An Overview of Aquatic Pollutants Arising from Highway Run-off

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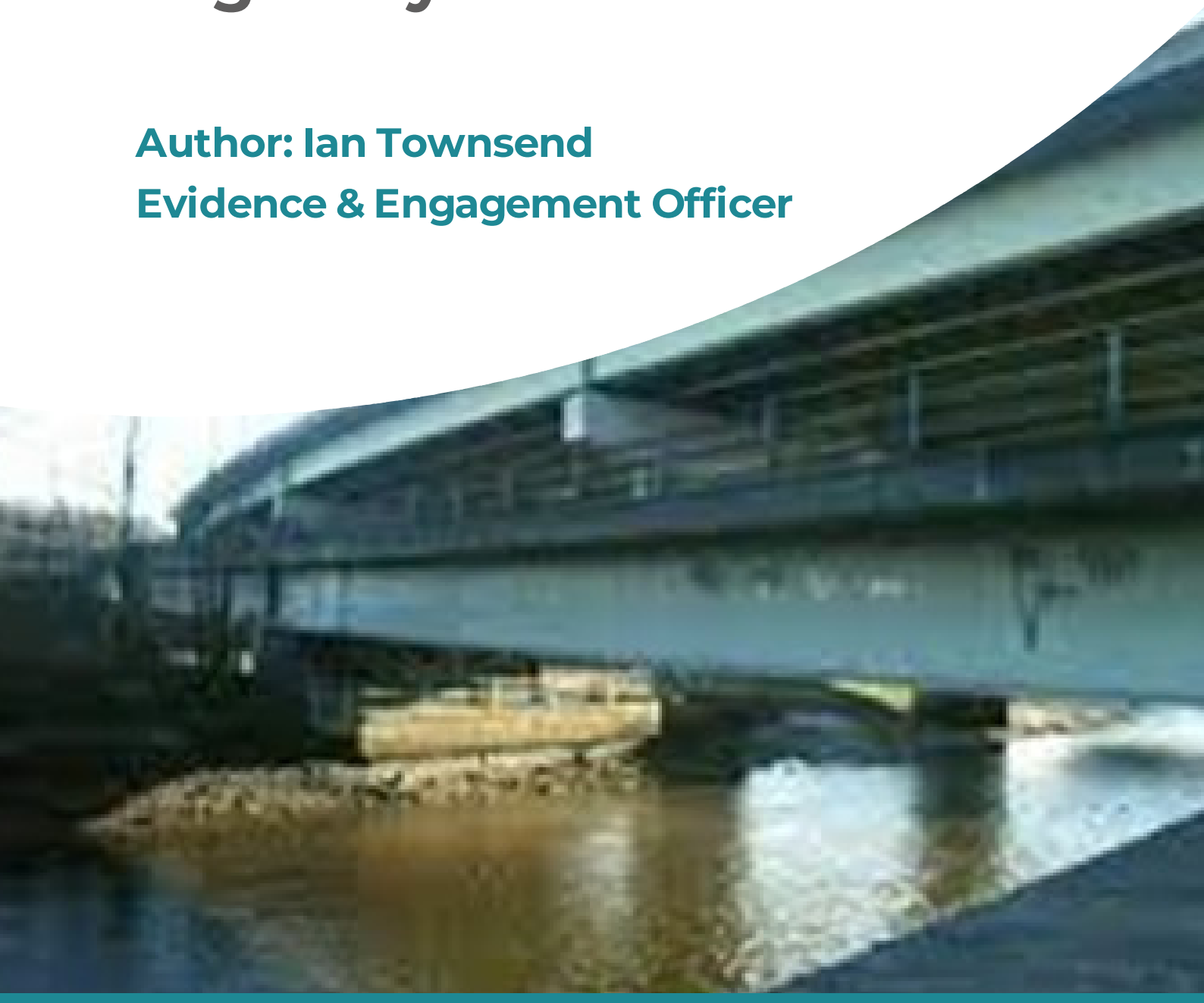

