Bultrini, G.; Padeletti, G. (2004), 'Thermal and microchemical investigation of automotive brake pad wear residues' *Thermochimica Acta*, **418**, 61-68.

Jones, A. M.; Yin, J.; Harrison, R. M. (2008), 'The weekday-weekend difference and the estimation of the non-vehicle contributions to the urban increment of airborne particulate matter', *Atmospheric Environment*, **42**, 4467-4479.

Kennedy, P.; Gadd, J. (2003), 'Preliminary examination of trace elements in tyres, brake pads, and road bitumen in New Zealand', Prepared for Ministry of Transport, New Zealand, Infrastructure Auckland; 2003.

Lawrence, S.; Sokhi, R. S.; Mao, H.; Ravindra, K.; Bull, I. D. (2009), 'Quantification of atmospheric particle emissions from non-exhaust sources using tunnel measurements and source apportionment modelling', *Proceedings of Short Papers presented at the 7th International Conference on Air Quality: Science and Application*, (Air Quality 2009), Istanbul, Turkey, 24-27th March 2009. ISBN 978-1-905313-64-8.

Lenschow, P.; Abraham, H. J.; Kutzner, K.; Lutz, M.; Preu, J. D.; Reichenbacher, W. (2001), 'Some ideas about the sources of PM_{10}', *Atmospheric Environment*, **35**, 23-33.

Luhana, L.; Sokhi, R.; Warner, L.; Mao, H.; Boulter, P.; McCrae, I.; Wright, J.; Osborn, D. (2004), 'Characterisation of exhaust particulate emissions from road vehicles (particulates)', FP5 Particulates Project.

Mattai, J., Hutchinson, D (2006), 'London atmospheric emissions inventory: 2003 Report', Greater London Authority, London. ISBN-1-85261-801-9

Miguel, A. G.; Cass, G. R.; Glovsky, M. M.; Weiss, J. (1999), 'Allergens in paved road dust and airborne particles', *Environmental Science and Technology*, **33**, 4159-4168.

NAEI (2008), National Atmospheric Emission Inventory, 'Emission factors for PM_{10} for road transport: Year 2007'.

Rogge, W. F.; Hildemann, L. M.; Mazurek, M. A.; Cass, G. R.; Simoneit, B. R. T. (1993), 'Sources of fine organic aerosol. 3. Road dust, tire debris, and organometallic brake lining dust: roads as sources and sinks', *Environmental Science and Technology*, **27**, 1892-1904.

Stocker, J.; Carruthers, D. (2007), 'Road vehicle non-exhaust particulate matter: Initial air quality model development and application, model uncertainty analysis and further model improvements', Report PPR224, Transport Research Laboratory (TRL).

Used Tyre Group (2007), www.tyredisposal.co.uk. Accessed 22/08/2007.

Venkatram, A.; Fitz, D.; Bumiller, K.; Du S.; Boeck, M.; Ganguly, C. (1999), 'Using a dispersion model to estimate emission rates of particulate matter from paved roads', *Atmospheric Chemistry*, **33**, 1093-1102.

Dr SAMANTHA LAWRENCE
Centre for Atmospheric & Instrumentation Research (CAIR), University of Hertfordshire, College Lane, Hatfield, Hertfordshire AL10 9AB, UK
Email: srl.lawrence@googlemail.com
http://strc.herts.ac.uk/cair/

BIOGRAPHICAL NOTE: Samantha Lawrence was the winner of The Institution of Environmental Sciences' **John Rose Award** in 2008 for her PhD research on the analysis of non-exhaust particles. With the prize money from this award, Samantha set up a web site (www.ies-uk.org.uk/non-exhaust) described in this article, to inform the wider public about non-exhaust emissions from vehicles. Details of the John Rose Award for 2009 are described on p 31 of this issue.

Veterinary antibiotics in the terrestrial environment

Although widely used, surprisingly little is known about the fate and chronic toxicity of some of the major classes of veterinary pharmaceuticals and their major metabolites in the terrestrial environment, as **Melanie J. Bottoms**, a final-year PhD student from the Department of Soil Science, University of Reading, explains.

Introduction

The last twenty years or so has witnessed increasing concern, both academic and public, regarding the fate of pharmaceuticals in the environment, and there is a growing body of knowledge regarding their presence and fate in numerous environmental matrices (Tolls, 2001; Boxall *et al*., 2002b). The majority of the work published to date has focussed heavily on aquatic systems, with an emphasis on investigating the fate of human pharmaceuticals in sewage treatment plants (Castiglioni *et al*., 2006; Göbel *et al*., 2004; Heberer, 2002) and drugs routinely used in aquaculture (Lai *et al*., 1995). Recently however, a number of workers have begun to consider the fate of veterinary antibiotics in the terrestrial environment.

A wide range of pharmaceuticals is used in the farming industry, for example sheep dips to protect animals from parasites; antibiotics for disease prevention and treatment; hormone treatments; growth promoters; vaccinations; and anthelmintics (wormers). It has been well documented that the chemicals utilised in sheep dips (organophosphates) are harmful to both human health and the environment (Boxall *et al*., 2004), and hormone treatments that have entered the environment can act as endocrine disrupters in fish (Nash *et*

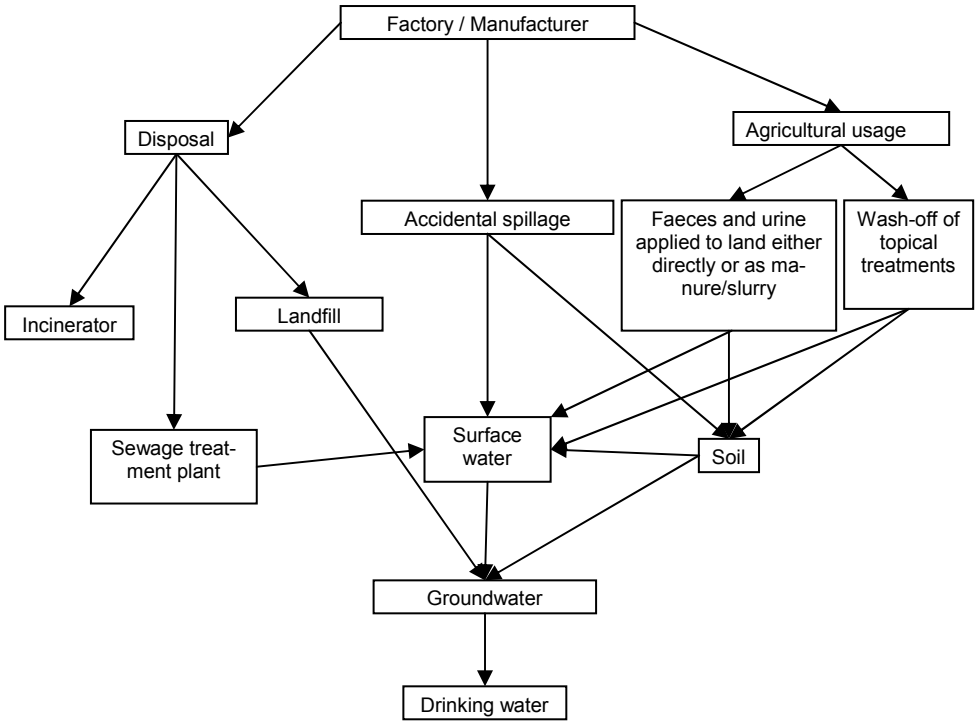


***Figure 1**: Pathways to the environment for agricultural veterinary pharmaceuticals from the point of manufacture.*

al., 2004). In 2003, it was reported that 100,000 to 200,000 tonnes of antibiotics alone were being used annually across the globe (Lindberg *et al*., 2004). It is clear that veterinary pharmaceuticals are widely used as both preventative medicine and treatment for a variety of animal ailments.

Routes of exposure

Figure 1 summarises the main routes of exposure to the environment for pharmaceuticals used in agriculture (excluding aquaculture). As can be seen, the primary routes of exposure are from the factory/manufacturer and from the end-user (in this case agriculture). It is unlikely that significant contamination will occur at the factory level, owing to the strict legislative controls to which pharmaceutical manufacturers are subjected.The term "veterinary pharmaceutical" encompasses a wide variety of substances with a wide range of application methodologies. Each of these methods of application will result in a different route of exposure to the environment. Sheep-dip chemicals, for example, are applied topically and can be subject to washing-off by rainfall, resulting in contamination of surface waters and soil (Boxall *et al*., 2002b). Medications that are administered via injection, bolus or in feed, meanwhile, will be excreted by the animal in its urine or faeces, either as the parent compound or as a metabolite (Halling-Sørensen *et al*., 1998). These excretions are then stored as slurry, which is applied to the land as fertiliser, thus allowing veterinary pharmaceuticals to leach into groundwater or be transported in run-off to surface waters (Boxall *et al*., 2002a). Indeed, it has been estimated that approximately 75% of antimicrobials are excreted back to the environment (Campagnolo *et al*., 2002). Other routes of exposure include discharge (accidental or otherwise) from storage facilities, inappropriate disposal methods and input to river systems from aquaculture (Halling-Sørensen *et al*., 1998).

Analytical methods

There are no universally accepted analytical methodologies for the detection of veterinary pharmaceuticals in environmental matrices. Most methods utilise liquid chromatography coupled to a mass spectrometer. A few reviews have been published summarising the techniques that have been developed to analyse for human and veterinary pharmaceuticals in soils and sediments (e.g. Kim and Carlson, 2005 and Díaz-Cruz *et al.,* 2003), and the most comprehensive overview is a summary by Boxall *et al.* (2002b).

