

Can Green Infrastructure Have an Impact on Microplastics Leaving from Combined Sewer Overflows

RESEARCH PROPOSAL
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1. Introduction

The pollution of microplastics into the natural environment and the human food chain was first brought to the public's attention in 2004 and has continued to gain increasing attention since (Thompson, et al., 2004). The release of microplastics is a known source of pollution into our global water and soil systems, and with the quantity of microplastics in the environment expected to increase over the next few decades there are concerns about the potential for it to have harmful effects if ingested by animals and humans, either directly or via the food chain.

Green infrastructure is able to capture and infiltrate rain where it falls, in turn reducing storm runoff which subsequently improves the health of the surrounding waterways (Fletcher, et al., 2013). Green infrastructure is trying to mimic the natural environment through permeable pavements, green roofs and bioretention basins (Gordon, et al., 2018). Sustainable drainage systems (SuDs) were introduced in 1997, with a major set of guidance notes being introduced in 2000 (CIRIA, 2000). In England and Wales, SuDs are designed for water quantity rather than quality (DEFRA, 2011).

Whilst acknowledging that the true impacts of microplastics on the health of humans and other animals are yet to be realised and are still a developing area of research. This report aims to quantify how effective green infrastructure is at retaining microplastics present within water runoff (particularly from highway drainage) and prevents them from being released to the waterways and surrounding environment via Combined Sewer Overflows. The report is to be an indication of the benefits that can be derived from the use of green infrastructure when compared to traditional drainage.

2. Literature Review

2.1 What are Microplastics?

Since their introduction in 2004 (Thompson, et al., 2004), microplastics have continued to gain a greater interest and understanding. Microplastics are from synthetic polymers with an upper limit of 5 mm yet have no specified lower limit (Arthur, et al., 2008; Thompson, et al., 2009).

Microplastics can be characterised into two sub-categories: primary and secondary microplastics.

- Primary microplastics (Cheung & Fok, 2017): Any manufactured microplastics that is classed as a microplastic from production. These are often used in industrial and commercial products, such as plastic powders, microbeads in cosmetic formulations etc.
- Secondary microplastics (GESAMP, 2016): Any microplastic that is derived from the breakdown or degradation of a larger plastic e.g. tyres, textiles, paints etc.

2.2 Microplastic Sources

The majority of microplastics entering the marine environment are land based, and the largest sources are secondary microplastics. Microplastics can be discharged to the environment directly e.g. tyre dust being blown into local soil or water bodies, or they can be discharged further down the cycle e.g. microplastics in the wastewater network being released to rivers or land via combined sewer overflows (CSOs), wastewater effluent and wastewater sludge. Figure 1 summaries the main land-based sources and pathways of microplastics into the aquatic environment.

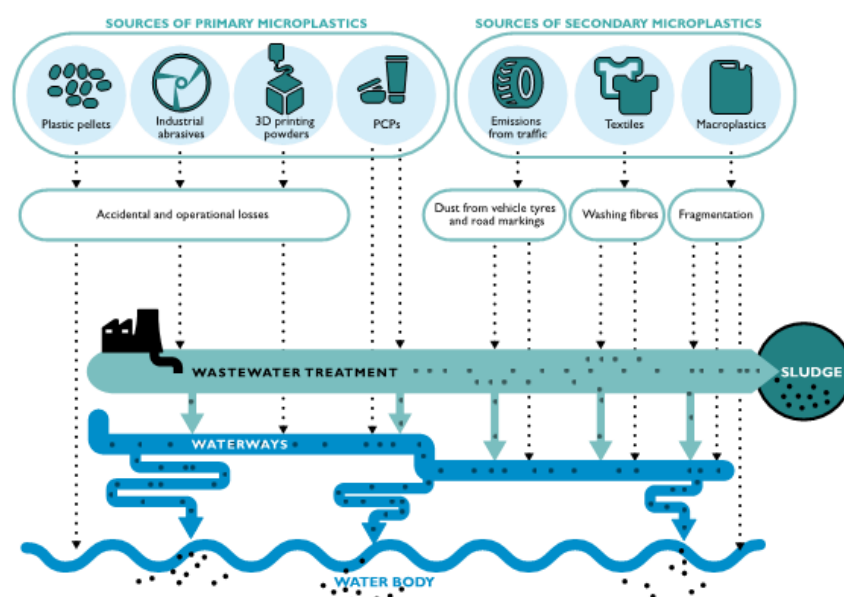


Figure 1: Microplastics and their pathways from land-based sources (Setälä, et al., 2017)

Studies have found that the largest source (nearly two thirds) of microplastics originate from road runoff i.e. tyres and road markings (CIWEM, 2017). These generally find their way to the environment via road runoff, storm discharges to the environment, CSOs or wastewater treatment works (WwTWs). Another significant source of microplastics is from washing of synthetic fabrics and textiles predominantly from domestic washing machines (CIWEM, 2017). Figure 2 shows the major pathways of microplastic release as defined by the International Union for Conservation of Nature and Natural Resources (IUCN).

