

**Specialist Professional and Technical
Services (SPATS) Framework
Lot 1**

**Task 1-902
Investigation of 'microplastics' from brake and tyre
wear in road runoff
Final Project Report**

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Executive Summary

In the two decades to 2010, The Highways Agency (HA, now Highways England) invested significantly in research to determine the polluting potential of road runoff both to surface water and groundwater. These research programmes, which included extensive monitoring and testing of road runoff from wide ranging sample sites, form the basis of Highways England policy and standards with respect to protection of the water environment from pollutants generated from road runoff, particularly the current standards CG 501 - Design of highway drainage systems and LA113 - Road drainage and the water environment. These HA research programmes pre-date subsequent interest in (and knowledge of) microplastic pollution, which has increased significantly in recent years.

Further to changed awareness of microplastics pollution, the Environment Agency has identified that some emerging contaminants (described herein as pollutants of concern), not identified in previous Highways England research, may have increased in use and prevalence and warrant further evaluation, both in water and sediments associated with road runoff.

The main aims and objectives of this project (Task 1-902) were to:

- Undertake a literature review to assess the risks of aquatic pollution from microplastic and other pollutants of concern from highway discharges
- Through a field sampling/ analysis programme establish the presence or absence of microplastics and other agreed pollutants in road runoff; and
- Make recommendations on further research and development (R&D) and/or changes to current Highways England policy and advice

As a result of COVID-19 restrictions, the field studies were abandoned and hence research proposals described in this final report have been based on findings from the literature review alone.

The literature review identifies a consensus that sources from (or carried by) road drainage comprise the single most important source of microplastics (plastics in the size range $\geq 100\text{nm}$; $< 5\text{mm}$) and that tyre and road wear particle sources (TRWP), which includes tyre wear and road markings, may make up 40% (though figures vary) of microplastics found in the water environment. Road side plastic litter and secondary, indirect sources from soils (which may originally be derived from roads or from sewage sludge applied to adjacent agricultural soils) are also important.

There is a lack of a standard sampling and analysis approach for microplastics and this constrains making comparisons across different studies. There are few specific studies, based on quantitative analysis of actual discharges from UK roads. Those that are available, fail to provide sufficiently robust evidence to determine the concentration and distribution of microplastics throughout the Strategic Road Network (SRN). Whilst, it is evident similar mechanisms apply to the distribution of microplastic pollution and sediments (such as traffic, rainfall, drained area) direct links between the effects of sediments and those attributable to microplastics have not yet been demonstrated by robust, quantitative study.

The project also considered the current understanding of other potential pollutants of concern associated with highway runoff. These were based on a long list of pollutants identified by the Environment Agency that included discharges from a range of potential sources, including those sorbed onto microplastics. However, definitive, quantitative information regarding the distribution and concentration of these pollutants in road runoff is also unavailable.

On the basis of the literature review, there is insufficient evidence to suggest current Highways England policies (including assessment and design guidance) are inappropriate or that changes to current policy are warranted or could be justified.

However, given the considerable unknowns, specific, SRN based and focussed research is needed to establish the full scale, nature and potential impact of microplastic pollution and other pollutants of concern found on or derived from the network. Recommendations have been made to gather a robust evidence base to inform future decision making.

A methodology statement, prepared for the field works for this project (and prior to their abandonment) set out requirements for pilot level field studies to be undertaken on the SRN. This may be used to help define a more widespread programme of field monitoring and sampling.

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APPENDICES

APPENDIX A - Literature Review

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1. Introduction

Report purpose

Highways England (HE) set out in Task 1-902 to investigate ‘microplastics’ from brake and tyre wear in road runoff.¹ The overall aims and objectives of the task were to:

- Produce a literature review assessing the risk on aquatic pollution from microplastic and other new or ‘exotic’ pollutants of concern from highway discharges
- Establish presence or absence of microplastics and other agreed pollutants in road runoff
- Make recommendations on further research and development (R&D) and/or changes to current policy in Design Manual for Roads and Bridges (DMRB) or existing HE management practices

The literature review was completed (Appendix A) and, based on initial findings, a sampling methodology (Appendix B) was developed to set out the steps needed to prepare a “pilot scheme” of sampling and analysis to determine the presence/absence of microplastics in road runoff and an indication of concentration levels. However, as a result of COVID-19 restrictions which prevented the field work necessary to undertake road runoff sampling, the scope of the project was changed. The sampling and analysis task was replaced by an additional identified task, to disseminate the project findings to a wider audience. The definition of this new task for wider engagement is provided in the recommendations (Section 4).