Legal requirements

The use and manufacture of veterinary pharmaceuticals is highly regulated, to avoid both risk to human health and risk to the environment. It is now a legal requirement, under EU Directives 81/851/EEC and 81/852/EEC as codified by Directive 2001/82/EC and amended by 2004/28/EC, that an environmental risk assessment is carried out on any new veterinary medicine (Koschorreck *et al*., 2002), and on older medicines when their licences come up for renewal (Boxall *et al*., 2002b). This process requires acute toxicity tests to be conducted to determine the lethal concentration (LC_{50}) or dose (LD_{50}) of the drug on representative indicator species (e.g. microorganisms, plants, and earthworms for terrestrial ecosystems) (European Medicines Agency, 2004). Chronic tests are also required on earthworms. If there are then specific concerns, chronic toxicity tests may be conducted on other indicator species (European Medicines Agency, 2004). All of these test stages, however, are only carried out if there is an indication that the compound may pose an environmental risk (Boxall *et al*., 2002b) as determined by its Predicted Environmental Concentration (PEC) (European Medicines Agency, 2004). As such, these tests are not carried out routinely on all drugs. The tests are also limited in scope. It is unlikely that the pharmaceuticals will be present in such concentrations as to cause death, but organisms may be subject to chronic exposure, the sub-lethal effects of which are unknown (Svendsen *et al*., 2005). An additional problem with the use of acute toxicity tests was demonstrated by Wollenberger *et al.* (2000), who conducted standard acute toxicity tests, and OECD (Organisation for Economic Co-operation and Development) Reproduction Tests on *Daphnia magna* (a freshwater crustacean) using oxolinic acid, a pharmaceutical routinely used in aquaculture. They found that although the LC_{50} was established as 4.6 mg/l, no test organism survived the full three-week reproductive test at oxolinic acid concentrations greater than 0.75 mg/l, a concentration substantially smaller than that derived using data from the acute toxicity tests (Wollenberger *et al*., 2000).

Resistance

Veterinary pharmaceuticals in the environment pose not only a potential environmental threat, but also a very real threat to human health. Public awareness has been heightened to health risks following media publicity of so-called 'super bugs', like methicillin-resistant *Staphylococcus aureus* (MRSA), which have become resistant to antibiotics. Indeed, genes coding for resistance to one group of veterinary antibiotics, the tetracyclines, have been found in groundwater (Chee-Sanford *et al*., 2001), surface water (Knapp *et al*., 2008) and river sediments (Pruden *et al*., 2006). They are becoming so prevalent in environmental matrices that resistance genes are now referred to as emerging contaminants (Pruden *et al*., 2006). These genes are not just present in the environment, they are being taken up by organisms. For example, Ash *et al.* (2002) found organisms resistant to both naturally occurring and modified antibiotics in US rivers, a large proportion of which contained plasmids coding for resistance, and Engemann *et al.* (2008) found evidence that tetracycline resistance genes were being incorporated into water-column biofilms. Bacterial resistance can be developed by the insertion of foreign DNA into the chromosome from a plasmid (Smith, 2004), and these findings are particularly concerning. These concerns have been added to by

work conducted by Knapp *et al.* (2008), who have demonstrated that anthropogenic tetracycline and oxytetracycline in surface waters can exert a resistance selection pressure. It is also believed that "contaminated" groundwater may act as a source of antibacterial resistant bacteria in the human-food chain (Campagnolo *et al*., 2002).

Veterinary antibiotics

A number of substances used in farming practice are known to be detrimental to the environment and have been well studied, for example sheep-dip chemicals (Boxall *et al*., 2002b) and anthelmintics (McCracken, 1993; Ridsdill-Smith, 1988; Strong, 1993; Wall and Strong, 1987; McKellar, 1997), but less is known about the fate, behaviour and effects of other groups of veterinary pharmaceuticals, e.g. antibiotics (Boxall *et al*., 2004). A number of drug families make up the class of pharmaceuticals commonly known as antibiotics. Two of the most widely used groups of antibiotics, **tetracyclines** and **β-lactams**, are discussed here.

Tetracyclines

The tetracyclines are possibly the most widely studied family of veterinary antibiotics. They are a broad-spectrum antibiotic, active against *Mycoplasma*, *Chlamydophila* and *Rickettsia* as well as a range of gram-positive and gram-negative bacteria (Russell, 2004). Of the tetracyclines, oxytetracycline is the most studied. It has been found to have an aerobic degradation half-life of 42-46 days, which was found to increase when sediment and sludge were added, and decrease when not in the presence of oxygen (Ingerslev *et al*., 2001). It has a low K_{ow} (Boleas *et al*., 2005), a K_{oc} of 27,792-93,317 (l/kg) (Rabølle and Spliid, 2000; Kay *et al*., 2004), and a K_d in sandy soil of 417 and in sandy loam soil of 1026 (Boleas *et al*., 2005). It is a mobile substance, which leaches readily and has been detected in rainfall runoff water (Kay *et al*., 2005c). However, pre-tilling soil prior to application of slurry has been found to reduce its movement through a macroporous clay soil (Kay *et al*., 2005a; Kay *et al*., 2005b). The application of manure can modify the fate and effects of oxytetracycline (Boleas *et al*., 2005). In fact, in an experiment by Boleas *et al*. in 2005, it was found that oxytetracycline (OTC) concentrations of 0.01 mg/kg soil promoted growth of wheat, causing a significant increase in biomass after 7 days in comparison to plants grown in control soil. However, when the oxytetracycline was administered with a co-addition of manure, inhibitory effects were observed at a concentration of 0.01 mg/kg soil. This suggests that the addition of manure increases toxicity to some plants (Boleas *et al*., 2005). OTC has been shown to reduce the growth of lettuce and carrot (grown in spiked soil) at environmentally realistic concentrations (Boxall *et al*., 2006). It inhibited shoot growth and root growth of alfalfa, by up to 61% and 85% respectively, for plants grown in a growth solution containing the drug at concentrations of 0.02 mM OTC (shoots) and >0.002 mM OTC (roots) (Kong *et al*., 2007). Kong *et al.* (2007) also demonstrated a linear uptake of OTC from a 0.004 mM OTC solution by alfalfa over 4 hours; uptake was both time and pH dependent.

In a series of bacterial tests measuring substrate-induced respiration in the presence of OTC with different soil types, it has been found that the more strongly sorbed the drug was the less bioavailable it was. Conversely, the less strongly sorbed it was the greater the inhibitory effect in the first instance, but the more quickly the bacterial community recovered (Thiele-Bruhn and Beck, 2005). The inhibitory effect of OTC on soil bacteria has also been demonstrated to be greater in the presence of copper, a common soil pollutant in both developing and developed industrial countries. Kong *et al.* (2006) found that both substances significantly decreased functional diversity and substrate use by bacteria. This effect was observed in the presence of just 11 μM oxytetracycline or 20 μM copper, but when the substances were applied together the effect was more pronounced, suggesting a synergistic effect (Kong *et al*., 2006).

β-Lactams

The β-lactam family is considered by some to be the most important group of antibiotics (Benito-Peña *et al*., 2006). β-Lactams include well-known groups of drugs, such as penicillins and cephalosporins (Russell, 2004). In 2004 it was reported that 50% of all antibiotics sold worldwide were β-lactams (Deshpande *et al*., 2004). Within the UK in 2007, the veterinary therapeutic antimicrobial market comprised 387 tonnes of antimicrobial active ingredient, nineteen percent of which were β-lactams (Goodyear, 2008). Of the products sold, thirty-five percent contained β-lactam drugs (Goodyear, 2008). Most β-lactams are active against both gram-negative and gram-positive bacteria, (Cha *et al*., 2006; Pérez-Lozano *et al*., 2006). They are regularly used in dairy farming to treat mastitis in lactating cattle. Indeed, of 179 antibiotics utilised for mastitis treatment in Western Europe and the US, 75% are β-lactams (Riediker *et al*., 2004). Unfortunately, there is growing resistance to these drugs. In 2004 it was reported that 60% of *Streptococcus pneumoniae* strains were resistant to the most frequently used β-lactam antibiotics (Deshpande *et al*., 2004).

Amoxicillin is a high-use β-lactam. In 2007, 51 tonnes of active penicillin ingredient were sold to the UK veterinary market alone (this figure includes sales of amoxicillin, ampicillin, cloxacillin, nafcillin and panthamate hydroide) (Goodyear, 2008), whilst in Germany approximately 100 Mg of amoxicillin is prescribed annually (Schreiber and Szewzyk, 2008). Basic physico-chemical data are known for this compound and can be seen in Table 1. Like the other members of the β-lactam family, amoxicillin is readily degraded in the environment (Cha *et al*., 2006), but it has been detected in river water at concentrations less than 10 ng/l (Christian *et al*., 2003). Amoxicillin has also been detected in sewage-treatment plant effluents in Italy at concentrations

up to 120 ng/l (Andreozzi *et al*., 2004).

Log K_{ow}	Log K_{oc}	DT_{50} in soil	pK_a
0.87	865.5 l/kg	0.16 – 0.29 days	2.8, 7.2

Table 1: *Physico-chemical characteristics of amoxicillin (taken from Boxall* et al.*, 2006).*

In aquatic environments, amoxicillin has been shown to have toxic effects on the blue-green alga *Synechococcus leopolensis* (EC_{50} = 2.22 µg/l) (Andreozzi *et al*., 2004), and inhibitory effects on biofilm formation of *Aquabacterium commune* (at 0.5 µg/l) and *Escherichia coli* (at 50 µg/l), whilst having positive effects for the formation of biofilm by *E.coli* (at both 0.5 µg/l and 50 µg/l) when also in the presence of iron (Schreiber and Szewzyk, 2008). In the soil environment very little work has been carried out. One study looked at the toxicity and uptake of amoxicillin by carrot and lettuce, no toxic effect or uptake being observed (Boxall *et al*., 2006), whilst another inconclusive study investigated whether the presence of amoxicillin in soil increased the proportion of amoxicillin resistant bacteria present in soil bacterial communities (Binh *et al*., 2007). Amoxicillin has received very little attention from researchers, especially when considered alongside the frequency of its use. This has been recognised within risk-assessment paradigms put forward in the literature, with both Boxall *et al.* (2003) and more recently Capleton *et al.* (2006) rating it as a high-priority substance for the acquisition of toxicity and fate data.

It is clear that further investigation of the environmental fate and effects of amoxicillin is required, but additionally the other β-lactams should not be overlooked. In the UK in 2007, only 6 tonnes of active antimicrobial ingredient of cephalosporins were sold, but this is increasing year on year and has nearly doubled since 2004 (3,240 kg in 2004 compared to 6,215 kg in 2007) (Goodyear, 2008). In the case of ceftiofur, a cephalosporin antibiotic, it is known that more than 95% of the dose is excreted within twenty-four hours of administration in the urine and faeces as a combination of the parent compound and the two major metabolites (desfuroylceftiofur and desfuroylceftiofur cysteine disulphide) (The European Agency for the Evaluation of Medicinal Products, 1999). The two major metabolites retain the β-lactam moiety (The European Agency for the Evaluation of Medicinal Products, 1999), and thus retain the potential for biological activity.