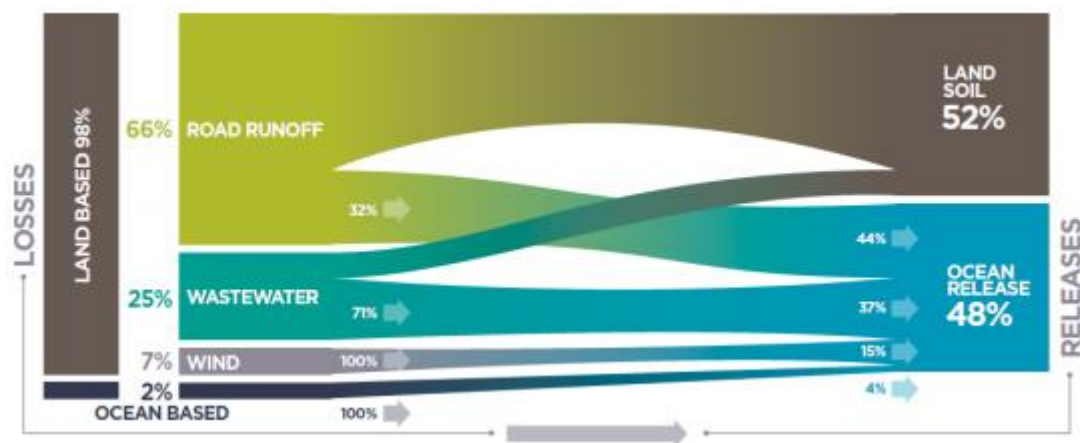


Figure 2: Contributions of different pathways to the release of microplastics (IUCN, 2017)

2.3 Impacts of Microplastics

2.3.1 Agriculture

A majority of microplastics that find their way to the WwTWs end up in the sludge system (Li, et al., 2018). It has become common practice to use treated sludge from WwTWs as fertiliser on agricultural land, meaning that sludge can potentially transport the captured microplastics to land (Schmidt, et al., 2006). Approximately 50% of sludge produced from WwTWs in Europe is applied to the land, whereas the rest is incinerated (Hann, et al., 2018). The possible negative environmental impacts of this practice have not been extensively researched. However, the very slow degradation of microplastics in nature meaning that they accumulate in the soil and release Persistent Organic Pollutants (POPs) which have the potential to enter the human food chain via crops and livestock grazing (Bakir, et al., 2014). POPs have been shown to be taken up by plants, but at a much lower rate than heavy metals (CIWEM, 2017).

2.3.2 Aquatic Environment

Microplastics in the oceans are often found suspended in the water where they enter the food chain predominantly by being ingested by filter feeders (Vroom, et al., 2017). Microplastics are also common in the gut contents of dead seabirds and their predators (UNEP, 2016). Organisms that ingest microplastics lack a digestive system that can degrade them, meaning fibres can accumulate and block their digestive tracts; similar to the effects that macro-plastics

have on larger organisms (Taylor, et al., 2016). Nutrition of small organisms is also compromised when they mistake microplastics for food (UNEP, 2016).

Although it is known that microplastics are ingested by the many commercial fish species (UNEP, 2016), very little is known about the impact of their consumption down the food chain. Microplastics may egested with faecal matter, retained in the digestive tract, or move between tissues (more commonly nano-plastics) and potentially transfer chemicals (UNEP, 2016). There is currently insufficient evidence to assess the transfer of contaminants in microplastics to flesh of marine life and eventually predators (UNEP, 2016). Therefore, the full effects of microplastics in marine biota are not yet established and are still developing area of research.

2.3.3 Humans

A study by the University of Newcastle in Australia identified drinking water as the largest source of microplastic ingestion for humans, with bottled water containing more microplastics than tap water mainly due to the bottling process and the plastics involved (University of Newcastle, Australia, 2019).

