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Persistent Chemical Pollutants

A legacy of persistent pollutants is widely distributed in the environment, increasing the potential for exposure of wildlife and humans. This POSTnote sets out the challenge this posed for regulators, current regulatory approaches and some of the emerging issues.

Overview

- Humans benefit from the use of chemicals, but a number of persistent chemicals have accumulated in the environment affecting wildlife and human health.
- Regulation has reduced levels of some persistent chemicals in the environment, but remaining levels of contamination in soils, sediments and waste may be of concern.
- Monitoring levels of persistent chemicals in wildlife has been critical in determining the extent of reductions. However, knowledge gaps remain in the understanding of the effects of human and wildlife exposure.
- After EU withdrawal, the UK will have to decide on approaches to managing risks from newly identified persistent and accumulative substances.

Background

A range of substances that persist in the environment can accumulate in organisms as they are difficult to metabolise and excrete (bioaccumulation). When these organisms are eaten, the substances increase in concentration as they travel up food chains (biological magnification). These include:

- Persistent organic pollutants (POPs); chemicals with a particular combination of properties that resist environmental degradation, have low solubility in water, accumulate in the fat or organs of organisms and have a range of toxic effects.[1]
- Potentially toxic metals (PTMs); such as mercury and lead, bind to proteins and are deposited in the tissues of organisms and may induce toxic effects.[2] PTMs occur naturally in geological deposits, but human activity is responsible for the majority of forms and concentrations that are present in the environment.[3,4]

In the late 1960s, a number of POPs were shown to accumulate in food chains and subsequently to cause adverse effects in both humans and wildlife.[5] These were highlighted by events such as the 1968 Yusho incident, a mass poisoning caused by cooking oil contaminated with polychlorinated biphenyls (PCBs),[6] and the 1969 mass mortality event of guillemots in the Irish Sea that had high levels of PCBs in their livers.[7] Although regulation has reduced the risk of widespread POP release, new risks continue to emerge and there are health and environmental effects of chemicals that have yet to be addressed.[8] The 2017 Chief Medical Officer's Report highlighted the adverse effects of chemical pollution on human health.[9] The 2017 Lancet Commission on pollution and health suggested that the effects on human health have been underestimated and more testing of chemicals for health hazards is required.[10] In addition to hazard testing,[11] regulatory chemical risk assessments also consider the likelihood of exposure and the probability of adverse effects occurring.[12] This POSTnote summarises the frameworks under which POPs and PTMs are regulated, assessing the legacy of contamination from historic emissions and emerging challenges for regulators.

Regulating Persistent Substances

The 2004 UN Stockholm Convention on Persistent Organic Pollutants requires parties to eliminate, restrict or reduce emissions of the 28 chemicals classified as POPs (Box 1). A number of other UN Multilateral Environmental Agreements (MEAs) on the production, distribution, use and disposal of hazardous chemicals also regulate PTMs, such as mercury and lead. These include: the Rotterdam Convention; the Basel Convention; the Aarhus Protocol to the UNECE Convention on Long-range Transboundary Air Pollution; and, the Minimata Convention on Mercury.[13] There are also international programmes that promote safe chemical management, including:

Box 1. Persistent Organic Pollutants (POPs)

The 12 chemicals initially classified as POPs include: pesticides, such as Aldrin; industrial chemicals, such as PCBs (Box 2); and unintentional by-products from combustion, such as dioxins.[14] Food is the main route of human exposure and POPs have a range of toxic effects on the liver, kidney and nervous, reproductive and immune systems and can cause cancer.[15] [16] EU regulations set maximum acceptable levels for some POPs (such as dioxins and PCBs) in food;[17] the Food Standards Agency undertakes targeted studies on levels in the UK food supply,[18] and provides funding to Local Authorities for testing. POPs have become widely distributed in the environment,[19,20] particularly in soils.[21] Predatory species accumulate higher levels of POPs than the organisms they prey on, harming populations of species at the top of food chains (apex predators).[22] For example, the decline in otter populations was traced back to the toxic effects of organochlorine pesticides.[23] The potential for long range environmental transport is also a characteristic of POPs, which can be emitted from soil to air and water through natural processes and then transported and deposited in areas with cold temperatures. Levels of a number of POPs are increasing in the Arctic.[24,25,26]

An additional 16 substances have been listed under the Stockholm Convention as POPs.[27] Some differ in their properties from the original 12 POPs and data on them may be more limited:

