Surface water runoff - the overlooked threat?   Bridget Woods Ballard, HR Wallingford

This paper presents initial findings from a component of an ongoing UKWIR research project on the costs and benefits of surface water disconnection, due to be published in 2024. It looks at the current and emerging regulatory and policy drivers relating to the management of the quality of urban surface water runoff, the evidence of risks to receiving water quality posed by urban surface water runoff and how they relate to other urban discharges and environmental quality standards, and the available evidence that SuDS can help mitigate those risks.

Urban surface water runoff is water which drains from roofs, roads, car parks pavements, driveways, and other surfaces. It is the mechanism by which pollutants generated on urban surfaces and atmospheric pollutants deposited on urban surfaces are transported and released into the receiving water environment. It represents a significant contributor to the degradation of surface water bodies in the UK. Urban diffuse pollution from streets, highways, homes, and businesses, both in and between towns and cities, prevents 18% of water bodies from achieving good ecological status (Defra, 2021). The impact of urban diffuse pollution is likely to be exacerbated under climate change scenarios when rivers suffer from lower summer flows, lower dilution, higher temperatures, and higher susceptibility to ecological damage.

The contaminants associated with urban runoff can be divided into different categories such as solids, heavy metals, toxic chemicals, biodegradable organic matter (chemical or biochemical oxygen demand COD/BOD), organic micropollutants (among them polycyclic aromatic hydrocarbons PAHs and polychlorinated biphenyls PCBs, PFOS and PFOA), pathogenic microorganisms (such as E-Coli), nutrients (nitrogen and phosphorus) and microplastics.

The source of pollutants can be natural (including soil, leaves and organic debris) or anthropogenic (including construction materials, traffic exhaust particles, roadway debris, road markings and tyre-wear, litter and waste breakdown, fertilisers, pesticides/herbicides, and pet faeces). Generally, the road-deposited sediment represents the most significant contaminant contribution in urban runoff (Piñon-Colin et al., 2020).

When surface water is collected and transferred within the combined sewerage system, the surface water will normally be treated, together with the wastewater, at the wastewater treatment works. Many persistent urban runoff contaminants will be captured in sludge and, in some cases, then applied to land from where it may be transferred in runoff directly to waterbodies. When combined sewers are overloaded, overflows will be triggered – spilling untreated mixed surface and waste waters to receiving waterbodies with potentially significant environmental and social impacts. Surface water disconnection from the combined sewer will potentially help reduce the frequency and volume of such spills but, without additional treatment, direct urban surface water discharges can then become new sources of contamination. The use of sustainable drainage components (SuDS) can provide opportunities for the reduction and mitigation of pollution from untreated surface water runoff.

Adverse potential impacts on receiving waters associated with storm water discharges include:

- Short-term changes in water quality during and after storm events including temporary increases in the concentration of one or more pollutants, toxics or bacteria levels;
- Long-term water quality impacts caused by the cumulative effects associated with repeated storm water discharges from a number of sources;
- Physical impacts (to waterbody morphology and ecology) due to erosion, scour, and deposition associated with increased frequency and volume of runoff.

Due to the very large number of influences on urban surface water quality (e,g, land use, rainfall event and inter-event characteristics, surface characteristics, temporal changes of pollutants in pipes etc), data can be highly variable and large datasets are required to draw meaningful conclusions. For the UK, where data is scarce, reliance has to be placed on datasets collected in the US and, increasingly, in Europe. The following table provides a very high level summary of relative risks posed by a range of different contaminants.

Pollutant	Sources & Impacts	Significance
Suspended solids	• Sources: soil erosion, dust, litter, human activity, atmospheric deposition, construction activities • Smothers habitat and aquatic life, limits light penetration and vegetation growth	Median urban runoff EMCs generally: 50-250 mg/l (but can be magnitudes higher): – EQSs: 10-30 mg/l – Urban runoff similar to CSO concentrations – Untreated wastewater 100-350 mg/l

	• Associated with toxic pollutants that adsorb to its surfaces. Smaller particles tend to carry a higher proportion of metals (but not all pollutants)	– Treated wastewater: around 20 mg/l – SuDS normally focussed on TSS capture: bioretention effluent concentrations: 4-10 mg/l

Public health contaminants	• Bacteria and disease-causing organisms mainly result from pet and bird faeces, rubbish and waste management facilities, decaying litter and plant matter, and misconnections Average misconnection rates (Ellis, 2013) 1-9% of sewer network, potentially contributing to up to 8% of WRD failures.
	  • Domestic misconnections: nitrates, phosphates, ammonia and bacteria
	  • Industrial/commercial misconnections: as above plus possible hydrocarbons, solvents and other hazardous substances
		Faecal coliform levels vary widely e.g. 2000-90,000/100 ml but possibly up to 2 OoM greater
		– Recreational standards < 500 / 100 ml
		– CSOs will have higher bacteria concentrations, untreated wastewater significantly higher
		– Treated wastewater will have very low concentrations
		– SuDS effluent concentrations highly variable, unlikely to reduce consistently to level of standards. Open SuDS can be exporters