A further study commissioned by the World Health Organisation (WHO) on microplastics in drinking water concluded that microplastics do not appear to pose a health risk at current levels (World Health Organisation (WHO), 2019). The WHO states that based on limited evidence available, chemicals and microbial pathogens associated with microplastics in drinking water pose a low concern for human health (World Health Organisation (WHO), 2019). The WHO concluded that although there is insufficient information to draw strong conclusions in the toxicity of nano-plastics, no reliable information suggests it is a concern. The studies so far contain significant data gaps, which still need to be addressed in future research (World Health Organisation (WHO), 2019).

2.4 Identification and quantification of microplastics

Microplastics are usually always identified and quantified by visual inspection, even if followed by chemical characterisation (Prata, et al., 2019).

2.4.1 Visual Inspection

Visual inspection allows for the microplastics to be classified based on their physical characteristics, either observed directly or with the aid of a microscope or stereoscope (Prata, et al., 2019). Visual inspection is used as a pre-selection before the chemical characterisation. Due to the subjective nature of visual testing, wide variations may be produced between observers. There is a risk at the microplastics being misclassified with other materials, and this is only flagged when chemical analysis is carried out (Hidalgo-Ruz, et al., 2012). Visual inspection can also categorise plastic particles by size, colour and shape (Prata, et al., 2019).

2.4.2 Chemical Characterisation

The two main chemical characterisation methods used for microplastics are Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy (Elert, et al., 2017). These have been

extensively used due to them both being non-invasive and can be applied directly to the extracted particles (Iveleva, et al., 2017).

2.4.2.1 FTIR

Was first used for microplastic detection in 2004 (Thompson, et al., 2004), and has continued to be a powerful and reliable technique (Käppler, et al., 2015). IR absorptions depends on the permanent dipole moment of a chemical bond (Elert, et al., 2017). FTIR in transmission mode allows to see both the size of particles through chemical differentiation and the visual characterisation of the analysed material (Elert, et al., 2017).

2.4.2.2 Raman Spectroscopy

Raman spectroscopy depends on a change in the polarizability of a chemical bond (Elert, et al., 2017). Raman spectroscopy is one of the few techniques that can be applied to aquatic samples directly (Kniggendorf & Meinhardt-Wollweber, 2011). Another advantage of Raman is that the thickness or shape of the sample do not constraint the results (Elert, et al., 2017). Although Raman spectroscopy has many advantages, it is yet to attain the same popularity as FTIR for the detection of microplastics (Araujo, et al., 2018).

2.5 Storm Water Network Solutions

One of the largest sources of microplastics into the natural environment is through storm water run-off (CIWEM, 2017). Much of the storm water run-off is from the road system which is a natural collector for tyre and road marking dust (Norwegian Centre for Transport Research, 2019). With each rainfall the settled tyre dust is washed into the storm drainage system which often discharges straight to the natural watercourse.

2.5.1 Reed Beds

For the purpose of this review, reed beds are assumed to be of a non-free-surface flow design. Reed beds have long been used as a method of cleaning treated effluent (tertiary treatment) and stormwater flow. When used as a tertiary treatment reed beds remove 60-80% of suspended solids (Meniscus, 2018).

Reed beds however have been noted to reduce the volume of microplastics leaving the treatment works, not stop them altogether. This varies dependent on size of the reed beds in comparison to the flow, however studies such as testing on Irish Water sites shows a reed bed effectiveness of 50% (Mahon, et al., 2014).

Reed beds may be more effective per area used than constructed wetlands based on their size, as they act as a physical filter to the microplastics (García, et al., 2003), and therefore rely less on retention time, however no studies which directly compare the two have been found.

Reed beds will require removal of built up solids, including microplastics and it is reported that the frequency can vary between 5 to 15 years (reedbeds.co.uk, 2019). Appropriate disposal methods would need to be considered to ensure that microplastics do not enter the environment at a later stage.

2.5.2 Constructed Wetlands

Constructed Wetlands potentially remove microplastics via biodegradation (bacteria or earthworm), filtration and sedimentation (Gargallo, et al., 2017). They rely heavily on retention time of flows to ensure that microplastics can be captured from the water and therefore take significantly more space than reed beds (Mulidzi, 2010).