AUGUST 2021

WESTCOUNTRY RIVERS TRUST

1. INTRODUCTION

A recent estimate indicates that the total length of the road network within Great Britain is close to a quarter of a million miles (Dept of Transport, 2019). The South West has the most extensive network of any area totalling over 31,000 miles. This therefore represents a major source of potential pollution for the region's waterbodies and on a national basis, the Environment Agency has identified pollution from urban/transport related sources as a contributing factor in 13% of failures to attain 'Good' ecological status under the Water Framework Directive (WFD).[1]

Highways-derived pollution can originate either by direct run-off from the road surface into adjoining waterbodies or indirectly via the local surface water drainage network. 'First Flush' events, in which storms or heavy downpours follow prolonged dry spells, can be particularly damaging to aquatic life as they typically result in markedly elevated concentrations of pollutants in receiving watercourses. This phenomenon appears to be increasing in frequency as a result of on-going climate change.

Pollutants derived from highways are multifarious originating not only from vehicles but also from the road surface itself. Vehicles generate debris derived from brake pads and tyres as well as particulates from exhaust emissions and leakages of oils, whilst the road surface can produce leachates from both tarmac and paints used in road markings. Furthermore, pesticides used for roadside weed control and rock salt and other de-icing materials represent significant episodic sources of pollution.

This document identifies the principal classes of pollutant arising from roads, outlines their respective potential for adverse ecological effects and briefly discusses their attenuation in the environment and during water treatment. The accompanying references provide more in-depth information if required.

Run-off from a road network totaling almost a quarter of a million miles exerts significant pressure on UK watercourses.

2. PRINCIPAL CLASSES OF ROAD RUN-OFF POLLUTANTS

Heavy Metals

A number of heavy metals commonly occur at environmentally damaging levels in the particulate matter transported into waterbodies from roads. Copper and zinc are ubiquitous in dust generated by brake pad wear and are often present in tyre debris whilst the platinum group metals ('PGMs' including platinum, palladium and rhodium) commonly occur due to losses from catalytic converters present in many vehicle exhaust systems.

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Dust generated by the wear of vehicle brake pads is a major source of heavy metals such as copper and zinc in road run-off.

Lead is now less of an issue since the adoption of lead-free petrol and the banning of its use in wheel balancing weights. The bioavailability and, therefore, toxicity of many metals in aquatic bodies is markedly influenced by the chemical form in which they are present and by factors such as pH, hardness & dissolved organic carbon content (DOC) – elevated levels of the DOC can significantly lower bioavailability.

Copper is one of the most toxic elements in the aquatic environment and in soft waters of the type prevalent in SW England, it is acutely toxic to many freshwater fish at concentrations as low 10-20µg/L. It is also highly toxic to unicellular algae, zooplankton, invertebrates and shellfish/molluscs[2,3].

Zinc is an essential trace element in many aquatic organisms but whilst plant species are generally fairly tolerant to elevated concentrations, in soft, low DOC waters fish become stressed above about 100µg/L zinc due to the suppression of calcium uptake.

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Some molluscs, insects & crustaceans can also be adversely affected at concentrations well below this [4]. There appears to be relatively little published data on the mobility, solubility and aquatic toxicity of PGM containing particulates. Their speciation (and therefore toxicity) in freshwaters is complex. Palladium has the highest solubility but platinum the highest toxicity - there is evidence of adverse effects on daphnia reproduction and fish health from ~15 µg/L upwards - and the growth of some macrophytes can be impaired by platinum or palladium levels of around 2000 µg/L. PGMs have been shown to readily accumulate in biota [5].

Metal laden dust is likely to accumulate on the beds of waterbodies receiving direct discharges of road run-off and benthic organisms may be adversely affected. Dependent on the prevailing aquatic chemistry, toxic metals may subsequently be re-mobilised. Particulate heavy metals are readily removed by standard drinking water treatment processes (coagulation/flocculation) but soluble material may require specialist (expensive) techniques for effective removal. Dependent upon the process used, during wastewater treatment heavy metals will partition between effluent and sludge with potential toxic impacts on receiving waters and farmland used for solids disposal.