Nutrients	• Sources: fertilisers, animal waste, misconnections, sediments, engine lubricants, corrosion inhibitors, atmospheric deposition • Variable sources, dissolved/particulate, different forms transfer • Causes eutrophication, algal blooms, species imbalances, public health threats and general decline in waterbody quality	Total P EMCs: 0-1 mg/l; Dissolved P EMCs: 0.05-0.16 mg (can be OoM greater): – Similar to recommended standards – Leaf litter and high P compost are significant contributors – SuDS only effective if routinely maintained Total N EMCs: 0 -5 mg/l; unionised ammonia 0.5-1.4 mg/l – Individual N compound contributions unlikely to be critical but unionised ammonia > intermittent standards by 1 OoM – Significant sectoral contribution to N loadings in waterbodies – Urban runoff levels likely to be OoM lower than treated wastewater unless high misconnection levels – Misconnections may require dilution factors > 100:1 – Consistent removal in SuDS is complex and challenging
Heavy metals	• Derive mainly from vehicles and building materials / roofing • Toxic to soil and plant health, bio-accumulated by fish and invertebrates, especially at sediment-accumulating sites, enter the food chain • Often adsorbed to sediments but can be dissolved • Coper, Nickel, Zinc, Cadmium and Chromium most likely to be present in sufficient quantities to cause toxicity (Lead presence decreasing)	• Older studies have suggested median EMCs likely to be similar to EQSs but more recent work aggregating large numbers of datasets suggests Cu, Zn and Pb EMCs are likely to be > than 100 x surface EQSs • Urban runoff likely to have similar or higher heavy metal concentrations to treated wastewater • SuDS designed for sediment removal, sorption and precipitation can effectively reduce concentrations to safe levels
Petroleum hydrocarbons	• Exhaust emissions, vehicle leaking, oil storage tanks, improper disposal of waste oil, • Components include: – Oil and grease – BTEX compounds (VOCs) – PAHs: more immobile, more persistent, more toxic, higher bioaccumulation rates, carcinogenic, alter ecosystems • Concentrations tend to be correlated with amount of traffic • Fluoranthene and Benzo(A)pyrene (linked to engine combustion) are of particular concern	• PAH concentrations in urban runoff likely to > treated wastewater and CSO effluent streams, requiring > 100 x dilution for acceptable toxicity levels. Stormwater poses the highest risk. • Sediment removal prior to capture in permanent water bodies is crucial; capture and degradation of PAHs is most effective in components that dry between events and expose contaminants to sunlight
Synthetic organic compounds	• Manufactured compounds including pesticides, insecticides, solvents, household and industrial chemicals • Even low concentrations of regular discharges are highly toxic to aquatic life, and indirectly to humans via the food chain, carcinogens	• PFOA and PFOS (forever chemicals – stain/grease/water repellent materials, wrappers, shampoos…) concentrations likely to be 2-3 OoM > EQSs, insecticides: 1 OoM > EQS ? • Likely to be higher concentrations in CSOs and wastewater effluents (WWTPs

	• There is some evidence that pesticide concentrations are higher in urban areas than agricultural areas • Misconnections mean domestic pharmaceuticals also found in a significant proportion of stormwater samples	typically do not remove these contaminants effectively) • UKWIR (2022) suggests wetlands may be effective at removing PFOS but data very limited
Microplastics	• Tyres, brakes, road marking materials, roof and building material 'coatings', roof membranes, PVC gutters, degraded litter, plastic pellets, microbeads… • Tyre derived microplastics include rubber core, plus additives, plus attached brake-abrasion particles • Impacts and relative toxicity poorly understood, though one compound 6PPD (a rubber derived chemical that prevents cracking and blowouts in tyres) is now known to have particularly high eco-toxicity levels • Typically hydrophobic with large surface areas so act as carriers of other pollutants (in particular, persistent organic pollutants) • Road runoff likely to contribute 40% of microplastics found in the water environment	• Initial findings indicate SuDS very effective at removal (depending on particle density) but efficacy rates may reduce through time and sinks could become sources

This paper has highlighted that surface water runoff contains many of the same pollutants as untreated wastewater, many at similar concentration levels, and has also highlighted the risk of discharges causing breaches of EQSs, without very high dilution factors. An associated challenge is that many of the emerging pollutants of concern have no associated EQS (as is also the case with microplastics). This leads to difficulties both in monitoring (e.g. selecting suitable limits of detection) and in understanding what might be considered a detrimental effect to the receiving water environment. Wicke et al. (2021) raises the issue that EQSs are developed for long exposure times and it remains unclear how short but high concentration peaks during storm events should be assessed. There is also significant uncertainty as to impacts of such a large mixture of different pollutants.

Further data collation, particularly in UK environments, is also required to confirm the capacity of SuDS to consistently reduce levels of a broad range of contaminants and contaminant mixes to environmentally acceptable thresholds. The current evidence base is drawn almost entirely from countries outside of the UK. Long term investigations into the impact of the bioaccumulation of some contaminants e.g. heavy metals, PFOA, PFOS and HBCDD in SuDS environments is also needed (UKWIR 2022). In particular, high concentrations of PFOS can destroy antioxidant systems and, while the level of toxicity remains unclear, this suggests the accumulation of these chemicals in SuDS may cause long term environmental degradation.

There are no current legislative drivers or standards in England for managing pollutant concentrations in surface water runoff. However, local authorities have a duty to take account of River Basin Management Plans (that will identify measures required to manage environmental quality in river catchments) when preparing and discharging development plans; water companies have a legal duty to avoid polluting waterbodies; and Highway England has a policy not to pollute. The main current policy driver for water companies is to reduce combined sewer overflows. This will require either online or offline attenuation, with additional flows being treated at WWTP over longer periods, or surface water disconnection and discharge direct to waterbodies. Primary and secondary processes at WWTPs will remove substantial proportions of the urban runoff contaminants (i.e. suspended solids, faecal indicator bacteria, nutrients, heavy metals, hydrocarbons and PAHs, synthetic organic compounds and microplastics), by virtue of extended settlement and biological treatment. However, many of these contaminants will become bound within sludge that will often then be applied to land as a soil enhancer – thus returning these contaminants to the environment, potentially in higher concentrations than originally found in stormwater.