- Perfluorooctane sulfonic acid binds to proteins in blood cells.[28] Other perfluorinated chemicals are being considered for listing under the Convention,[29] but data are lacking on whether exposure levels could lead to adverse health effects,[30] such as endocrine disruption (Box 5). Studies suggest they may affect body weight regulation and neurological development of foetuses.[31,32,33]
- Primary exposure to the three brominated flame retardants listed as POPs may be via house dust, indoor air or consumer products, but data remains limited.[34,35] Studies suggest these compounds are endocrine disruptors affecting the thyroid.[36,37] A meta-analysis of levels of brominated flame retardants in the UK environment suggested most now resides in soils, but a substantial proportion may either have been degraded, transported away or still be in products and/or waste (Box 3).[35]
- Short-chain chlorinated paraffins (SCCPs) are manufactured as complex mixtures and have a range of uses from lubricants to plasticisers. SCCPs were placed on the candidate list as a substance of very high concern under REACH (see below) because of their persistent properties. Their use is restricted under the EU POPs Regulation and are listed under Annex A of the Stockholm Convention. However, they can still enter the EU market in formulations of imported products.[38,39,40,41,42]

- The International Programme on Chemical Safety, which has evaluated chemicals of major public health concern since the 1970s.[43]
- The Strategic Approach to International Chemicals Management, a global chemicals policy framework.[44]

EU and UK Regulation

Historically, chemicals regulation that controlled health hazards was separate from that for environmental hazards, but these have now been brought together in the EU's legislative framework.[45] A recent assessment of 60 years of EU chemicals legislation has estimated its social and economic benefits at tens of billions of Euros per year. Benefits include a reduction in healthcare costs and environmental damage and an increase in productivity.[8] For example, uses of POPs are restricted under EU Regulation 850/2004 on Persistent Organic Pollutants, which was amended in 2010 after additional substances were added to the Convention.

The EU is amending the POPs Regulation to assign an advice role to the European Chemicals Agency (ECHA) and aligning it with other legislation including the regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH, EC 1907/2006, see CBP-7681).[46,47] The three core actions of REACH are: gathering information on chemicals, improving the understanding of chemical safety and controlling dangerous chemicals. To provide data on chemicals' properties, companies are required to carry out tests on chemicals manufactured or imported above the one tonne threshold.[48] Chemicals with persistent and bioaccumulative properties may be listed as Substances of Very High Concern under REACH.[49]

To assess progress against the UK National Implementation Plan (required by the Convention),[50] there are a number of inventories that provide accounts for human emissions of persistent substances, such as the national atmospheric emissions and POPs multi-media emissions inventories.[51,52] There are also networks to monitor the levels of some POPs and PTMs, including the Toxic Organic Micro-Pollutants (TOMPS) programme and heavy metal networks.[53,54] In its 25 Year Environment Plan, the Government has committed to reducing the levels of harmful chemicals entering the environment, including eliminating POPs emissions.[55]

Assessing the Legacy of Contamination

Inventory data shows that UK POPs and PTM emissions have declined markedly since the 1980s and 90s,[50,56] but pollution from previous emissions will persist in soils, aquatic sediments and waste for many years. For example, PCBs are having detrimental effects on marine mammals in European waters (Box 2).[57,58] The POPs inventory data also show that while overall emissions have decreased, diffuse pollution sources are contributing a greater proportion, such as the open burning of waste. For example, polychlorinated naphthalenes (PCNs) are POPs that were manufactured in the UK until the mid-1960s. A study of archived UK soils showed a decline in overall PCN levels from a peak in the 1950s apart from an increase after 1970 in the types of PCNs produced as a combustion by-product.[59] Landfilled waste and recycled materials contaminated with persistent substances are also diffuse pollution sources contributing to emissions of POPs (Box 3).[60]

The Stockholm Convention's Global Monitoring Plan (GMP) of ambient air, human samples and water suggests that regulation has been successful in reducing levels of POPs in the environment.[61] Other monitoring data for persistent substances are collected to meet various international, EU and UK requirements, with the EU Information Platform for Chemical Monitoring providing a coordinated approach to this data.[62] This includes: monitoring for the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the EU Water Framework Directive (WFD), and wildlife and human biomonitoring schemes.

Measurements of POPs and PTMs for OSPAR

Monitoring under the OSPAR Convention (implemented via the EU Marine Strategy Framework Directive) includes POPs, such as PCBs and brominated flame retardants (Box 1), as well as various PTMs. Measurements focus on

Box 2. Polychlorinated Biphenyls (PCBs)
PCBs were often manufactured as a complex mixture that remains challenging to analyse (there are 209 PCB formations, known as congeners).[63] PCBs were sold in the UK until 1981, most commonly as heat exchange fluids in equipment, but were also used in products such as building materials.[64] Seven congeners, including one of the 12 that show toxic activity similar to that of dioxins,[65] are the focus of monitoring programmes in the EU.[66] The major source of PCB emissions is from electrical equipment, such as transformers. Emissions have fallen significantly in the UK since 1980,[67] but almost 350,000 items of registered PCB-containing equipment were still in use in 2016.[50] UNEP has raised concerns about the slow rate of elimination of these known 'closed' sources in Europe,[68,64] but the UK Government has committed to eliminating such sources of PCBs by the Stockholm Convention 2025 target.[55]