Spraying of pavements, kerbs, footpaths and roadside verges can result in periodic pollution of adjoining rivers and streams with pesticides.

Pesticides

Herbicides are widely applied by local authorities and highways agencies to combat weed growth on pavements, footpaths, kerbs and roadside verges. Run-off or direct over-spraying into surface drains is therefore inevitably prevalent. The most recent available data on UK amenity pesticide use [6] indicates that in 2016, nationally, a total of 11.6 tonnes of herbicide active substances were applied in road-related situations. This primarily comprised glyphosate (90%) plus a significant mass of 2,4-D (9%) and minor amounts of other acid herbicides such as dicamba, MCPA & mecoprop-P.

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Glyphosate ('Round Up') is a highly controversial compound cited by some as being a significant environmental pollutant and possible human carcinogen. It is applied on a huge scale to provide total weed control and despite the fact that it binds to hard surfaces and particulate matter and is rapidly degraded (principally to AMPA), spray drift and accidental over-spraying of both watercourses and surface water drains can result in occasional significant concentrations in rivers and streams.
Glyphosate exhibits moderate acute (short term) toxicity to fish, aquatic invertebrates & crustaceans and moderate chronic (long term) toxicity to fish. Chronic toxicity to aquatic invertebrates and both acute and chronic toxicity to algae is categorised as low [7]
No information is provided regarding toxicity to sediment dwelling organisms, possibly because the compound rapidly degrades on contact with the riverbed. The compound is very effectively removed by even the most basic water treatment processes.

2,4-D ('Esteem, Killex, Tordon 101') is a selective herbicide used to control broad-leaved weeds. In common with many other acid herbicides, it is highly water soluble, fairly persistent in water and mobile in the environment.
It is categorised as moderately toxic on both an acute & chronic basis to mammals and on an acute basis only to fish and aquatic plants.
Toxicity to algae and aquatic inverts is low[8]. Significantly though, the acute toxicity of 2,4-dichlorophenol, one of the principal breakdown products of 2,4-D, is rated as high to aquatic mammals and moderate to fish, aquatic invertebrates, aquatic plants and algae.

Rubber Particles & Microplastics

Including rubber debris derived from tyres, road run-off has been identified as the single largest source of microplastics (MPs) in the water environment (at least 40%)[9]. It has been estimated that around 68,000 tonnes of rubber particles are generated annually from tyre wear on UK vehicles up to 19,000 tonnes of which is transported to watercourses adjoining roads via run-off[10]. As well as contributing to the detrimental effects of excess sediment (see below), rubber particles act as vectors for the input of a wide range of trace pollutants, some of which have significant ecological impacts.

Recent studies[11] have revealed the complex composition of tyre particle leachates and have identified phthalate plasticisers (some of which are proven endocrine disrupting compounds), benzothiazole vulcanisation accelerants (some of which are suspect carcinogens), phenolic anti-oxidants and zinc (see 'Heavy Metals' above) as predominant pollutants. Ecotoxicity studies revealed significant impacts on algal growth and mussel early stages development, survival and motility.

Rubber particles derived from tyre wear are vectors for the input of a plethora of damaging pollutants into watercourses.

Very recent research has shown rubber particle leachates to contain 6-PPD quinone, a transformation product of a tyre anti-ozonant, which is acutely toxic to some species of salmonid fish and has been implicated as the causative agent in a number of major fish kills in the USA. Concentrations of this compound as low as 1µg/L can be lethal to some salmonids and it has been shown that just one gram of rubber debris can leach up to 10µg of 6-PPD quinone.[12]

In order to exhaustively remove the above-mentioned pollutants during drinking water production, treatment processes featuring high carbon footprint GAC filtration is required, and wastewater treatment is likely to produce sludge enriched with some of these substances which is a potential issue where disposal to land is practiced.
Other significant sources of MPs in road run-off include thermoplastic road markings, the degradation of roadside plastic litter and inputs from soils contaminated, for example, by sewage sludge application or the disintegration of plastic sheeting used in agriculture. PVC, polystyrene, polypropylene, polyesters & polyethylene have been identified as the pre-dominant MPs present in the water phase of storm water retention ponds receiving primarily road run-off[13].