A Coalition Clean Baltic paper (Coalition Clean Baltic, 2017) suggests that constructed wetlands are appropriate as either a tertiary WwTW process, or as a storm water cleaning system. Stormwater retention ponds have been shown significant quantities of microplastics in the sediments (Lui, et al., 2019). Studies of two Free Water Surface (FWS) wetlands in Sweden indicate removal efficiencies of between 90-100% for microplastics greater than 20µm (Jönsson, 2016) .

It should be noted however that the microplastic content is generally not recoverable and therefore constructed wetlands are often highly polluted with microplastics. It has been found that wildlife using the wetlands can ingest microplastics from this area, meaning that not all microplastics are safely removed from the wider environment (Reynolds & Ryan, 2018).

2.5.3 Sustainable Drainage Systems (SuDs)

Sustainable drainage solutions are typically designed to prevent rainwater from entering combined sewer overflows by diverting flows to a watercourse via a drainage system which comprises of natural elements e.g. planted beds and ponds (Butler & Davies, 2011). Through sedimentation or soil filtration, SuDs can reduce the amount of microplastics from roads entering the water courses (CIRIA, 2007).

There is currently limited publicly available research on the effectiveness of urban SuDs in microplastic removal.

The natural elements of the SuDs will require maintenance including the removal of solids build ups (removal intervals will depend on asset type, location, flow quality etc.). Therefore, careful consideration of disposal of these solids should be made as these will contain microplastics.

3 Method

The aim of this report is to quantify how effective green infrastructure is at retaining microplastics present within water runoff (particularly from highway drainage) and prevents them from being released to the waterways and surrounding environment via Combined Sewer Overflows (CSOs), when compared to traditional drainage.

The green infrastructure which will be tested is 'Greener Grangetown', Cardiff, Wales. Greener Grangetown is a successful retro installation of SuDs features into an existing urban streetscape (GreenBlue Urban, 2018). The work was commissioned by City of Cardiff Council, Dŵr Cymru Welsh Water and Natural Resources Wales and led by Arup.

3.1 Sample Location

Samples are to be taken from ten rainfall events at three different types of intermittent discharge:

- A small number of CSOs in similar urban areas;
- Surface water drainage with recently installed green infrastructure in the Grangetown area of Cardiff; and
- Surface water sewer discharges containing highway drainage without green infrastructure.

Prior to starting the sampling project, the CSOs suggested in the above need to be assessed for suitability using Event Duration Monitoring (EDM) data to confirm frequency of operation, consents to locate the sampling points and deemed accessibility. It is imperative that all sample locations can be safely accessed with no requirements for confined space entries or significant traffic management and will not be at risk of being parked over or otherwise obstructed. Each location also needs to have verified flow to avoid the potential for abortive samples.

All sample locations are unscreened and have a cumulative impact on the River Taff (Figure 3). The exact sample locations are listed below:

- Sample 1 - Clarence Embankment - ST18744402
- Sample 2 - Taff Terrace - ST18743709
- Sample 3 - Bargoed St pre-GI - granite channel in raingarden
- Sample 4 - Bargoed St post-GI - Highway MH
- Sample 5 - Taff Embankment - ST18744801

(Sample location 5 shown in Figure 3 is a public surface water network which was identified at Taff Embankment. This surface water network receives surface water from approximately 10,000 m² of roofs, yards and highways on a small estate and discharges directly to the River Taff).