The UK has also committed to undertake research on the contribution of its unknown sources,[50] such as PCBs from materials in buildings and landfilled waste.[69,70,71,64] Levels of most PCB congeners are declining, but still persist at high levels in estuarine and coastal habitats.[72] Studies suggest that relatively high concentrations of PCBs still persist in fish in the Thames.[73,74,75] PCBs also occur in high levels in top marine predators; such as sea eagles, seals, whales and dolphins; in the Northeast Atlantic and Mediterranean.[76] For example, in 2017 a killer whale found dead on the Isle of Tiree in Scotland contained among the highest levels of PCBs ever recorded, which were linked to its infertility.[77,78] The population that it was part of is likely to die out.[79] Research suggests that the majority of PCBs emitted have been transported away from the UK and most of the remaining contamination resides in soils (Box 1).[80] Human exposure through food such as oily fish has declined to an estimated 70% of Tolerable Daily Intake,[81] but PCBs still occur in some products, such as paints, inks and textiles, as a by-product of pigment production.[82]

marine sediments and the organisms in which these contaminants tend to accumulate. Although overall contamination is decreasing, levels of cadmium are increasing locally in some areas of the North-East Atlantic and in other areas mercury and lead remain high.[83]

Environmental Quality Standards

The WFD lists 'priority substances' that include POPs and PTMs, for which environmental quality standards (EQS) are set. Persistent substances with low water solubility contaminate sediments and will concentrate in bottom feeding aquatic organisms, and then may build-up in food chains. EQS for organisms are set at low values on the basis of 'worst case' assumptions to protect the environment and humans.[84,85] Defra published a report on developing an evidence base of the extent of contaminated sediment in England in 2017.[86] High levels of PTM contamination have been found in some river catchments in north east (zinc, cadmium, copper and lead), and south west (arsenic, copper and tin) England.[86] A recent risk analysis of 71 chemical substances polluting UK Rivers suggested that metals may pose the greatest risk to freshwater wildlife.[87]

Under the EU Environmental Quality Standards Directive, the UK keeps inventories of priority substances and their releases into water.[50] Soils may be a source of priority substances, with urban soils being the most contaminated.[88] Some waste streams applied to agricultural soils,[89] such as paper sludge, poultry litter ash and sewage sludge, may also contain priority substances, including POPs.[90,91] Studies estimate that 6.24% of agricultural soils in Europe may have high levels of PTM contamination.[92] In the UK, there are an estimated 400,000 hectares of chemically contaminated land.[100] Comprehensive assessments of the human health effects of most forms of soil pollution have not yet been published, with the exception of lead (Box 4).[10]

Box 3. Contamination of Products and Recycled Waste
The UK is a signatory of the EU Rapid Alert System for dangerous non-food products (RAPEX), which facilitates information sharing between member states, including on products containing banned substances.[93] The Environment Agency's Chemical Compliance Team monitors and enforces restrictions on chemicals in products that pose environmental risks. For example, lead, cadmium, mercury, chromium and hexachlorobenzene (a POP originally used as a fungicide) have been found in fireworks imported into the EU,[94] and were the focus of a 2013 campaign. In January 2018, BEIS created the Office for Product Safety and Standards, a national oversight body tasked with identifying consumer risks, such as from restricted chemicals.

Products containing recycled materials may pose POP and PTM risks.[60] For example, an analysis in the Netherlands found that 22% of the brominated flame retardant POPs in waste electrical and electronic equipment end up in recycled plastics.[95] Other studies have found them in recycled plastic items on the EU market, such as toys.[96,97] Article 6 of the Stockholm Convention bans the recycling of POPs, but there is an exemption that allows the recycling of plastics and foams containing POPs until 2030. To comply with EU Regulation 850/2004 on POPs, items should have a 'low POP content limit' of less than 0.1% by weight.[98] EU waste legislation also sets out producer responsibility and rules on management of waste.[99] For example, the Directive on electrical and electronic waste imposes an obligation on manufacturers and importers of products to make relevant information on the presence and location of hazardous substances in their products available to recyclers.

Monitoring Wildlife and Human Exposure

Information on hazards posed by chemicals is combined with data on their supply volumes, use and fate in the environment to assess risks. Data from monitoring can also be used to estimate exposure. Exposure can be divided into external (the total environmental dose an organism is exposed to) and internal (the dose absorbed and distributed throughout the body).

Monitoring 'sentinel' wildlife species, such as birds of prey that hunt over relatively large areas and are comparatively long lived, provides a measure of internal exposure over time and a geographic area. The long-term UK predatory bird scheme monitors regulated chemicals; such as POPs, mercury, and lead; in the livers and eggs of selected species of predatory and fish-eating birds and otters.[101] Similarly, the UK Cetacean Strandings Investigation Programme monitors POPs levels in stranded porpoises, dolphins and whales.[78]

Human internal exposure to persistent substances can be monitored in breastmilk and blood. For example, the WHO/UNEP Human Milk survey showed declining trends in POPs exposure in Europe between 1987 and 2011.[102] The US National Health and Nutrition Examination Survey has collected blood samples since the 1980s for human biomonitoring.[103] These data suggest that levels and patterns of human exposure vary with socioeconomic status,[104] geographic location,[105] diet, age and body mass index.[106,107,108] The UK is participating in a Horizon 2020 project to co-ordinate a similar human biomonitoring initiative across 28 countries. Priorities include