The extent to which MPs impact the freshwater (and wider) environment is a burgeoning area of on-going research. They can cause damage to the alimentary canal of small organisms and laboratory studies have suggested that decreased movement and feeding and increased buoyancy may occur in some species, although this is yet to be proven in the wild. Microplastic particles can accumulate harmful non-polar pollutants such PAHs, some classes of pesticides, PCBs & PBDE flame retardants but it is yet to be conclusively demonstrated that these toxins can be released following inadvertent ingestion of MPs by aquatic organisms[14].

Recent research has indicated that standard drinking water and wastewater treatment processes are highly efficient at the removal of MPs[15]. The consequence of this, however, is that sludges arising from these processes are enriched with these pollutants and are therefore a vehicle for their reintroduction to the environment when disposal to land is practiced.

Polycyclic Aromatic Hydrocarbons (PAHs)

A huge family of organic compounds comprising variable numbers of fused benzene rings, PAHs occur in some mineral oils and coal tar-based products and are also generated by the incomplete combustion of organic (carbon-based) materials. Aqueous solubility decreases with increasing molecular weight and these pollutants principally enter watercourses adsorbed to dust washed off from roads. PAHs are deposited on to road surfaces as a result of the combustion of fuel by vehicles. Residual PAHs from bitumen used in road surfacing materials, fuel spills and particulates from brake and tyre wear can also contribute to their accumulation on roads.

Exhaust emissions deposit significant amounts of PAHs onto road surfaces.

These compounds are relatively persistent in the environment with biodegradation rates ranging from months to several years[16] and given their propensity for binding to solids, they tend to accumulate within the sediments of polluted waterbodies. PAHs exhibit many deleterious effects on aquatic life forms. Compounds such as benzo(a)pyrene are proven potent mammalian carcinogens and PAHs are also known to be highly toxic, mutagenic and damaging to the immune system. Their high fat solubility contributes to their bio-accumulative properties. PAHs are readily removed during standard drinking water and wastewater treatment processes, but the resultant sludges can often be enriched with these pollutants, a significant issue where these materials are subsequently disposed of to land.

Mineral Oils

Hydrocarbons derived from mineral oils such as petrol, diesel & lubricating oils are ubiquitous pollutants of road networks. Oil leaks, road spray wash-off, incomplete combustion of fuels and spills from accidents/breakdowns all result in the contamination of road surfaces. Scouring by rainfall or road cleaning can mobilise this pollution either as free oil or material adsorbed to particulates and historic studies have shown that sediments from small urban streams frequently exhibit levels of total petroleum hydrocarbons (TPH) above the threshold level for classification as special waste [17].

Hydrocarbon residues are highly complex mixtures spanning a large range of volatility and including low molecular weight aromatics such as 'BTEX' compounds (benzene, toluene, ethylbenzene & xylene), paraffins, olefins, PAHs (see above) and numerous high molecular weight contaminants. Gross oil pollution from spills can result in oxygen depletion of affected watercourses and directly impact floating insect and plant species but more insidious effects can arise from low level chronic inputs. For example, BTEX compounds, prevalent in petrol and including the known carcinogen, benzene, can bioaccumulate and PAHs are known to be persistent pollutants which are carcinogenic and mutagenic [17].

Grass filter strips, swales & retention ponds have been shown to be highly effective, not only in attenuating hydrocarbon run-off, but also in promoting the degradation of such pollutants, especially where dry conditions prevail for significant periods of time [17]. Basic drinking water treatment processes are not adept at removing residues of petrol, diesel, kerosine or lube oil. Low concentrations can be removed using GAC but high levels of oil cause serious operational problems in both drinking water and wastewater treatment.