Conclusions

The environmental fate of veterinary products is still a developing area of research. Work needs to proceed rapidly in order to enable policy makers to act with the most robust scientific evidence to protect both human health, and our environmental legacy for future generations. In particular, research to determine the ecotoxicological effects of the β-lactam drugs on key terrestrial indicator species would help establish the high priority substances from an environmental perspective. Additionally, characterisation of the major degradation products of the high use veterinary antibiotics is required. This is especially the case for the β-lactams, which are prone to hydrolysis in the environment (Cha *et al.*, 2006), as there is little knowledge regarding the properties of β-lactam degradation products.

Acknowledgements

The author would like to thank her funding bodies, the EPSRC and the University of Reading's Research Endowment Trust Fund. She would also like to thanks her supervisors Dr. Mark E. Hodson, Dr. Andrew Parker and Prof. Rainer Cramer for their support.

References

Andreozzi, R.; Caprio, V.; Ciniglia, C.; De Champdoré, M.; Lo Giudice, R.; Marotta, R.; Zuccato, E. (2004), 'Antibiotics in the environment: Occurrence in Italian STPs, fate, and preliminary assessment on algal toxicity of amoxicillin', *Environmental Science and Technology*, **38**, 6832-6838.

Ash, R. J.; Mauck, B.; Morgan, M. (2002), 'Antibiotic resistance of gram-negative bacteria in rivers, United States', *Emerging Infectious Diseases*, **8**, 713-716.

Benito-Peña, E.; Partal-Rodera, A. I.; León-González, M. E.; Moreno-Bondi, M. C. (2006), 'Evaluation of mixed mode solid phase extraction cartridges for the preconcentration of ß-lactam antibiotics in wastewater using liquid chromatography with UV-DAD detection', *Analytica Chimica Acta*, **556**, 415-422.

Binh, C. T. T.; Heuer, H.; Gomes, N. C. M.; Kotzerke, A.; Fulle, M.; Wilke, B.-M.; Schloter, M.; Smalla, K. (2007), 'Short-term effects of amoxicillin on bacterial communities in manured soil', *FEMS Microbiology Ecology*, **62**, 290-302.

Boleas, S.; Alonso, C.; Pro, J.; Fernández, C.; Carbonell, G.; Tarazona, J. V. (2005), 'Toxicity of the antimicrobial oxytetracycline to soil organisms in a multi-species-soil system (MS.3) and influence of manure co-addition', *Journal of Hazardous Materials*, **122**, 233-241.

Boxall, A. B. A.; Blackwell, P.; Cavallo, R.; Kay, P.; Tolls, J. (2002a), 'The sorption and transport of a sulphonamide antibiotic in soil systems', *Toxicology Letters*, **131**, 19-28.

Boxall, A. B. A.; Fogg, L. A.; Blackwell, P. A.; Kay, P.; Pemberton, E. J. (2002b), 'Review of veterinary medicines in the environment', R&D Technical Report P6-012/8/TR, Cranfield Centre for EcoChemistry, Environment Agency,

Bristol; available online http://publications.environment-agency.gov.uk/pdf/SP6-012-8-TR-e-p.pdf

Boxall, A. B. A.; Fogg, L. A.; Kay, P.; Blackwell, P. A.; Pemberton, E. J.; Croxford, A. (2003), 'Prioritisation of veterinary medicines in the UK environment', *Toxicology Letters*, **142**, 207-218.

Boxall, A. B. A.; Fogg, L. A.; Kay, P.; Blackwell, P. A.; Pemberton, E. J.; Croxford, A. (2004), 'Veterinary medicines in the environment', *Reviews of Environmental Contamination and Toxicology*, **180**, 1-91.

Boxall, A. B. A.; Johnson, P.; Smith, E. J.; Sinclair, C. J.; Stutt, E.; Levy, L. S. (2006), 'Uptake of veterinary medicines from soils into plants', *Journal of Agricultural and Food Chemistry*, **54**, 2288-2297.

Campagnolo, E. R.; Johnson, K. R.; Karpati, A.; Rubin, C. S.; Kolpin, D. W.; Meyer, M. T.; Esteban, J. E.; Currier, R. W.; Smith, K.; Thu, K. M.; McGeehin, M. (2002), 'Antimicrobial residues in animal waste and water resources proximal to large-scale swine and poultry feeding operations', *The Science of the Total Environment*, **299**, 89-95.

Capleton, A. C.; Courage, C.; Rumsby, P.; Holmes, P.; Stutt, E.; Boxall, A. B. A.; Levy, L.S. (2006), 'Prioritising veterinary medicines according to their potential indirect human exposure and toxicity profile', *Toxicology Letters*, **163**, 213-223.

Castiglioni, S.; Bagnati, R.; Fanelli, R.; Pomati, F.; Calamari, D.; Zuccato, E. (2006), 'Removal of pharmaceuticals in sewage treatment plants in Italy', *Environmental Science and Technology*, **40**, 357-363.

Cha, J. M.; Yang, S.; Carlson, K. H. (2006), 'Trace determination of ß-lactam antibiotics in surface water and urban wastewater using liquid chromatography combined with electrospray tandem mass spectrometry', *Journal of Chromatography A*, **1115**, 46-57.

Chee-Sanford, J. C.; Aminov, R. I.; Krapac, I. J.; Garrigues-Jeanjean, N.; Mackie, R. I. (2001), 'Occurrence and diversity of tetracycline resistance genes in lagoons and groundwater underlying two swine production facilities', *Applied and Environmental Microbiology*, **67**, 1494-1502.

Christian, T.; Schneider, R. J.; Färber, H. A.; Skutlarek, D.; Meyer, M. T.; Goldbach, H. E. (2003), 'Determination of antibiotics residues in manure, soil, and surface waters', *Acta Hydrochimica et Hydrobiologica*, **31**, 34-44.

Deshpande, A. D.; Baheti, K. G.; Chatterjee, N. R. (2004), 'Degradation of ß-lactam antibiotics', *Current Science*, **87**, 1684-1695.

Díaz-Cruz, M.; López de Alda, M. J.; Barceló, D. (2003), 'Environmental behaviour and analysis of veterinary and human drugs in soils, sediments and sludge', *Trends in Analytical Chemistry*, **22**, 340-351.

Engemann, C. A.; Keen, P. L.; Knapp, C. W.; Hall, K. J.; Graham, D. W. (2008), 'Fate of tetracycline resistance genes in aquatic systems: migration from the water column to peripheral biofilms', *Environmental Science and Technology*, **42**, 5131-5136.

European Medicines Agency (2004), *Guideline on Environmental Impact Assessment for Veterinary Medicinal Products: Phase II*, European Medicines Agency, London; available online http://www.emea.europa.eu/pdfs/vet/vich/079003en.pdf

Göbel, A.; McArdell, C. S.; Suter, M. J.-F.; Giger, W. (2004), 'Trace determination of macrolide and sulfonamide antimicrobials, a human sulfonamide metabolite, and trimethoprim in wastewater using liquid chromatography coupled to electrospray tandem mass spectrometry', *Analytical Chemistry*, **76**, 4756-4764.

Goodyear, K., (2008), *Sales of Antimicrobial Products Authorised for Use as Veterinary Medicines, Antiprotozoals, Antifungals, Growth Promoters and Coccidiostats, in the UK in 2007*, Veterinary Medicines Directorate, Surrey.

Halling-Sørensen, B.; Nors Nielson, S.; Lanzky, P. F.; Ingerslev, F.; Holten Lützhøft, H. C.; Jørgensen, S. E. (1998), 'Occurrence, fate and effects of pharmaceutical substances in the environment: A review', *Chemosphere*, **36**, 357-393.

Heberer, T. (2002), 'Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: A review of recent research data', *Toxicology Letters*, **131**, 5-17.

Ingerslev, F.; Toräng, L.; Loke, M. L.; Halling-Sørensen, B.; Nyholm, N. (2001), 'Primary biodegradation of veterinary antibiotics in aerobic and anaerobic surface water simulation systems', *Chemosphere*, **44**, 865-872.

Kay, P., Blackwell, P. A., Boxall, A. B. A. (2004), 'Fate of veterinary antibiotics in a macroporous tile drained clay soil', *Environmental Toxicology and Chemistry*, **23**, 1136-1144.

Kay, P.; Blackwell, P. A.; Boxall, A. B. A. (2005a), 'A lysimeter experiment to investigate the leaching of veterinary antibiotics through a clay soil and comparison with field data', *Environmental Pollution*, **134**, 333-341.

Kay, P.; Blackwell, P. A.; Boxall, A. B. A. (2005b), 'Column studies to investigate the fate of veterinary antibiotics in clay soils following slurry application to agricultural land', *Chemosphere*, **60**, 497-507.

Kay, P.; Blackwell, P. A.; Boxall, A. B. A. (2005c), 'Transport of veterinary antibiotics in overland flow following the application of slurry to arable land', *Chemosphere*, **59**, 951-959.

Kim, S-C.; Carlson, K. (2005), 'LC-MS^2 for quantifying trace amounts of pharmaceutical compounds in soil and sediment matrices', *Trends in Analytical Chemistry*, **24**, 635-644.

Knapp, C. W.; Engemann, C. A.; Hanson, M. L.; Keen, P. L.; Hall, K. J.; Graham, D. W. (2008), 'Indirect evidence of transposon-mediated selection of antibiotic resistance genes in aquatic systems at low-level oxytetracycline exposures', *Environmental Science and Technology*, **42**, 5348-5353.

Kong, W.-D.; Zhu, Y.-G.; Fu, B.-J.; Marschner, P.; He, J.-Z. (2006), 'The veterinary antibiotic oxytetracycline and Cu influence functional diversity of the soil microbial community', *Environmental Pollution*, **143**, 129-137.

Kong, W.-D.; Zhu, Y.-G.; Liang, Y. C.; Zhang, J.; Smith, F. A.; Yang, M. (2007), 'Uptake of oxytetracycline and its phytotoxicity to alfalfa (*Medicago sativa* L.)', *Environmental Pollution*, **147**, 187-193.

Koschorreck, J.; Koch, C.; Rönnefahrt, I. (2002). 'Environmental risk assessment of veterinary medicinal products in the EU: A regulatory perspective', *Toxicology Letters*, **131**, 117-124.