Box 4. Effects of Lead Exposure
Lead is considered a 'non-threshold' substance; this means no known safe blood concentration of lead can be established.[109] Before its use was regulated in the 1970s, humans were mainly exposed through vehicle emissions, contaminated soil, indoor and outdoor dust, food and other sources such as paint. Although lead production has increased since the 1970s,[110] population exposure has declined.[111] Blood lead levels in UK children fell from 140—360 micrograms (µg) per decilitre (dl) in 1964 to around 37 µg/dl in 1991–2 and have fallen further since.[9] Lead can affect children's brain development, and can cause anaemia, kidney impairment, damage the immune and reproductive systems and cause cardiovascular disease.[112,113,114] A recent study in the US, based on human biomonitoring data of lead in blood, has suggested there are still 400,000 deaths per year attributable to the effects of lead exposure. This was because lower concentrations of lead in blood than previously assumed (less than 5 µg/dl) could be linked to cardiovascular disease deaths.[115]

A British Geological Survey study has estimated that urban areas in England still have a 'normal background concentration' of lead of 820 mg/ kg of soil.[116] This is higher than the Category 4 Screening Levels used to classify whether residential land is contaminated (200–310mg/kg).[117] A number of rivers are also affected by diffuse lead pollution from contaminated floodplains and old mine workings.[86] Floods can re-suspend contaminated sediments, depositing them on floodplains,[118] as occurred in 2012 in a Welsh catchment contaminated by historical mining activities leading to lead poisoning of livestock.[119] In the UK, the Environment Agency and Natural Resources Wales have programmes of remediation measures to stop metal pollution from abandoned mines affecting rivers.[120,121 122] Technologies exist for remediating PTM-contaminated soils that are a source of diffuse pollutants,[123] but the options may be pragmatically limited by cost or if areas have extensive built urban infrastructure. Requirements for identifying and remediating contaminated land are set out by the Environmental Protection Act 1990.[124]

perfluorinated substances, brominated flame retardants (Box 1) and the PTM's cadmium and chromium VI.[125]

Emerging Challenges
Access to Data on Persistent Substances
The Government will publish a Chemicals Strategy setting out the regulatory framework after EU withdrawal.[55] To trade with the EU, the UK will have to comply with chemicals regulations on imports (REACH and the Classification, Labelling and Packaging Regulation) and exports (the Prior Informed Consent Regulation).[126] The UK Competent Authority (HSE with EA on environmental aspects) takes part in evaluations of the data and decision-making at the European Chemicals Agency (ECHA) on persistent and bioaccumulative chemicals. The UK is seeking 'associate membership' of ECHA after EU withdrawal to have access to data and contribute to evaluation, as Norway does.[127] However, the UK will not have voting rights and decisions can be controversial.[128]

Increasing Complexity
Technological improvement and new approaches could increase the amount of evidence available,[9] but demand for this would need to be driven by regulatory frameworks. Examples include new analytical techniques that can detect chemicals in the environment at ever lower concentrations, and the 'lifecycle epidemiology' approach that seeks to understand the effects of all types of exposure from conception onwards.[129] Referred to as 'exposomics',[130] this approach combines data on a human individuals' exposure to chemicals,[131] with their biological responses using techniques such as proteomics (the protein responses) and metabolomics (metabolite responses).[132] However, interpretation of such data can be challenging.[133]

Limitations and Uncertainties in Evidence
Limitations and uncertainties in evidence on persistent chemical risks has created challenges for defining safe levels of exposure.[45] Even when testing has demonstrated adverse outcomes knowledge gaps remain about how chemicals interact with biological systems, such as whether exposure to mixtures could result in a combined effect.[134,135] For example, some POPs such as dioxins are emitted as a complex mixture of chemical forms, to which is assigned a 'toxicity equivalence factor' for each form to allow the effects of a given mixture to be estimated.[136] However, such data are sparse and regulation remains on an individual substance basis. There is ongoing EU and UK research projects on mixture toxicology.[137,138] Adverse outcomes may also arise from a combination of factors and stressors, creating complexities for apportioning the effects of chemical exposure. Some commentators suggest weight of evidence approaches, using the available data, systematic review and meta-analyses to determine whether harmful effects are occurring (Box 5).[139,140,141] However, others argue that substances should be proven to be safe before their use is allowed, rather than risk based approaches.[142]

As monitoring resources are finite, it can be argued that monitoring wildlife to identify new risks should be a greater priority. However, commentators have highlighted that without better knowledge and monitoring of species' populations and their natural fluctuations, it is challenging to arrive at definitive answers on harmful effects of chemicals.[143] The challenge of understanding wider ecological risks has also been highlighted.[144,145,146] For example, effects on groups of species interacting in a habitat, such as soil micro-organisms; or on the benefits arising from natural processes (ecosystem services), such as soil fertility. While there is limited evidence from research studies, commentators suggest that levels of persistent chemicals in the environment may also be affected by climate change. For example, more extreme weather events may re-mobilise substances in sediments and soils, and rising temperatures may increase levels of POPs emitted from soil to air or rates of their degradation (Box 1).[147,9]