Direct run-off of mineral oil residues can result in high levels of hydrocarbons in the sediments of adjoining watercourses.

Salt & De-icing Agents

Over two million tonnes of rock salt (sodium chloride) are spread onto the UK road network each year in order to improve road safety when wintery conditions prevail. Other salts including magnesium chloride, calcium chloride and calcium/sodium acetates, are applied in lesser amounts. During protracted frosty but relatively dry weather this can result in the build-up of large amounts of salt on the margins of roads. Subsequent heavy rainfall can then transport much of this material into adjoining waterbodies within a short period of time resulting in huge spikes in salinity which can adversely affect aquatic life[18].

High concentrations of chloride have been shown to inhibit growth and reproduction in various aquatic species, have adverse effects on food sources and disrupt osmo-regulation in amphibians. Furthermore, large inputs of salt can produce a dense layer on the bottom of waterbodies, inhibiting the exchange of gasses with the overlying water leading to oxygen depletion and inevitable stress to numerous organisms. Vehicle spray from heavily salted roads also causes dieback of adjoining vegetation and contaminates roadside soils.

In the UK over two million tonnes of rock salt per annum are applied to improve road safety in wintery weather.

Chloride is a very persistent pollutant in enclosed bodies of water such as groundwater aquifers and isolated lakes. It readily leaches to groundwater, can therefore potentially also indirectly reach surface water bodies and is not readily removed by conventional drinking water treatment processes which can lead to taste problems. Techniques being developed to minimise the impact of de-icing agents include dispensing materials in solution, resulting in better targeted application and the consequent use of less salt, fitting application regulators to gritting vehicles and developing smart gritters which can gauge road temperature and the amount of residual salt from previous applications.

Sediment

In wet weather, road surfaces and their associated drainage networks can act as conduits for the input of damaging amounts of particulate material into receiving waterbodies. Sources of sediments include topsoil from adjoining agricultural land and, in particular, construction sites[19], dust from the wearing of brake pads, rubber particles derived from tyres and periodically, sand/grit applied for traction purposes in wintery weather.

As well as acting as vectors for the input of damaging trace pollutants such as nutrients, heavy metals, PAHs, pesticides and other organic compounds, sediment can exert adverse effects on a more gross scale. The turbidity arising from sediment pollution can exclude light which can inhibit photosynthesis in riverbed flora reducing biodiversity and dissolved oxygen levels, and can curtail feeding in a number of aquatic animals. It can also result in waterbodies absorbing more heat from sunlight resulting in lower dissolved oxygen levels which can seriously stress fish populations, especially in the summer months. Deposition of sediment onto spawning gravels is thought to be a significant contributor to the decline in salmonid fish species such as Atlantic salmon & sea trout. In a major run-off event, just 10,000 litres (~2200 gallons) of sediment-laden water can transport sufficient solids to cover one square metre of gravels with an inch-thick layer of silt.

Road surfaces can act as conduits for damaging amounts of sediment to enter adjoining waterbodies.

The excessive amounts of sediment periodically present in some surface waters can make drinking water treatment challenging with an inevitable increase in the use of associated chemicals and energy and adverse effects on costs and carbon footprint. Sediment from road run-off can contribute to the sludges produced by both clean and wastewater treatment being laden with troublesome levels of some of the toxic trace pollutants mentioned above.

3. CONCLUDING COMMENTS

Featuring as it does a plethora of potentially damaging pollutants which show a marked temporal variation in both composition and concentration, highway run-off undoubtedly represents a major pressure on the water quality and ecology of adjoining waterbodies.

However, initiatives such as sustainable urban drainage systems (SUDS) [20] can be highly effective in reducing the impacts of run-off, not only in terms of reducing peak flows and associated flood risks, but also in attenuating the inputs of pollutants such as those detailed in section 2 above. Roadside swales, permeable pavements, constructed wetlands, retention ponds and green roofs are examples of SUDS interventions now being widely adopted. In addition, many of these measures provide significant societal and biodiversity benefits, providing 'green oases' [21] in built up areas.