Lai, H.-T.; Liu, S.-M.; Chien, Y.-H. (1995), 'Transformation of chloramphenicol and oxytetracycline in aquaculture pond sediments', *Journal of Environmental Science and Health: Part A*, **30**, 1897-1923.

Lindberg, R.; Jarnheimer, P.-A.; Olsen, B.; Johansson, M.; Tysklind, M. (2004). 'Determination of antibiotic substances in hospital sewage water using solid phase extraction and liquid chromatography/mass spectrometry and group analogue internal standards', *Chemosphere*, **57**, 1479-1488.

McCracken, D. I. (1993), 'The potential for avermectins to affect wildlife', *Veterinary Parasitology*, **48**, 273-280.

McKellar, Q. A. (1997), 'Ecotoxicology and residues of anthelmintic compounds', *Veterinary Parasitology*, **72**, 413-435.

Nash, J. P.; Kime, D. E.; Van der Ven, L. T. M.; Wester, P. W.; Brion, F.; Maack, G.; Stahlschmidt-Allner, P.; Tyler, C. R. (2004), 'Long-term exposure to environmental concentrations of the pharmaceutical ethynylestradiol causes reproductive failure in fish', *Environmental Health Perspectives*, **112**, 1725-1733.

Pérez-Lozano, P.; García-Montoya, E.; Orriols, A.; Miñarro, M.; Ticó, J .R.; Suñé-Negre, J. M. (2006), 'Stability evaluation of amoxicillin in a solid premix veterinary formulation by monitoring the degradation products through a new HPLC analytical method', *Journal of Pharmaceutical and Biomedical Analysis*, **42**, 192-199.

Pruden, A.; Pei, R.; Storteboom, H.; Carlson, K. H. (2006), 'Antibiotic resistance genes as emerging contaminants: Studies in Northern Colorado', *Environmental Science and Technology*, **40**, 7445-7450.

Rabølle, M.; Spliid, N. H. (2000), 'Sorption and mobility of metronidazole, olaquindox, oxytetracycline and tylosin in soil', *Chemosphere*, **40**, 715-722.

Ridsdill-Smith, T. J. (1988), 'Survival and reproduction of *Musca vetustissima* Walker (Dipteral Muscidae) and a scarabaeine dung beetle in dung cattle treated with avermectin B1', *Journal of the Australian Entomological Society*, **27**, 175-178.

Riediker, S.; Rytz, A.; Stadler, R. H. (2004), 'Cold-temperature stability of five ß-lactam antibiotics in bovine milk and milk extracts prepared for liquid chromatography-electrospray ionization tandem mass spectrometry analysis', *Journal of Chromatography A*, **1054**, 359-363.

Russell, A. D. (2004), 'Types of antibiotics and synthetic antimicrobial agents', In *Hugo & Russell's Pharmaceutical Microbiology*, 7th edn., Denyer, S. P.; Hodges, N. A.; Gorman, S. P. (eds.), pp 152-186, Blackwell Science, Oxford.

Schreiber, F.; Szewzyk, U. (2008), 'Environmentally relevant concentrations of pharmaceuticals influence the initial adhesion of bacteria', *Aquatic Toxicology*, **87**, 227-233.

Smith, A. (2004), 'Bacterial resistance to antibiotics', In *Hugo & Russell's Pharmaceutical Microbiology*, 7th edn., Denyer, S. P.; Hodges, N. A.; Gorman, S. P. (eds.), pp 220-232, Blackwell Science, Oxford.

Strong, L. (1993), 'Overview: The impact of avermectins on pastureland ecology', *Veterinary Parasitology*, **48**, 3-17.

Svendsen, T. S.; Hansen, P. E.; Sommer, C.; Martinussen, T.; Grønvold, J.; Holter, P. (2005), 'Life history characteristics of *Lumbricus terrestris* and effects of the veterinary antiparasitic compounds ivermectin and fenbendazole', *Soil Biology and Biochemistry*, **37**, 927-936.

The European Agency for the Evaluation of Medicinal Products (1999), *Committee for Veterinary Medicinal Products: Ceftiofur Summary Report (2)*, EMEA/MRL/498/98.

Thiele-Bruhn, S.; Beck, I.-C. (2005), 'Effects of sulfonamide and tetracycline antibiotics on soil microbial activity and microbial biomass', *Chemosphere*, **59**, 457-465.

Tolls, J. (2001), 'Sorption of veterinary pharmaceuticals in soils: A review', *Environmental Science and Technology*, **35**, 3397-3406.

Wall, R.; Strong, L. (1987), 'Environmental consequences of treating cattle with the antiparasitic drug ivermectin', *Nature*, **327**, 418-421.

Wollenberger, L.; Halling-Sørensen, B.; Kusk, K. O. (2000), 'Acute and chronic toxicity of veterinary antibiotics to *Daphnia magna*', *Chemosphere*, **40**, 723-730.

MELANIE J. BOTTOMS
Department of Soil Science,
School of Human and Environmental Sciences,
University of Reading,
Whiteknights, Reading RG6 6DW

BIOGRAPHICAL NOTE: Melanie J. Bottoms graduated with a BSc (Hons) in Maritime Environmental Management from Southampton Solent University in 1998. She completed her MSc in Water Science at Lancaster University in 2004 and is currently (2009) in her final year of a PhD in Soil Science at the University of Reading. This article provides a brief summation of work already completed by other workers, providing a context for Melanie's doctoral work.

The future of water and energy: some links that provide solutions and challenges

Professor J. A. (Tony) Allan from the School of Oriental and African Studies (SOAS), University of London and King's College London presented this year's **ECG Distinguished Guest Lecture**, which took place in Burlington House on March 4th

Introduction: the invisible features of water and energy supply. The provision of water and energy services is not well understood by users. The global impacts of water and energy and their synergies are not even well understood by those who manage these resources. Users, managers and policy-makers do not take into account a range of invisible – natural and economic – processes, which underlie the supply of water and energy. In addition, some scientists who analyse the use and sustainability of water and energy resources have also neglected the invisible features of water and energy. The invisibles have not been recognised to be part of the underlying fundamentals that bring natural resource security.

The Stockholm Water Prize Sculpture, which was awarded to Professor Allan, the Stockholm Water Prize Laureate for 2008

Invisible features of water supply. In the water sector, the issues which have been economically and politically invisible are first, **soil water**, secondly **virtual** [embedded] **water** and thirdly **economic development** plus the international trade that it enables. All these interacting invisibles in the water cycle – in the environment, in agriculture, in the economy and in trade – have enabled local water scarcities to achieve a degree of water and food security.

Invisible features of energy supply. Energy is potentially as invisible as water in the economy but energy – whether gathered from the forest, hewn from the ground or pumped as oil and gas – has always involved evident toil and treasure. Society has always been aware of the costs of providing energy. Although it has at the same time been very bad at getting price signals to capture the value of non-renewable energy resources. *Both water and energy are usually and significantly massively under-priced.*

Utilization of water and energy. The major use of water in our economies is in the production of food. Ninety per cent of the water an individual or an economy needs is used to provide food. Water consumption *per head* – which is almost all renewable water – has not changed very significantly since the beginning of industrialisation two hundred years ago. Consumption of energy per head has on the other hand increased by orders of magnitude per head since the beginning of industrialisation. These increases in energy consumption have been possible through the use of **dirty non-renewable energy**.

The total use of water resources has also increased in the recent past. But this increase is because world population has trebled in the past 50 years not because the use per head has risen significantly. The increase in the use of energy on the other hand is mainly because of the

high levels of energy use per head of the richest billion people in the world. They have demonstrated the worrying scale of a society's appetite for energy in a more equal and industrialised world. While water use per head has not risen significantly, the appetite for energy use per head has been shown to be as much as 200 times pre-industrial levels.

The role of virtual water. The role of virtual water 'trade' in ameliorating water scarcity is possibly the most significant invisible commodity. Virtual water 'trade' is economically invisible and more important it is politically silent. Energy is a much more visible natural resource as the energy market is the biggest element of global trade by value. Society is aware of many of the costs of developing energy resources and has accommodated to paying for coal, oil and gas and for electrical energy. However, not until recently has it begun to acknowledge the toxic environmental consequences and costs of the way dirty non-renewable energy has been utilised.

Politicization of water and energy sources. Both water and energy are strategic resources and they can be very easily politicised. The visibility of the value of energy and its asymmetric distribution enhances its strategic significance and its tendency to cause armed conflict. Competition for energy causes wars. Democratic states go to war over oil and gas. Super-powers have used the global reach of their companies and the supportive influence of their military power to gain control of the energy market in the past. They are discovering the challenges of retaining that control. It is in the nature of international politics that the powerful players can obscure the energy component of conflict in a soup of complex conflictive issues.

Water does not cause armed conflict although it is a major source of inter-state conflict short of war in many parts of the world. The invisibility of the environmental processes – namely soil water, and of economic processes – that is trade, that bring solutions to the water scarce obscures the outcomes of mismanaging water. It is easy for knowledge to be constructed that deludes water consumers and politicians responsible for water allocation. Water users and water managers enjoy the relief that the invisible environmental and economic solutions bring them. Anxiety over water scarcity has been easily back-grounded. As a consequence, water scarce societies have not been helped to reverse their extravagant and polluting ways of managing water resources.

Water scarcity. Despite the spectacular amelioration of water scarcity by the invisible trade in food commodities, there are hotspots on every continent where water resources are scarce and the environmental services of water have been very seriously impaired. The Yellow River in China in most years does not reach the sea. The Colorado in the United States and Mexico, the Nile the Middle East, the Aral Basin rivers in Central Asia, the Indus in South Asia and the Murray in Australia scarcely reach the sea. Groundwaters are dangerously depleted in every Middle Eastern country as well as in dry tracts of all the other continents.

Energy scarcity. The shadow of energy scarcity is even more alarming. Anxiety over the supply of the very flexible and undervalued fossil energy resources – especially oil and gas – was palpable in the summer of 2008. This anxiety has proved to be easily back-grounded with the arrival of the global financial and credit crises of 2009. Oil price spikes affect rich and poor directly and they can have serious and unfathomable knock-on effects when they cause price spikes in other key commodities as occurred in 2007-2008. The price of traded food staples increased sharply in 2008 with serious impacts on poor communities world-wide.