Box 5. Identifying Endocrine Disruptors (EDCs)
Endocrine disruptors (EDCs) are substances that have adverse effects on the functions of organisms' hormonal systems. EU legislation on pesticides and biocides for identifying EDCs requires a 'weight of evidence approach' (interpreting and assessing the available body of evidence) to establish a link between how a chemical interacts with the endocrine system of an organism and its subsequent effect.[148] ECHA and the European Food Safety Authority (EFSA) recently published guidelines for identifying EDCs,[149] but many chemicals have not been tested for EDC properties and there are uncertainties about ecological and human health effects.[150,151]

Endnotes
1 Science for Environment Policy, 2017, *Persistent organic pollutants: towards a POPs-free future: Future Brief 19*. Brief produced for the European Commission.

2 Peralta-Videa, J, *et al*, 2009, *The International Journal of Biochemistry & Cell Biology*, 41, 1665–1677
Nieder, R, Benbi, D, Reichl, F, 2018, *Role of Potentially Toxic Elements in Soils*, In: Soil Components and Human Health, Springer, Dordrech
3 More, A, *et al*, 2017, *GeoHealth*, 1, 211-219
4 EEA, 2011, *Hazardous substances in Europe's fresh and marine waters: An overview*, EEA Technical report No 8/2011
5 Carson, R, 1962, *Silent Spring*, Houghton Miffin Mariner Books
Jensen, S, Johnels, A, Olsson, M, Otterlind, G, 1969, *Nature*, 224, 247.
6 Koppe, J, and Keys, J, 2001, *PCBs and the precautionary principle*, In: Late Lessons from Early Warnings: the precautionary principle 1896-200, Edited by David Gee, European Environment Agency
7 Holdgate, M, 1971, *The Seabird Wreck of 1969 in the Irish Sea*, NERC.
Holdgate, M, 2003, *Penguins and Mandarins*, The Memoirs of Martin Holdgate
8 European Commission, 2017, *Study on the cumulative health and environmental benefits of chemical legislation*, Amec Foster Wheeler Environment & Infrastructure UK Limited
9 Annual Report of the Chief Medical Officer 2017, *Health Impacts of All Pollution - what do we know?*
10 Landigran, P, *et al*, 2017, *The Lancet Commission on pollution and health*,
11 OECD and EU test guidelines
12 Agerstrand, A and Beronius, A, 2016, *Environment International*, 92-92, 590-596
13 UNEP, the Minamata Convention on Mercury
14 Stockholm Convention, The 12 initial POPs under the Stockholm Convention
15 Stockholm Convention, What are Pops
Leng, L, *et al*, 2016, *Environment International*, 88, 133–141.
Ellsworth, R, *et al*, 2015, *Environmental Research*, 138, 291–297
IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, 2015, *Polychlorinated Biphenyls*
Skakekkebaek, N, et al, 2016, *Physiological Reviews*, 96 (1), 55-97
16 Chiesa *et al*, 2016, *Chemosphere*, 153:162-169
17 Regulation (EC) 1881/2006 on setting maximum levels for certain contaminants in food as amended by Regulation (EC) 1259/2011 establishes maximum acceptable levels for dioxins, furans, dioxin-like PCBs and non-dioxin-like PCBs in food.
18 Food Standards Agency, Persistent Organic Pollutants
19 Bartrons, M, *et al*, 2016, *Scientific Reports*, 6, Article number: 2544
20 Lake, I, *et al*, 2014, *Sci Total Environ*, 491-492, 184-191
21 Schuster, J, *et al*, 2011, *Changes of Persistent Organic Pollutants in Atmospheric Concentration and Soil Load in the UK and Norway over 10 Years*, In: Interdisciplinary Studies on Environmental Chemistry - Environmental Pollution and Ecotoxicology, Eds., Kawaguchi, M, *et al*.
22 Barni, M, *et al*, 2016, *Science of The Total Environment*, 550:900-909
Ratcliffe, D, 1967, *Nature*, 215, 208-210
Beyer, J *et al*, 2014, *Mar. Environ. Res*., 96, 81-91
Beckvar, N, *et al*, 2005, *Environ. Toxic. Chem*., 24, 2094-2105
Uchida, M, *et al*, 2010, *J. Toxicol*. Sci., 35, 605-608
23 Mason, F, and MacDonald, S, 1993, *Science of The Total Environment*, 138 (1-3), 127-145
24 Macdonald, R. W., Harner, T. & Fyfe, J. *Sci. Total Environ*. 342, 5–86 (2005).
25 Vorkamp, K et al, 2015, *Environmental Pollution*, 196, 284-291
26 Pacyna, J *et al*, 2015,. *Environmental Science and Policy* 50: 200-213
27 Stockholm Convention on Persistent Organic Pollutants (POPs), 2017, *The 16 New POPs*
28 Ng, C and Hungerbühler, K, 2014, *Environmental Science and Technology*, 48 (9): 4637–4648
Conder, J, et al, 2008, *Environmental Science and Technology*, 42:995-1003
29 Stockholm Convention, Thirteenth meeting of the Persistent Organic Pollutants Review Committee (POPRC.13)
30 US EPA, *Research on Per- and Polyfluoroalkyl Substances (PFAS)*
Annual Report of the Chief Medical Officer 2017, *Health Impacts of All Pollution - what do we know?*
Calafat, A, *et al*, 2007, *Environmental Health Perspective*, 115: 15
Schaider, L, *et al*, 2017, *Environmental Science Technology Letters*, 4:105-11
Begley, T, *et al*, 2005, *Food Additives and Contaminants*, 22:1023-31
Fromme, H, *et al*, 2009, *International Journal of Hygiene and Environmental Health*, 212 (3), 239-70
Olsen, G, *et al*, 2007, *Environmental Health Perspective*, 115:1298-305