In addition to effectively capturing many of the pollutants present in road run-off, SUDS interventions such as retention ponds can enhance biodiversity and provide 'green oases' in built-up landscapes.

With ever increasing volumes of traffic and a constantly expanding road network, collaborating with highways agencies and local authorities to better identify the origins of such pollution and minimise its impact therefore represents a key activity in safeguarding the well-being of waterbodies in the Westcountry and beyond.

REFERENCES

1. ‘The State of the Environment: Water Quality’ (Environment Agency, February 2018).
2. ‘Impacts of Copper on Aquatic Ecosystems and Human Health’. (F.Solomon, pp 25-28, Mining.com, January 2009).
3. ‘Effects of Copper on Fish and Aquatic Resources’. (C.A.Woody & S.L.O’Neal, Fisheries Research & Consulting, Anchorage, Alaska, June 2012).
4. ‘Zinc in Freshwater & Marine Water’. (Australian & New Zealand Guidelines for Marine & Freshwater Quality, October 2000).
5. ‘Critical Review of Platinum Group Elements in Aquatic Ecosystems’. (C.Fortin et al, Research Report No. R-1269 to Canadian Network of Toxicology Centers, April 2011).
6. ‘Amenity Pesticide Usage in the United Kingdom 2016’. FERA Pesticide Usage Survey Report 278. D.Garthwaite et al.
7. University of Herts Pesticides Properties Database 2021 (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/373.htm)
8. University of Herts Pesticides Properties Database 2021 (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/4.htm)
9. ‘Investigation of ‘Microplastics’ From Brake and Tyre Wear in Road Run Off’. (Specialist Professional and Technical Services (SPaTS) Framework, Lot 1, Task 1-902. Final Report, September 2020).
10. 2021 River Basin Management Plans ‘Pollution from Towns, Cities & Transport’ (Environment Agency, October 2019).
11. ‘Chemical composition and ecotoxicity of plastic and car tire rubber leachates to aquatic organisms’ (M.Capolupo et al. Water Research, Vol 169, 115270 Feb 2020)
12. ‘A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon’ (Z.Tian et al. Science, 08 Jan 2021: Vol. 371, Issue 6525, pp. 185-189 DOI: 10.1126/science.abd6951)
13. ‘Microplastics in urban and highway stormwater retention ponds’. (F.Liu et al. Science of the Total Environment 671 (2019) 992–1000).
14. ‘Microplastics in Freshwater and Soil (Executive Summary). (The Royal Society, November 2019).
15. ‘Sink to River – River to Tap. A Review of Potential Risks From Nanoparticles & Microplastics’. (UKWIR Report Ref. No. 19/EQ/01/18. 2019).
16. ‘Polycyclic Aromatic Hydrocarbons (PAHs): Sources, pathways and environmental data’ (Environment Agency October 2019).

17. ‘Oil and SUDS: Managing a Priority Urban Pollutant’ (F.Napier et al, SEPA, 12th International Conference on Integrated Diffuse Pollution Management (IWA DIPCON 2008)).
18. ‘How Road Salt Harms the Environment’. (J.Hinsdale, Columbia Climate School, December 2018, https://news.climate.columbia.edu/2018/12/11/road-salt-harms-environment/)
19. ‘The Pollution Conveyed by Urban Run-Off – A Review of Sources’. (A.Muller et al. Science of the Total Environment 709 (2020) 136125. https://doi.org/10.1016/j.scitotenv.2019.136125).
20. ‘Sustainable Drainage Systems’. https://en.wikipedia.org/wiki/Sustainable_drainage_system.
21. ‘Urban Wetland Design Guide – Designing wetlands to improve water quality’. (Enfield Council ISBN 978-0-900881-78-7).