Managing energy and water: three synergies. Nature's energy and Nature's water resources are linked by society's economic systems. Society's futures are dependent on how its engineers and markets manage them. There are three important synergies that must be handled effectively to meet the needs of society. There are also two important outcomes that must be avoided to ensure that the environment can provide essential atmospheric services and water environment services. The three synergies are:

- energy from water
- water from energy, and
- economic diversification plus trade.

The two outcomes that must be avoided are:

- the poisoning of the atmosphere in using and managing energy, and
- the degradation and exhaustion of surface and ground waters.

The three synergies are *clean* energy-managing solutions that will first, provide water for society. Secondly, is the synergy that will provide clean energy for society without destroying the environment. The third synergy is the political economy, which through its diversified livelihoods and international trade can bring water and energy security.

The **first synergy** is the production of energy with water – e.g. hydropower and bio-energy. Hydropower is generally clean, although it has other environmental and social impacts. Bio-energy is only appropriate in water-rich environments such as Brazil. In almost all other circumstances its green benefits are purchased at a very high cost by the water environment.

The **second synergy** is the manufacture of water with clean energy, e.g. desalination. At present, desalinated water is produced with dirty fossil fuel. It will be possible to produce

clean solar energy that will convert salt water to usable water without a major carbon footprint. The **third synergy** involves the already tried and tested global systems of diversified economies enabling the 'import' of water intensive commodities – especially food. These three synergies can counteract future water and energy scarcities without damaging either the atmosphere or our water resources.

Future technologies. There is no single way out of the business-as-usual environmental tragedy. The three proposed synergies have to be established. The mix of technologies will vary. Solar thermal energy is the clean energy generation solution highlighted here. But solar voltaic, wind, tide and other clean strategies will contribute to solutions. Clean renewable solar thermal energy distributed by a new high-voltage DC transmission could meet most of the existing energy demands as well as help to meet the strategic demands for high quality water. The use of precious renewable fossil energy could be massively reduced if renewables were to be mobilised. The extraordinary qualities of flexibility and storability of non-renewables must be properly evaluated.

Water and energy security. The example of renewable solar thermal helps us think about the complex and interrelated issues of water and energy security. It will also be necessary to identify and address the behavioural (consumption) challenges that face society in the water and energy sectors. Solar thermal energy helps us see the connections between our energy and water futures. Such knowledge will help in the discussion about the behavioural, economic and technical challenges of a clean and secure water and energy future.

An epigrammatic conclusion. It is possible to capture the importance of society's consumption behaviour in achieving clean and sustainable natural resource futures. Our water consumption options can be understood in the following rhyme: 'Down from five to two point five' (Allan, 2008). Non-vegetarians consume about 5.0 cubic metres of water per day. Vegetarians only use about 2.5. Even a shift to 3.5 cubic metres per day would suffice. The atmosphere could be enhanced by a similar change in diet. 'Down from seven to save the heavens.' (Pachauri, 2008) The joint IPCC 2000 Nobel Laureate was commenting on the impact of methane from ruminants on the atmosphere. He was suggesting a meat-free day per week.

By such healthy personal consumption and a range of clean technologies we shall be able to match the demands of a future global population of eight to nine billions with its much higher energy demands. The main problems are and will be society's consumption preferences.

Further reading

Allan, A. (2001). *The Middle East Water Question: Hydro-politics and the Global Economy*, I. B. Tauris, London.

Allan, J. A. (2009). Energy and water: interdependent production and use and mutuality of impacts, In Mason, M. and Mor, A, eds., *Renewable Energy in the Middle East: Enhancing Security through RegionalCooperation*, Springer, Berlin. In press.

Barnaby, W. (2009), 'Do nations go to war over water?', *Nature*, **458**, 282-283

Easter. K. W.; Rosegrant, M. W.; Dinar, A., eds. (1998). *Markets for Water: Potential and Performance*, Kluwer Academic, Norwell, MA.

Falkenmark, M.; Lundquist, J.; Widstrand, C. (1989). Macro-scale water scarcity requires micro-scale approaches: aspects of vulnerability in semi-arid development, *Natural Resources Forum*, **13**(4), 258–67.

Hoekstra, A. Y. and Chapagain, A. K. (2007). *Globalization of Water: Sharing the Planet's Freshwater Resources*, Wiley-Blackwell, Oxford

Rogers, P. (2008), 'Running out of water: a six point plan to avert a global crisis', *Scientific American*, August 2008, pp 27-35.

Professor J. A. (TONY) ALLAN

School of Oriental and African Studies, University of London, Thornhaugh Street, Russell Square, London WC1H 0XG

& King's College London, Strand, London WC2R 2LS

E-mail: ta1@soas.ac.uk

This article is based on a presentation by Professor Allan at the ECG's 2009 Distinguished Guest Lecture and Symposium 'The Future of Water'.

Economic perspectives on water access and affordability

Introduction

The supply of potable water to the urban population has long been recognised by public policymakers as one of the key underpinnings of civic society[1]. The public policy rationale underlying this has, however, proved rather difficult to pin down; with policymakers, ancient and modern, struggling to articulate clearly their particular policy objectives. Where clarity over objectives and the trade offs between them has been lacking, frequent recourse has been made to vague 'water is special' arguments for *ex post facto* justification of actions taken: an approach derided by Hirshleifer *et al*. (1960) as a smokescreen for sloppy thinking,

> "Much nonsense has been written on the unique importance of water supply to the nation or to particular regions. Granted that the nation, or any individual thereof, could not survive without water, that does not show uniqueness. No human can survive without food, without oxygen…without clothing, yet somehow we do not have frequent conferences and symposiums of public-spirited bodies on "the clothing problem"…Whatever reason we cite, however, the alleged unique *importance* of water disappears upon analysis."
>
> Hirshleifer, De Haven and Milliman (1960, pp 4-5)

For the purpose of this analysis, ***three policy objectives*** are suggested; echoing the three 'pillars of sustainable development' articulated at the 2002 World Summit on Sustainable Development[2]:

1. *Social policy objectives* which might include matters such as the promotion of public health and social inclusion.
2. *Economic policy objectives* which might typically cover the management of public finances and the promotion of productive efficiency.
3. *Environmental policy objectives* including species conservation and environmental protection.

Clearly policymakers will consider all three objectives across time. However, this paper argues that at particular points in time the relative weight given to the different categories of objective will not only differ, but will be discernable from the statements and actions of policymakers themselves. In other words, one might work back from policy decisions and actions to policy priorities in a fairly straightforward way.

Changing public policy priorities

Evidence for a change in public policy priorities (in relation to the water industry in England and Wales) is offered by Bakker (2001). She suggests that over the past three decades the evolution of water charging policies has revealed a shift in public policy priorities, away from those emphasising social equity to those emphasising economic equity. Thus a system supporting the equalization of charges between regions *via* direct transfers between water authorities and companies was withdrawn, full cost recovery embraced and a system of economic regulation introduced to control the operations of the privatised regional water authorities. Some movement in the other direction has recently been observed with, for example, the ban on domestic disconnection for non-payment of charges. Nevertheless these and other recent changes have done little to alter the overall direction of travel.

[1] Sophisticated and costly systems were used to bring large quantities of water great distances to serve the densely populated city of Rome. The most famous account of Rome's water system (*De aquae urbis Romae*) is attributed to Sextus Julius Frontinus, 'curator aquarum' (water commissioner) in the first century AD.

[2] See Point 5 of The Johannesburg Declaration on Sustainable Development, 4 September 2002. http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POI_PD.htm (consulted on 20 April 2009)

In Scotland, a similar shift in public policy priorities may be discerned, albeit that this shift has been less pronounced and has occurred with a time lag. Thus more recently than in England and Wales, the principle of full cost recovery has been embraced, the complex system of water and sewerage charge reliefs for charitable and other organisations has been phased out, and an independent economic regulator[3] created to ensure the supplier works within strict economic and financial targets.

And so to this paper's central question: what impact have these recent changes in public policy priorities had on low income households[4]?

Impact on low income households

In order to answer this we consider water 'affordability' which, in the UK, is understood as, and hence calibrated in terms of, the percentage of gross or net household income spent on water and sewerage services as a proportion of all income[5]. Thus the higher the proportion of household income spent on water and sewerage charges the less affordable those charges are deemed to be. The fact that domestic households may no longer suffer the ultimate sanction of disconnection for non-payment of charges underlies a preference in the literature for use of the term 'water affordability' rather than the more emotive and less genuinely descriptive 'water poverty'. And whilst mitigating, it does not remove, the problem of economic access. Households which spend a high proportion of their income on water and sewerage services have fewer budgetary options than the wealthy. Those on an unmeasured supply arguably have even fewer options than those who pay by meter. Regardless of charging and payment method, however, where household incomes are inadequate to meet charges, debt levels rise, bringing with it a number of well-documented social problems[6].

Drawing illustrative material from recent work relating to Scotland, **Table 1** records the mean percentage gross weekly household income[7] spent on water and sewerage charges for households classified according to income deciles, at points in time between 1997/8 and 2005/6.

Income Decile	1997/8	1999/2000	2001/2	2003/4	2005/6
1 Lowest	1.41	2.11	2.81	2.90	3.02
2	0.92	1.43	1.70	1.92	1.93
3	0.76	1.21	1.43	1.65	1.65
4	0.72	1.13	1.33	1.48	1.50
5	0.62	1.00	1.18	1.36	1.29
6	0.56	0.90	1.15	1.22	1.18
7	0.48	0.79	0.99	1.10	1.00
8	0.45	0.66	0.87	0.99	0.93
9	0.36	0.58	0.71	0.81	0.74
10 Highest	0.26	0.39	0.52	0.51	0.48

Source: Family Resources Surveys. Note: Equivalised Income

Table 1: *Scotland: Mean % gross weekly household income spent on water and sewerage*

The change is marked, and reflects, primarily, rapidly rising water and sewerage charges over the period following restructuring of the industry in 1996. **Table 2** analyses the same period by household composition, whilst **Table 3** focuses only on households in the lowest income decile. A similar pattern of increased proportions of household income

[3] The Water Industry Commission for Scotland.
[4] Often amongst the economically most vulnerable members of society.
[5] See Sawkins and Dickie (2005).
[6] Some of these are set out in a report by Save the Children (1996) which explored the impact of meters on the consumption patterns of low income households.
[7] All estimates presented in this paper have been equivalised.