31 Liu, G, *et al*, 2018, *PLOS Medicine*, 15(2): e1002502
32 Weiss, J, *et al*, 2009,*Toxicological Sci*, 109(2): 206-16
33 Rappazzo, K, *et al*, 2017, *Int J Environ Res Public Health*, 14(7): 691
34 Wattigney, W, *et al*, 2015, *Journal of Environmental and Public Health*
35 Harrad, S, 2015, *Emerging Contaminants*, 1: 39-53
36 Allen, J, *et al*, 2016, *Environ Health*, 15: 60
37 Oulhote, Y, *et al*, 2016, *Journal of Clinical Endocrinology & Metabolism*, 101 (2), 590–598
38 Van Mourik, L, *et al*, 2016, *Chemosphere*, 155, 415-428
39 Stockholm Convention, Short-chain chlorinated paraffins (SCCPs)
40 Miller, P, and DiGangi, J, 2017, *Toxic industrial chemical recommended for global prohibition contaminates children's toys*, IPEN
41 Gluge, J, *et al*, 2016, *Science of The Total Environment*, 573, 1132-1146
42 Article 7(2) and 33 of REACH Regulation (EC) No 1907/2006
43 International Programme on Chemical Safety
44 Strategic Approach to International Chemicals Management
45 Hazardous Substances Advisory Committee, 2013, *Hazard and Risk Assessment of Substances*: The HSAC approach.
46 Regulation (EC) No 1907/2006, Article 58(3)
47 Explanatory Memorandum for European Legislation 7470/18
48 OECD and EU test guidelines
49 Management of PBT/vPvB substances under REACH
Annex XIII of Regulation (EC) No 1907/2006
50 HM Government, 2017, *National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants*
51 National Atmospheric Emissions Inventory
52 Defra, 2016, A further update of the UK's Persistent Organic Pollutants Multi-media Emissions Inventory, Amec Foster Wheeler Environment and Infrstructure UK Ltd
53 The Toxic Organic Micro-Pollutants (TOMPs) network
54 The Heavy Metals Network
55 HM Government, 2017, A Green Future: Our 25 Year Plan to improve the Environment
56 Brown, R, *et al*, 2010, *Annual Report for 2009 on the UK Heavy Metals Monitoring Network*
57 Jepson, P, *et al*, 2016, *Scientific Reports,* 6, Article number: 18573
58 Jepson, P and Law, R, 2016, *Science*, 352 (6292): 1388-1389
59 Meijer, S, *et al*, 2001, *Environ. Sci. Technol*., 35 (21), pp 4205–4213
60 Bernard, A, and Buonsante, V, 2017, *Keeping it Clean: How to protect the circular economy from hazardous substances*, Client Earth and the European Environmental Bureau
61 Magulova, K and Priceputu, A, 2016, *Environmental Pollution*, 217: 82-84
62 European Commission, Information Platform for Chemical Monitoring
63 Megson, D, *et al*, 2013, *Journal of Chromatography A*, 1318: 276-283
64 Stuart-Smith, S and Jepson, P, 2017, *Marine Policy*, 84, 69-75
65 Ahlborg, U, *et al*, 1994, *Chemosphere*, 28: 1049–-1967
66 Ghandi, N, et al, 2014, Environ. Sci. Technol. 49, 1, 123-131
67 http://naei.beis.gov.uk/overview/pollutants?pollutant_id=45
68 UNEP/DTIE, 2016, *Consolidated Assessment of Efforts made Toward the Elimination of Polychlorinated Biphenyls*
69 Johansson, N, et al, 2003, *Organohalogen Compounds* 63, 381-384
70 https://www.pcbinschools.org/-pcbs-in-caulk-studies
71 Law, R, and Jepson, P, 2017, Science, 365 (6334), 148
72 Nicolaus, E, *et al*, 2015, *Marine pollution bulletin*, 95 (1), 469-479
Bjurlid, F, et al, 2018, *Science of The Total Environment*, 616–617, 1374-138
EEA, 2011, Hazardous substances in Europe's fresh and marine waters: An overview, EEA Technical report No 8/2011
Hutchinson, T, *et al*, 2013, *Mar Pollut Bull*,74(2):517-25
73 Lu, Q, *et al*, 2015, Science of the Total Environment 533: 187-195
74 Nicolaus, E, *et al*, 2015, *Marine Pollution Bulletin* 95: 469-479
75 OSPAR, Status and Trends of Polychlorinated Biphenyls (PCB) in Fish and Shellfish
76 Jepson, P and Law, R, 2016, *Science*, 352 (6292): 1388-1389
Jepson, P, et al, 2016, *Science Reports*, 6, Article number: 18573
ICES, 2016, *Report of the Working Group on Marine Mammal Ecology*
77 BBC News, 'Shocking' levels of PCB chemicals in UK killer whale Lulu
78 UK Cetacean Strandings Investigation Programme
79 BBC News, A last refuge for Europe's blighted killer whales
80 Harrad, S, *et al*, 1994, *Environmental Pollution*, 85(2), 131-46
81 Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment, 2010, *Occurrence of mixed halogenated dioxins and biphenyls in UK food: preliminary results*
82 Guo, J, *et al*, 2014, *Environ. Sci. Technol*., 48 (15), pp 8573–8580
Hu, D, and Hornbuckle, C, 2010, *Environ. Sci. Technol*., 44 (8) 2822-2827
Lehmann, G, *et al*, 2015, *Environmental Health Perspectives*, 123(2), 109-113
83 OSPAR Annual Report 2017
84 EC, 2011, Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Guidance Document No. 27, Technical Guidance For Deriving, Environmental Quality Standards Technical Report - 2011 - 055
85 Sousa, J, *et al*, 2017, *Journal of Hazardous Materials*, 344, 146–162
86 Defra, 2017*, Developing an Evidence Base for In-Situ Contaminated Sediment in England*
87 Johnson, A, *et al*, 2017, *Science of the Total Environment*, 599–600 (2017) 1372–1381
88 Environment Agency, 2007, *UK Soil & Herbage Pollutant Survey*
89 Environment Agency, 2014, *Waste exemption: U10 spreading waste to benefit agricultural land*