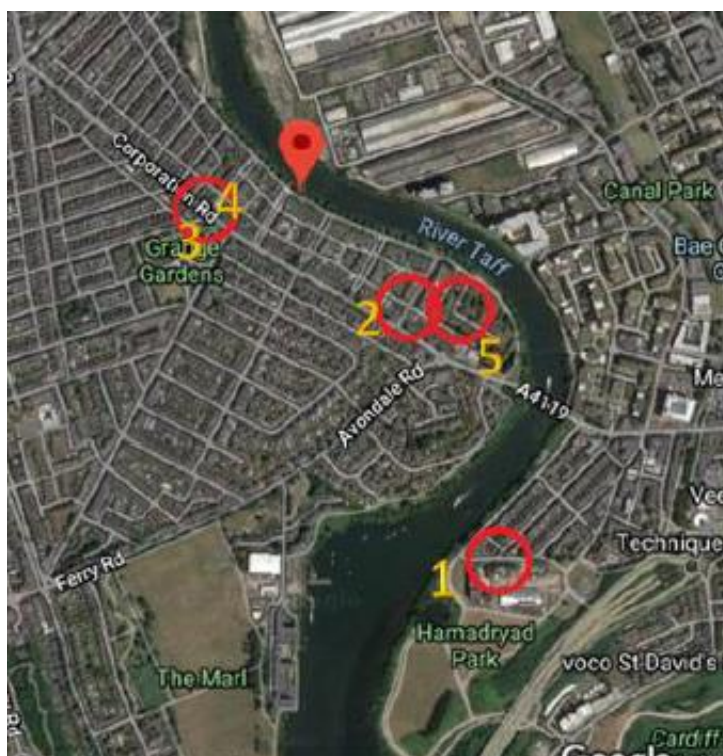


Figure 3: Sample Locations

3.2 Sample Collection

It is suggested that ten samples will be taken over a six month period during rainfall events at the five sample locations (Figure 3). The sample volumes are to be 1 litre for surface water/highway runoff and 500 ml for foul sewage. The samples need to be collected with a sampling can and stored in appropriate glass bottles to avoid the potential for plastic leaching into the contents which could potentially effect results.

This will result in a total of 50 samples to be taken over the specified time period, which will need to be analysed. From the data that is produced the results will be cross referenced with local rainfall data on the sample dates.

3.3 Sample Analysis

Samples are to be analysed in a laboratory using both FTIR and Raman spectroscopy. The samples are to be treated with acid in order to dissolve natural organic particles, filtered through a nuclepore filter (pore size 10 μm) and coated with gold. The analysis is to then be performed using both FTIR and Raman spectroscopy for identification of elements. This analysis will provide the number of microplastics per 1000 ml, with only particles with a grain size $>10 \mu\text{m}$ being analysed. Plastics which could be potentially identified in the results include:

- Polyethylene (PE)
- Polypropylene (PP)
- Polystyrene (PS)
- Polyurethane (PUR)
- Polymethyl methacrylate, plexiglass (PMMA)
- Polyethylene terephthalate (PET)
- Polyvinylchloride, vinyl plastics (PVC)
- Polytetrafluorethylene, Teflon (PTFE)

4 Results

The raw data will be generated and stored using an Excel spreadsheet. For ease of understanding, the data for each sample (No. microplastics per litre) will be tabulated such as Table 1.

Table 1: Example of Microplastic Data

Location	Polymer type	Sample date	Nr. / l	Sample date	Nr. / l	Sample date	Nr. / l
Clarence Embankment	A	14/01/2022	50	25/03/2022	95	01/04/2022	50
	B	14/01/2022	50	25/03/2022	95	01/04/2022	50
	C	14/01/2022	50	25/03/2022	89	01/04/2022	50
	D	14/01/2022	30	25/03/2022	75	01/04/2022	45
	E	14/01/2022	30	25/03/2022	80	01/04/2022	45
Taff Terrace	A	14/01/2022	20	25/03/2022	30	01/04/2022	20
	B	14/01/2022	20	25/03/2022	33	01/04/2022	20
	C	14/01/2022	20	25/03/2022	35	01/04/2022	20
	D	14/01/2022	20	25/03/2022	30	01/04/2022	20
	E	14/01/2022	20	25/03/2022	35	01/04/2022	20
Bargoed Street Pre-Green Infrastructure	A	14/01/2022	25	25/03/2022	200	01/04/2022	40
	B	14/01/2022	75	25/03/2022	215	01/04/2022	35
	C	14/01/2022	25	25/03/2022	165	01/04/2022	30
	D	14/01/2022	25	25/03/2022	175	01/04/2022	40
	E	14/01/2022	25	25/03/2022	180	01/04/2022	35
Bargoed Street Post-Green Infrastructure	A	14/01/2022	20	25/03/2022	10	01/04/2022	20
	B	14/01/2022	20	25/03/2022	15	01/04/2022	20
	C	14/01/2022	20	25/03/2022	5	01/04/2022	10
	D	14/01/2022	20	25/03/2022	5	01/04/2022	10
	E	14/01/2022	20	25/03/2022	10	01/04/2022	10
Taff Embankment	A	14/01/2022	60	25/03/2022	30	01/04/2022	60
	B	14/01/2022	80	25/03/2022	35	01/04/2022	60
	C	14/01/2022	20	25/03/2022	35	01/04/2022	50
	D	14/01/2022	20	25/03/2022	30	01/04/2022	55
	E	14/01/2022	20	25/03/2022	35	01/04/2022	55

*Polymer types A, B and C have just been used as a reference.

The data can be displayed as graphs (Figure 4), generated by Excel.