Household composition (Scotland)	1997/98	2005/6
Single person without children	0.3	0.8
Couple without children	0.4	0.8
Three or more adults no children	0.5	1.1
Single person with children	0.6	1.2
Couple with children	0.5	1.1
Three or more adults with children	0.6	1.3
Single pensioner	0.5	1.2
Pensioner couple	0.7	1.3
All households	0.5	1.0

Source: Family Resources Surveys. Note: Equivalised Income

Table 2: *Household water and sewerage charges by household composition. Mean % gross weekly household income spent on water and sewerage.*

Household composition (Scotland)	1997/98	2005/6
Single person without children	1.1	3.1
Couple without children	1.6	4.3
Three or more adults no children	1.8	3.5
Single person with children	1.1	2.3
Couple with children	1.8	3.7
Three or more adults with children	1.5	*
Single pensioner	1.1	2.7
Pensioner couple	1.7	3.5
All households	1.5	3.0

Source: Family Resources Surveys. Note: Equivalised Income

Table 3: *Household water and sewerage charges by household composition: lowest income decile. Mean % gross weekly household income spent on water and sewerage.*

spent on these services is observed.

Changes in charge levels are, of course, only one aspect of affordability. Another is the changes in income levels which, for households in the lowest income decile, are bound up with changes in social security benefit arrangements. Without describing current social security arrangements in detail it is sufficient to note that there is currently no dedicated benefit relating to water and sewerage charges. Simplifying somewhat, the primary benefit that may be applied by households to their water charges is the personal allowance element of income support, a means-tested benefit

	2001-2	2002-3	2003-4	2004-5	2005-6	2006-7	2007-8
North of Scotland	16.80%	0%	0%	-2.24%			
East of Scotland	18.50%	-0.63%	9.90%	5.00%			
West of Scotland	19.60%	17.30%	9.90%	5.00%			
All Scotland					4.04%	1.41%	3.48%
Inflation	1.80%	1.70%	2.90%	3.00%	2.80%	3.20%	4.30%
Rossi Index	1.60%	1.70%	1.30%	1.80%	1.00%	2.20%	3.00%

Sources: Water charge increases: Public Water Authorities and Scottish Water. Inflation: figures from UK National Statistics http://www.statistics.gov.uk/. Rossi Index: National Statistics Online

Notes: Water charge: figure for 2001-2 relates to change between 2000-1 and 2001-2 etc.; Inflation: defined as percentage change in Retail Prices Index (all items) over 12 months; 12-month inflation figures for 2001 recorded in 2001-2 etc.; Rossi Index: Annual % change in Rossi is calculated using September RPI and applied the following April. Rossi Index is based on RPI less housing costs, i.e. RPI (all items) index less rent, mortgage interest payments, council tax and depreciation costs; Income Support (income-related benefits in general) is uprated in line with September's 12-month rate of the Rossi Index

Table 4: *Annual average water and sewerage charge increases. Inflation and benefits uprating (Rossi Index)*

which is increased annually according to an index – the Rossi index – applied by the Government. Whilst indexation of benefits does seek to mitigate the effect of inflation on the purchasing power of households it does not, indeed cannot, do that perfectly. More problematic from the point of view of water affordability, however, is the extent to which this indexation has lagged behind increases in water and sewerage charges. **Table 4** sets this out clearly by recording annual average water and sewerage charge increases alongside a measure of inflation[8] and the Rossi index used for benefits uprating.

To analyse the extent to which benefits-indexation has lagged water and sewerage charge increases in Scotland over the last decade, **Table 5** records the notional benefit element within the income-support personal allowance attributable to water as a percentage of the average charge. As is clear from the Table from the claimant's point of view, the position has deteriorated markedly during this period.

Affordability and increasing water scarcity

So much for the recent past; what of the near future?

Clearly social and economic concerns will continue to influence the evolution of public policy towards water. More significantly, however, we might anticipate that greater priority will be given to environmental objectives as the Government seeks to implement the European Union's Water Framework Directive against a backdrop of increasing water scarcity.

Already political debate over new charging structures to support environmental objectives such as species preservation and environmental protection is well advanced in the UK. As this debate matures it will be important not only to track its development, but to undertake research into the impact of environmentally inspired initiatives on low income and economically vulnerable households. Without this, the chance of building a lasting public policy consensus over water and sewerage service delivery over the next decade – one of the key underpinnings of civic society – seems remote.

[8] The Retail Prices Index (or RPI).

Year	Benefit element (weekly) uprated by Rossi £	Average water & sewerage charge: annual (weekly) £	Benefit element as % of average charge
1995/6	2.32	107 (2.06)	113%
1996/7	2.39	115 (2.21)	108%
2001/2	2.64	231.64 (4.45)	59%
2004/5	2.76	272 (5.23)	53%
2005/6	2.79	283 (5.44)	51%
2006/7	2.85	287 (5.52)	52%
2007/8	2.94	297 (5.71)	51%

Sources: Annual average water charges: 2004/5 to 2007/8: Scottish Water Annual Reports and Accounts. 2001/2: Water Industry Commissioner for Scotland (2001) *Strategic Review of Charges 2002-2006*, Stirling, Figure 38.1, p 356.

Notes: The opening figure is derived from that taken from correspondence from the House of Commons Library to Ms Jackson MP (17th May 1996). Weekly charges = annual charges/52. This is used as the basis for the benefit series (uprated by Rossi/New Rossi)

Table 5: *Changes in income support benefit element and average Scottish household water charges.*

References

Bakker, K. J. (2001), 'Paying for water: water pricing and equity in England and Wales', *Transactions of the Institute of British Geographers*, **NS 26**, 143-164.
Family Resources Survey, 1997-98 [computer file]. Colchester, Essex: UK Data Archive [distributor], 10 January 2000. SN: 4068.
Family Resources Survey,1999-2000 [computer file]. Colchester, Essex: UK Data Archive [distributor], 12 September 2001. SN: 4389.
Family Resources Survey, 2001-2002 [computer file]. Colchester, Essex: UK Data Archive [distributor], 8 May 2003. SN: 4633.
Family Resources Survey, 2003-2004 [computer file]. Colchester, Essex: UK Data Archive [distributor], 6 April 2005. SN: 5139.
Family Resources Survey, 205-2006 [computer file]. Colchester, Essex: UK Data Archive [distributor], 16 November 2007. SN: 5742.
Hirshleifer, J. De Haven, J.,C. and Milliman, J.,W. (1960), *Water Supply: Economics, Technology and Policy*, University of Chicago Press, Chicago and London.
Save the Children (1996), *Water Tight: The Impact of Water Metering on Low-income Families*, Save the Children, London.Sawkins, J. W.; Dickie, V. A. 2005, 'Affordability of household water and sewerage services in Great Britain', *Fiscal Studies*, **26**, No. 2, 225-244.
Scottish Water (various), *Annual Report and Accounts*, Scottish Water, Dunfermline, Scotland.

Professor JOHN W. SAWKINS,

Department of Economics, School of Management and Languages, Heriot Watt University , Edinburgh, EH14 4AS

This article is based on a presentation by Professor Sawkins at the ECG's 2009 Distinguished Guest Lecture and Symposium 'The Future of Water'.

The ECG interview: Monitoring heaven's breath

In the second of a series of interviews for the ECG *Bulletin*, **Adrian Kybett** talks to **Ruth Purvis** about her airborne (and ground-based) work in monitoring the

atmosphere.

Dr Ruth Purvis is a Research Fellow at the Facility for Ground-based Atmospheric Measurement, based at the University of York www.ncas.ac.uk/fgam/

What inspired you to become a scientist?

At school I guess I was a bit of a geek and enjoyed my science lessons. We had a great chemistry teacher who also organised lots of outdoor pursuits so I guess we found him a bit cool!

At the end of my final year at school I was torn between science and journalism but a visit to a career fair helped put things into perspective when I met a really uninspiring journalist. It then seemed a natural progression onto science A-levels then a degree in Chemistry at the University of Leeds.

How did you come to specialise in atmospheric chemistry?

By accident I suppose. I finished my M. Chem. and was offered a PhD in computational chemistry. I had spent a year of my degree in industry and did not enjoy it that much so thought staying in Academia might work well for me. Six months into the PhD I was not enjoying it, then my supervisor left and advised me that the PhD was not really going anywhere and it may be best to give up. A professor in Leeds, Prof Mike Pilling, gave me excellent advice and told me that I had the capability to do a PhD and maybe try a different area; a colleague had a PhD working with a research aircraft and would I be interested. I had a brilliant three years which involved fieldwork in Scotland, Ireland, Germany and Switzerland and decided that atmospheric chemistry was the career for me!

Describe your work at the Facility for Airborne Atmospheric Measurement (FAAM)…

I was employed at FAAM as an atmospheric chemist and one of my main duties was the maintenance and calibration of the chemistry instruments fitted permanently to the aircraft. Universities and the Met. Office can apply for funding to use the aircraft in the UK or anywhere around the world. The FAAM team is small unit (13 people from Met. Office and NERC) so everyone cannot go with the aircraft all the time so I ended up being trained to operate several instruments. One of the main duties I had on campaign was as a Flight Manager, which is taking responsibility of the aircraft 'primary instruments' (gps, wind speed and direction, temperature, video cameras, etc.), the communications with the aircrew and ground when in flight and most importantly the data-recording system. Also you ended up getting involved with campaign logistics; it is not easy getting two tonnes of equipment to Niger!

When on campaign, as with all fieldwork, you end up working long days. A typical science flight is about five hours but your day starts with instrument warm-up and pre-flight brief at least two hours before flight. Then post-flight you have another briefing, instrument shutdown, putting protective covers on

the instruments if we do not have a hangar and the all important data processing and backup. Although these campaigns are usually good fun, the difficult thing at FAAM is that you have to go on a detachment several times a year, often spending three months a year away from home.

Whilst full-time at FAAM I worked on some amazing projects which took me all over the world, Africa, Antigua, USA to name a few! The good thing about working at FAAM, besides the travel, is the wide variety of work that you can be involved with. My knowledge base has improved dramatically and although an atmospheric chemist I now have a broader understanding of aerosols, meteorology, contrails, clouds, etc.