Maximum Permissible Concentrations of Potentially Toxic Elements (PTE) in Soil after Application of Sewage Sludge to Agricultural Land & Annual Rates of Addition
90 Rigby, H, *et al*, 2015, *Agriculture*, 2015, 5, 1289-1328
Investigation of the Potential Transfer and Uptake of Contaminants into Food Arising From The Use of Recycled Waste in Agriculture
91 The Chemical Investigations Programme Phase 2, 2015-2020
92 Toth, G, *et al*, 2016, *Environment International*, 88, 299–309
93 EC, Rapid Alert System for dangerous non-food products
94 Chemical Watch, *Swedish Chemicals Agency publishes results of glove and firework investigations*
Chemical Legislation European Enforcement Network, 2012, *EUROPOP: Final report*
Schwarz, S, Knorr, A and Lohrer, C, 2014, *Journal of Pyrotechnics*, 33, 3-8
95 DiGangi, J, *et al*, 2017, *POPS recycling contaminates children's toys with toxic flame retardants*, IPEN
Leslie H, *et al*, 2013, IVM/IVAM Report: 13-16
96 Puype, F, *et al*, 2015, *Food Additives & Contaminants: Part A, Chemistry, analysis, control, exposure & risk assessment* 32: 410-426
97 Ionas, A, *et al*, 2014,*Environment International* 65: 54-62
98 Commission Regulation (EU) No 1342/2014 of 17 December 2014 amending Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes IV and V
99 Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries
Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles
Directive 94/62/EC of the European Parliament and of the Council on packaging and packaging waste
Directive 2012/19/EU on waste electrical and electronic equipment (WEEE)
100 Land remediation: Bringing brownfield sites back to use
101 Predatory Bird Monitoring Scheme
102 WHO Regional Office for Europe, 2015, *Human biomonitoring: facts and figures*
103 National Report on Human Exposure to Environmental Chemicals
104 Tyrell, J, *et al*, 2013, Environ Int, 59:328-35
105 Wattigney, W, *et al*, 2015, *Journal of Environmental and Public Health*
106 Thompson, M, and Boekelheide, K, 2013, *Environ Res*. 121: 23–30
107 Wood, S, *et al*, 2016, *Environ. Sci.: Processes Impacts*, 18, 1157-1168
108 Depledge, M, *et al*, 2013, *Marine Environmental Research* 83, 93-95
109 EFSA Panel on Contaminants in the Food Chain (CONTAM), 2010, *Scientific Opinion on Lead in Food*, EFSA Journal, 8(4):1570
110 International Lead Association. Lead uses—statistics
111 Landirigan, P, 2018, Lancet Public Health
112 WHO, Lead poisoning and health
113 Needleman, H, *et al*, 1979, *N Engl j Med*, 300: 689-95
114 Goodlad, J, *et al*, 2013, *Clin Psychol Rev*, 33(3):417-25
115 Lanphear, B, *et al*, 2018, *Lancet Public Health*, 3, No. 4, e177–e184
116 Ander, E, *et al*, 2013, *Science of the Total Environment* 454-455, 604–618
117 Defra, 2014, SP1010: Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination – Policy Companion Document
118 Brewer, P, and Taylor, M, 1997, *Catena* 30 (2–3), 229-249
Coulthard, T, and Macklin, M, 2003, *Geology*, 31 (5), 451-454.
119 Foulds, S, *et al*, 2014, *Science of the Total Environment*, 476–477 165–180
120 UK Government, Metal mine water treatment
121 Natural Resources Wales, Metal mine water pollution
122 Restoring Europe's Rivers, Case study:Force Crag Mine Remediation
123 Mahar, A, *et al*, 2015, *Pedosphere* 25 (4), 555-568