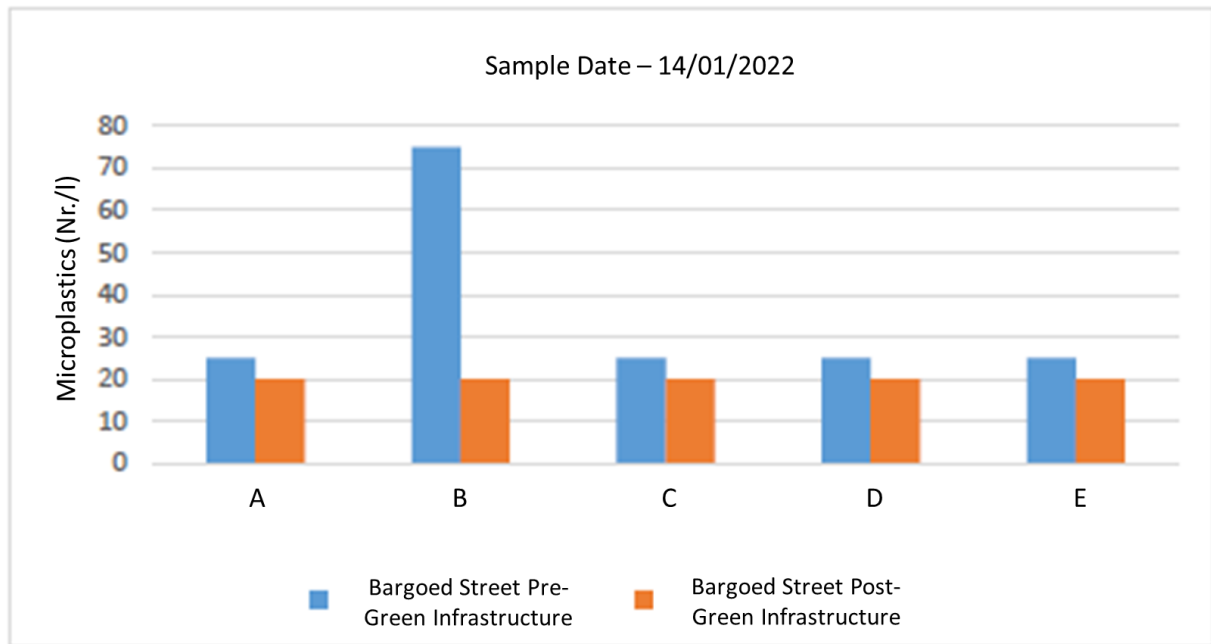


Figure 4: Example graph for types of microplastics identified at Bargoed Street, pre and post green infrastructure

From the data, one would assume the following observations may be made:

- The concentration of microplastics in combined sewage is consistently lower than the concentration found in just surface water/highway run off.
- A significant reduction in the microplastic concentration in highway runoff that has been passed through green infrastructure is observed.
- The levels of particular microplastics are generally higher than in flow containing foul sewage.
- Standard deviation results in combined sewage overflows that have passed through green infrastructure will be low due to the filtration effect of the green infrastructure.

5 Evaluation

There is a lack of understanding of the effects of microplastic pollution on humans and other organisms and their efficient removal from the water cycle. There is a substantial lack of knowledge on the impacts of green infrastructure on the removal of microplastics from waterways. The main focus in recent years has been on reducing the occurrence of primary microplastics by limiting their usage in products such as cosmetics or detergents.

This review has uncovered that whilst high removal efficiencies of microplastics are possible with conventional treatment technologies, large amounts of microplastics are still released into the environment through various pathways (e.g. roads, CSOs, outfalls, sludge) and therefore there is huge scope for improvement in these areas.

A 2019 study by the UK Water Industry Research (UKWIR, 2019) concluded that if the question was about how successful the Water Industry is at removing microplastics $>25\mu\text{m}$ from raw water or sewage, then the answer would appear to be very successful; $>99\%$ for wastewater and $>99.99\%$ for water treatment. However, it would be difficult to ascertain how successful the industry is at removing all microplastic particles, including the ultra-small varieties as the current methodology puts major constraints on being able to quantify particles smaller than $25\mu\text{m}$.

It is worth acknowledging that the UKWIR research focuses on how successful water companies are on treating the water that gets to the treatment works. However, as has been shown in this report, many microplastics do not make it to the treatment works and are lost to the environment before this stage, and this will need further focus if the issue of microplastic pollution is to be combatted. This is where green infrastructure needs to be investigated further.

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