I suppose the downside is that you do not get involved in the post-flight research. You hand over the data and then that is FAAM's duty over, it makes it more difficult to improve your publication record. I guess that is the difference being a PDRA at a University and working as a scientist in a service facility.

And your work at the Facility for Ground-based Atmospheric Measurement (FGAM)…

I am now working on a data analysis project within FGAM. I am hoping to extend the use of the aircraft to provide a UK-based long-term observation platform. Whilst at FAAM I noticed that all the projects we did were case studies, and thought it may be useful to try and tie all the data together in one database. I hope to come up with some long-term datasets for areas over the UK. I still work with the aircraft, (approximately a third of my time is allocated to FAAM work), but I am now involved more as a research scientist. It is nice now to use the data that I helped collect and actually be doing some post-flight research!

It is very different working in FGAM compared to FAAM. FGAM is a distributed facility so staff are based in Universities all over the country, but you end up working in the same place as other NCAS staff (FGAM is a service within the National Centre for Atmospheric Science).

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

Go for it, so far I have had a great experience and met people who have become friends for life. I would definitely recommend it as a career, you get to travel as part of your job which has to be a good incentive!

However, it will probably not make you a millionaire, so it you are motivated by money it may not be the right career choice for you! Often most of the jobs are PDRA' s which tend to be project-based, permanent positions are few and far between so you need to make yourself flexible and be willing to move on in a few years – either location or on to a new project.

What are some challenges facing the environmental chemistry community now?

I think in the current economical climate it has to be the funding. In the past the challenges have always been to do with the science but I think this has changed in the past year. Even though I like to think I am working in a politically relevant area (i.e. climate change/ global warming) it does not mean that we have guaranteed funding.

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

Having my first paper published! It was a year into my PhD and after having such as disaster the first time round it felt like a real achievement. I guess the other rewarding aspect is the people you meet. As you spend spending weeks away from home you forge strong friendships with those around you, there are not many careers where you could end up living with your colleagues on a regular basis!

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

This is a difficult one to answer as I have wanted to be a scientist from such a young age. I love sport so I guess a career in that area, as a coach or a PE teacher.

& What do you do when not working?

Sport participating and watching. I play netball regularly, am an umpire and have done some coaching. I am also a bit of a football fan and support Middlesbrough FC.

The Institution of Environmental Sciences

The John Rose Award 2008

Atmospheric particle pollution has been linked to a number of health issues, and a study by the European Commission calculated that air pollution reduces life expectancy by an average of almost nine months across the European Union (2005 data). Road transport is a major source of atmospheric particle emissions, particularly within urban areas. Current legislation has only focused on reducing emissions from the exhaust pipe of vehicles. New studies have shown that other unregulated vehicle-related emissions, such as non-exhaust emissions, can equal or surpass exhaust contributions.

The winner of **The Institution of Environmental Sciences** (IES) **John Rose Award** in 2008 was **Samantha Lawrence**, for her PhD research on non-exhaust particles. Samantha Lawrence has used the £1000 grant to publicise her work on non-exhaust emissions and to launch a campaign to encourage the Government to create appropriate legislation to control non-exhaust emissions. In collaboration with the IES, Samantha has also created a web site with information on her research, interactive features and learning resources. Please visit www.ies-uk.org.uk/non-exhaust.

The IES hosts the John Rose Award every year to reward outstanding pieces of environmental post-graduate research, which have the potential to motivate people and facilitate environmental improvement. The £1000 grant is used to publicise the results of the work to the general public.

The John Rose Award 2009

We are pleased to announce that applications for the **John Rose Award 2009** are now welcome. The applicant must have completed, or be in the writing-up stages of a postgraduate piece of work that can contribute to positive environmental change. Upon winning the Award, applicants will receive £1000 to promote their research to the public, along with the chance to speak at the prestigious Burntwood Lecture to an audience of scientists and environmental professionals. The Award will be officially presented by Paul Leinster, Chief Executive of the Environment Agency at the 2009 Burntwood Lecture on 11th November at the Royal Society in London.

Please visit http://www.ies-uk.org.uk/awards/awards.php for more information and to apply. The closing date for applications is **2nd October 2009**.

CHARLOTTE COOK,

Institution of Environmental Sciences,

38 Ebury Street, London SW1W 0LU

Tel: +44 (0)20 7730 5516

Fax: +44 (0)20 7730 5519

Email: charlotte@ies-uk.org.uk

Website: www.ies-uk.org.uk

Meeting Report

2009 Environmental Chemistry Group Distinguished Guest Lecture and Symposium

The Future of Water

The Environmental Chemistry Group held its Thirty-Sixth Annual General Meeting with the Distinguished Guest Lecture and Symposium **The Future of Water** on 4th March 2009 at Burlington House. The 2009 Distinguished Guest Lecturer was **Professor Tony Allan** (KCL).

The symposium was designed to bring together different macro-perspectives on water, and fundamentally it addressed the realities of environmental strategies for water in terms of the economic, legislative and political forces which dominate environmental change. Each of the contributors brought a precise, well-evidenced and independent perspective to the symposium topic.

John Sawkins (Heriot-Watt University) began the symposium with a presentation entitled "Economic Perspectives on Water Access and Affordability" and described how potable water has long been recognised as one of the key underpinnings of civic society and how public policy has for reasons of public health, economics, and environmental protection sought to facilitate the delivery of water to the population. The balancing of these public-policy objectives is difficult and sometimes lacks clarity. This has been especially true because water has low substitutability and hence it has been argued that it has unique importance and deserves special treatment. However, public policy has increasingly commoditised water and (*via* privatisation) sought full cost recovery, i.e. public policy has moved from prioritising social objectives to policies prioritising economic objectives. This 'new' policy (manifest as privatisation) has had a great impact household finances; for households in the lowest income decile the Mean Percentage of Gross Weekly Household Income spent on water and sewerage increased from 1.41% to 3% from 1997/8 to 2005/6. The shift of policy to full economic recovery from households poses the question as to whether the affordability of water should still be a responsibility for government at all, and whether a shift (driven by, for instance, the WFD) to environmental priorities should occur – and the mitigation of the effects of such a shift of policy on economically vulnerable households be sidelined as an issue. John Sawkins closed his paper with a quote from Samuel Johnson "A decent provision for the poor is the true test of civilisation."

Discussion took place around the 'affordability' of water in the UK, with one of the positions being taken arguing that water was currently not unaffordable to any household in the UK and that the supply of water as a 'free good' has led to a situation where the population ceases to value it. The view was also taken that tariff structures needed to reflect the abilities of all social groups to pay, and although full cost recovery was unanimously seen as the way ahead, mechanisms for supporting the economically vulnerable to pay were needed. But it was also clear that the current form of such interventions was inappropriate, inefficient and only partially effective.

Richard Carter's (Cranfield University) presentation ("Navigating Water Futures in Sub-Saharan Africa") moved from the UK to give a more global perspective on the future of water; this future had a very different significance when contextualised by a continent which faces the prospect of climate change with an already inherently variable climate, fast-growing urbanisation, profound degradation of land and water, low-income economies, limited governmental political will, weak institutions and poor governance ("Bleak trends seem to be the future"!). However,

in some areas (e.g. Central Africa) the unavailability of water has much more to do with the shortage of service provision than a physical shortage, and this is exacerbated by the 'naturally' high rainfall variability, with some areas (e.g. Sudan, Malawi) showing coefficients of variability of 30-25% and more. This variability in rainfall is compounded by a high variability in groundwater recharge which is strongly linked to average rainfall but depends more on the site and the temporal distribution of rain – and variability is at its highest at the beginning of the planting season when the rains begin. The added impact of climate change is difficult to evaluate – most of Sub-Saharan Africa is predicted to experience a ±10-20% change in Mean Annual Rainfall. Given the population growth, the increased urbanisation, and the fact that agricultural production in the region has remained static for 40 years, huge stresses will develop. Large-scale solutions – dams, hydropower, and large scale irrigation – are necessary, but the financing, managing and environmental impacts of them are very problematic. Small-scale solutions – water conservation, enterprise solutions to water supply, and farmer-managed irrigation – are realistic and effective but do not intervene at the necessary scale. But without solutions, famine, poverty, disease and environmental degradation will get much worse. The need for nationally owned policies for the modernisation and the intensification of agriculture, and for investment in water infrastructure, is paramount. The discussion which occurred was somewhat more muted than for the previous paper where the problems seemed to be much more tractable than the almost terminal situation in Sub-Saharan Africa. The human predicament there will outweigh any real consideration of the environment for the foreseeable future and the implications of this for the Sub-Saharan natural environment will be profound.

Lars Steffensen (Ebullio Capital Management LLP) spoke eloquently about the way in which a transparent futures market for water could bring a reduction in investment risk and a consequent growth in investment in water provision ("H_2O Cif Shanghai – the next big thing . . .?"). Price discovery was identified as being the first stage in any water-futures trading – how does water cost impact on the price of commodities such as wheat and aluminium? And then the fundamentals of trading were considered – where would water be traded (New York, London and Chicago all have the necessary infrastructure for commodity trades to occur), what are the grades of water which can be traded (potable, grey, brown?), what is the lot size (1000 tonnes?), where are the delivery points (are the consumers mainly in urban centres?) and who would regulate the trades (FSA?). The benefits would be significant – investment in new water capacity would be easier because there would be a long-term lock-in on the future value of water, liquidity would be provided to the investors by speculation, and farmers could hedge against the price of water – just as they do currently for fertiliser prices and energy. The application of a "Cap n Trade' process where only the water in excess of a 'cap' (i.e. water defined as essential (e.g. for public health)) was traded, was seen as the way ahead. Futures markets are historical drivers of growth and wealth creation and they do this by encouraging investment, allowing long-term planning (because the rate of return becomes more predictable), and because risk is reduced. This presentation was discussed with all of the papers in the Open Forum and, as might be expected, evoked a strong but rational debate.