Bolan, N, *et al*, 2014, *Journal of Hazardous Materials*, 266, 141-166
CL:AIRE, Leading Sustainable Land Use
Khalid, S, *et al*, 2017, *Journal of Geochemical Exploration*, 182 (B), 247-268
Mahar, A, *et al*, 2016, *Ecotoxicology and Environmental Safety*, 126, 111-121
124 UK Government, *Guidance - Land affected by contamination*
125 HBM4EU priority substances
126 Regulation (EC) no 1272/2008 of the European Parliament and of the Council
Regulation (EU) no 649/2012 of the European Parliament and of the Council
127 Chemical Watch, Prime minister: UK to seek 'associate membership' of ECHA
128 E.g. Chemical Watch, Ipen says lead chromates authorisation is 'unlawful'
129 Vineis, P, *et al*, 2017, *International Journal of Hygiene and Environmental Health*, 220 (2), Part A, 142-151
130 The National Institute for Occupational Safety and Health (NIOSH), Exposome and Exposomics
131 Escher, B, *et al*, 2017, *Environment International*, 99, 97-106
132 Cui, Y, *et al*, 2016, *Environ Health Perspect*, 124(8): A137–A140
133 National Academies of Sciences, Engineering, and Medicine, 2017, *Using 21st Century Science to Improve Risk-Related Evaluations*
134 Heys, K, *et al*, 2016, RSC Adv, 6, 47844-47857
135 Kienzler, A, *et al*, 2016, *Regulatory Toxicology and Pharmacology*, 80, 321-340
Kienzler, A, *et al*, 2014, *Assessment of Mixtures - Review of Regulatory Requirements and Guidance*, JRC Science and Policy Reports
Bopp, S, *et al*, 2015, *Scientific methodologies for the combined effects of chemicals – a survey and literature review*
136 Van den Berg, M, *et al*, 2006, *Toxicol Sci*.;93(2):223-41. Epub 2006 Jul 7.
137 EuroMix
138 NERC, the Emerging Risks of Chemicals in the Environment programme
139 Hazardous Substances Advisory Committee, 2015, *Considering evidence: the approach taken by the Hazardous Substances Advisory Committee in the UK*.
140 Whaley, P *et al*, 2016, *Environment International*, 92-93, 556-564
141 Ågerstrand, M, and Beronius, A, 2016, *Environment International* 92-93, 590-596
142 Chemtrust, 2017, No Brainer, The impact of chemicals on children's brain development: a cause for concern and a need for action
143 Johnson, A and Sumpter, J, 2016, *Environmental and Toxicology and Chemistry*, 35 (7), 1609-1616
144 Hazardous Substances Advisory Committee, 2016, *HSAC paper on key research question in ecotoxicology*
145 Brown, A, *et al*, 2017, *Integrated Environmental Assessment and Management*; 13(1):17-37
146 EFSA Scientific Committee, 2016, *Guidance to develop specific protection goals options for environmental risk assessment at EFSA, in relation to biodiversity and ecosystem services*
147 UNEP/AMAP, 2011. *Climate Change and POPs: Predicting the Impact*
Jonsson, S, 2017, *et al*, *Sci. Adv.* 3:e1601239
LeMonte, J, *et al*, 2017, *Environmental Science and Technology*, 51(11): 5913-5922
148 Commission Regulation (EU) 2018/605 of 19 April 2018 amending Annex II to Regulation (EC) No 1107/2009 by setting out scientific criteria for the determination of endocrine disrupting properties
149 Guidance for the identification of endocrine disruptors in the context of Regulations (EU) No 528/2012 and (EC) No 1107/2009
150 Fuhrman, V, *et al*, 2015, *Journal of Hazardous Materials*, 286, 589-611
151 Windsor, F, *et al*, 2017 *Biological Reviews*