Prathivadi Anand (University of Bradford) began by posing the question as to what amount of water it is 'reasonable' for an individual to expect to be able to access and then moved on to explore how climate, culture and economic factors made any answer subjective. Hence the UN target for 2015 to ". . . reduce by 50% the proportion of people without sustainable access to safe drinking water and sanitation" itself becomes subjective – as do the data which attempt to measure global progress towards it. By all current measures the proportion of people without access to water or sanitation has remained the same since 1990 and hence the 2015 target will not be met; but, when the subjectivity inherent in the way the target has been stated is revealed, this is inevitable. Having accepted that 'sustainable access to safe drinking water' is a relativistic concept (and so therefore is 'scarcity') it becomes necessary to create a new paradigm by which water can be discussed, "It's not the quantity of water which is the question, it is the outcomes." In this respect for an individual, an adequate (or a scarce) amount of water becomes determined by a specific set of actions ('functionings') that an individual has reason to value, and it is these entitlements which should be determined by the institutional structures that command resources. Making access to water a human right is meaningless unless it is implemented and focussed on substantive freedoms within a society by creating good (and responsive) governance which attends to the capabilities of the governed sidelines the idea of 'how much water' in favour of how much is achieved by access to it.

The Distinguished Guest Lecture ("The future of water: three weddings and avoiding two funerals?") began with **Tony Allan** emphasising his view that the nexus between water and energy make it impossible to discuss them independently – hence his lecture would consider both. He first described the way in which 'natural' soil water was sufficient for mankind for the first hundred thousand years of existence but as soon as domesticated sources of meat became available, diet changed and more water was required – and the industrial revolution further increased demand. Professor Allan hypothesised that this early evolutionary experience made man 'blind' to the use and value of water since so much of the human experience has been with rain-fed agriculture with invisible embedded water – hence current approaches to pricing the value of water are wrong because they reflect this 'blindness'.

Having offered an evolutionary-perception explanation of the problem man has with the value of water (a problem themed in all of the symposium presentations) the 'three weddings' of the Lecture title were discussed – each represented a link between water and energy: water can be manufactured with energy, energy can be generated directly with water (or indirectly via biofuel), and local energy and water security has been enabled by trade. For instance, because of its status as a trading nation, Singapore can import its food (and hence, indirectly, the irrigation water used to grow it) and it also can pay for sufficient energy to produce 50% of its 'blue' water by desalination. The 'two funerals' of the title are those of water resources (already seriously depleted and degraded) and the atmosphere (due to the use of stored solar energy in the form of fossil fuels); these are linked and exert strong positive feedback. As with many of the previous speakers, the predictions were harsh, 'A hundred years to depletion'; though the movement of water via trade (soil water in distant catchments is moved via food to 'energy-rich' nations with sufficiently developed economies to trade manufactured goods) can ameliorate the situation. Hence, cheap energy (provided *via* solar thermal energy from the world's deserts) is a solution for water 'scarcity' – desalination, water recycling, and trade can occur, water depletion and carbon dioxide emissions will cease. But the necessary creative precautionary constructive engagement for such interventions are lacking, and the attention of providers, politicians, the media and consumers is too fickle to produce a situation by which such technically feasible solutions can get political support.

Discussion in the open forum, which followed the five presentations, was extensive. The 'capitalist' approach of futures trading was challenged on ideological grounds. Its basis in the fundamental drivers of human behaviour seemed unacceptable when lives and the environment seemed likely to suffer. Who will stop malign rulers trading their country's water at the expense of the population; especially when the origins of water may be difficult to trace? However, although there was a reluctance to accept it, all of the speakers agreed about the anthropocentric nature of man and, unless world peace, perfect democracy and change in man's nature are imminent, it is challenging to produce an approach which could better regulate global water than trading it.

Dr LEO SALTER

Cornwall College, Pool,
Redruth, Cornwall

March 2009

Meeting Report

ECG Atmospheric Chemistry Forum

The first Atmospheric Chemistry Forum to be organised by the RSC's Environmental Chemistry Group took place at Burlington House on 2nd April 2009. The Forum was targeted at PhD students and early career post-doctoral researchers in the field of atmospheric chemistry, interpreted in its broadest possible sense. Twenty-five delegates attended, all of whom delivered a talk or a poster presentation introducing current key issues in their area and showcasing something of their own research. Supervisors were deliberately excluded: that and the fact that the Forum was kept small contributed to an ethos that this was the delegates' own event to discuss their research and share their expertise.

The Forum's most popular subject area was the **atmospheric oxidation of volatile organic compounds** (VOC), with four talks and six posters spanning laboratory studies of the kinetics of VOC oxidation reactions, development of VOC oxidation mechanisms, modelling studies examining how anthropogenic and biogenic VOC emissions affect the atmospheric environment and air quality, and field observations of ambient VOCs including aircraft measurements made over the rain forest and palm oil plantations of Borneo during the recent NERC OP3 field campaign.

Other presentations and discussions could broadly be grouped into four areas:

1. **Aerosols** – laboratory and field studies of aerosol particles and their heterogeneous reactions, nucleation of ice cloud particles;
2. **Radical chemistry in the troposphere** – NO_x and tropospheric ozone production, formaldehyde photochemistry, emerging spectroscopic techniques for measuring ambient concentrations of radicals;
3. **Halogen chemistry** – halocarbons and iodine compounds in the marine boundary layer, stratospheric ClO chemistry;
4. **Data synthesis**, uncertainties and establishing trends from observational time series.

Included in that last category was an excellent and wide-ranging tour through some of the "Uncertainties in Atmospheric Chemistry" given by **Prof. Mike Pilling** (Leeds University) in the Forum's Invited Lecture.

The Forum finished with a question-and-answer session where an 'expert panel' comprising **Jacqui Hamilton** (York University), **Adrian Kybett** (NERC National Centre for Atmospheric Science) and **Caroline Tolond** (RSC Advice & Guidance Manager) fielded a diverse range of career-related queries from the floor. The consensus of the sizeable fraction of the Forum that later reconvened in a local hostelry was that we should do this again, maybe in 18 months to two years' time.

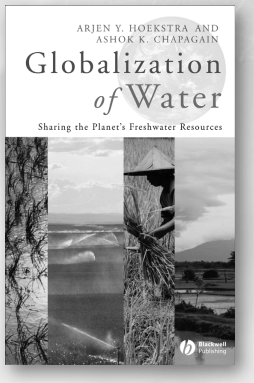
A selection of talk and poster abstracts from the Forum will be published in the January 2010 issue of the ECG *Bulletin*. The organisers gratefully acknowledge the award of an RSC Travel Grant: we have no doubt that the ability to offer our delegates travel bursaries contributed substantially to the Forum's success.

STEPHEN BALL and **WILLIAM BLOSS**

Atmospheric Chemistry Representatives on the EGC Committee

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 Sureprint, 1 Eastern Road, Haywards Heath, West Sussex RH16 3NG Tel: 01444 456673.

Discover our fascinating books in
Earth & Environmental Science



KEY TITLE

Globalization of Water
Sharing the Planet's Freshwater Resources

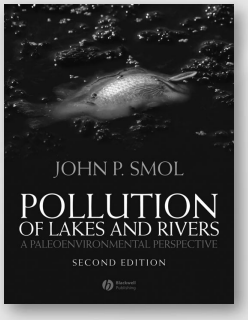
By Arjen Y. Hoekstra and Ashok K. Chapagain

"… an authorative and stimulating book to read…"

– South African Geographical Journal

ISBN: 978-1-4051-6335-4
Hardcover • 232 pages • 2007
£32.50 • $55.00 • €42.90

Also available online.
For further information, visit:
www.interscience.wiley.com/onlinebooks
OnlineBooks™ ISBN: 978-0-470-69622-4



SECOND EDITION

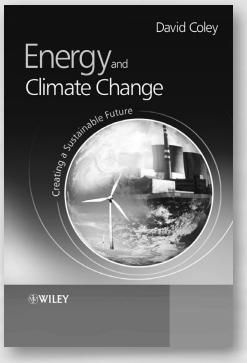
Pollution of Lakes and Rivers
A Paleoenvironmental Perspective

By John P. Smol

"… Simply put, the second edition is an excellent book."

– Journal of Phycology

ISBN: 978-1-4051-5913-5
Paperback • 396 pages • 2008
£32.50 • $55.00 • €42.90



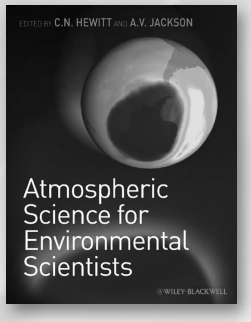
KEY TEXT

Energy and Climate Change
Creating a Sustainable Future

By David Coley

Features many worked problems, exercises, and a website containing additional material of use to lecturers and students.

ISBN: 978-0-470-85313-9
Paperback • 672 pages • 2008
£34.95 • $60.00 • €44.90



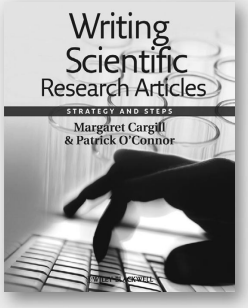
NEW

Atmospheric Science for Environmental Scientists

By C. Nick Hewitt and Andrea V. Jackson

Most up-to-date treatment of key issues such as stratospheric chemistry, urban air pollution, and climate change.

IISBN: 978-1-4051-5690-5
Paperback · 320 pages · 2009
£37.50 · $84.95 · €47.90



NEW – ESSENTIAL SKILLS

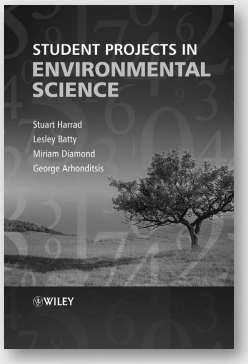
Writing Scientific Research Articles
Strategy and Steps

By Margaret Cargill and Patrick O'Connor

"… a most useful addition to the literature covering scientific writing."

– Aquaculture International

ISBN: 978-1-4051-8619-3
Paperback · 184 pages · 2009
£17.99 · $29.95 · €22.90



KEY TEXT

Student Projects in Environmental Science

By Stuart Harrad, Lesley Batty, Miriam Diamond and George Arhonditsis

Takes a case-study approach, and includes practical worked examples and self-assessment tasks.

ISBN: 978-0-470-84566-0
Paperback · 174 pages · 2008
£19.99 · $45.00 · €24.90

To view our entire collection of Earth & Environmental Science books, visit www.wiley.com/go/earthscience

ORDER YOUR COPIES NOW!

To read your step-by-step guide to our extensive range of **OnlineBooks™**, go to **www.interscience.wiley.com/onlinebooks-lifesci**

WILEY-BLACKWELL

05951