The final objective of Task 1- 902 is to make recommendations on further R&D, delivered within this final summary report. This report seeks to address the following:

- Provide a reasoned argument/conclusion that identifies if microplastics or any other emergent pollutants of concern are a potential environmental risk from highway runoff discharges on the Strategic Road Network (SRN)
- If microplastics and/or other new pollutants are identified as a potential pollution risk, whether existing assessment and design practices in HD45/HD33² are sufficiently up-to date and/or robust enough to manage this risk or would need to be adapted
- The identification of any essential future research activities in this area and indicative budgets

It should be noted that the focus of effort for this project has been on the relatively new topic area of microplastics and this was a primary consideration in the shaping of the literature review key questions (Appendix A). Emergent pollutants of concern have formed a secondary focus for the literature review but were considered in greater detail in the development of the Methodology statement.

Three terms have been used to describe the chemical component of this work in the project and report objectives above, ‘exotic’ pollutants of public concern; emergent pollutant of concern; and other new pollutants. Henceforth, in this report these are referred to generically as pollutants of concern. It should be noted that this term is not referring to the Watch List which has been formally identified as emerging or little-known pollutants across the EU.

Report layout

This report is structured as follows:

- Section 2 sets out the scale of the problem on the strategic road network
- Section 3 considers existing HE guidance and whether this remains appropriate
- Section 4 sets out the final report recommendations

¹ The literature review included other potential sources from road runoff including road markings and litter as well as indirect sources such as from soils adjacent to roads

² HD45/ HD33 were identified in the Task 1-902 scope of works as reproduced here, these have now been replaced by LA 113 and CG 501 respectively, see further below

2. Scale of the Problem on the Strategic Road Network

Context and setting - microplastics

Release of microplastic contaminants potentially poses a threat to the water environment (in the water column, in sediments and biota) and also potentially provides a threat to human health (e.g. Karbalaei et al, 2018).

Research into microplastics is being undertaken across a wide spectrum of environments, both in the UK and internationally, with an increasing body of academic and stakeholder interest. It is clear that this field of research (i.e. microplastic pollution of the water environment) is rapidly evolving and is the subject to an ever increasing body of research. From the first paper on microplastic published in circa 2004, research has accelerated almost exponentially from about 2012/ 2013. Even during the course of undertaking the literature review, numerous new papers have emerged, which emphasised the need to focus the research questions adopted. Apart from very early works, these research works post- date Highways England's extensive body of research into contaminants received from road runoff (see further below)

A large body of this research identifies road networks as a significant contributor to microplastics in the water environment. Estimates vary but evidence suggests that globally, between ~30-40% of microplastics passing from freshwater systems to oceans are sourced from tyre road and wear particles or TRWPs as they are commonly named (Boucher & Friot, 2017; Siegfried et al., 2017).

Microplastics - definition and associated issues

Whilst there are a number of definitions of plastics and microplastics, they are most commonly based on the size ranges below:

- Macroplastics: $\geq 25\text{mm}$
- Mesoplastics: $\geq 5\text{mm} < 25\text{mm}$
- Microplastics: $\geq 100\text{nm} < 5\text{mm}$
- Nanoplastics: $< 100\text{nm}$

However, as evident from the literature review, in a wider research context, there are a number of key issues that need to be addressed, before (or perhaps in parallel with) establishing a better understanding of how the SRN may contribute to the environmental risk from microplastics. These are:

- A lack of sampling and analytical standards
- No clear legislative drivers and a lack of defined environmental quality standards (EQS)
- A rapidly evolving field, often with different approaches, compromising comparison between different research efforts, with an occasionally contradictory evidence base
- Poor definition of toxicity/ harm from microplastics

Clearly addressing these issues is not within the remit of Highways England, however an appreciation of this wider context is needed when considering appropriate actions relevant to the SRN, particularly when it comes to measuring and understanding the yardsticks through which the potential impacts from the SRN on the water environment may be compared.

Microplastics in road runoff

Microplastics encountered in road runoff are most likely to be secondary microplastics, i.e. derived through mechanical wear or chemical degradation. The main sources of microplastics from the SRN are likely to be:

- Tyre and Road Wear Particles (TRWP) – from abrasion of tyres, and road markings via direct runoff.
- Degradation of roadside litter
- Indirect sources from microplastics concentration in soils (from both agricultural sources derived from sewage sludge application and those generated from the road)

The most important single contributor to microplastics in the water environment is TRWP, comprising perhaps 40% (although figures vary) of microplastics in the water environment. However, there is insufficient definitive research to identify the overall contribution from the UK road network. Equally, different contributions of each individual source from roads are uncertain (i.e. the distribution between tyre wear, road markings and the other sources noted above) although the literature review did identify methods that help distinguish the different sources, such as:

- Tyre wear particles appear as an elongated shape, are black, have the inclusion of mineral road samples and are in the size range 5-250 µm
- Road markings can be identified visually from their colouring (red/yellow/white) and the incorporation of glass beads
- Thermo-analytical techniques can be used to identify tyre wear particles
- Polymer composition can help identify the possible sources (direct from SRN or not) of the microplastics

The literature review identified that sampling of microplastics from the road network will be dictated by a number of key considerations including that:

- Microplastics tend to accumulate in sediments
- Sediment transport processes will influence microplastic distribution
- Microplastics occurrence will decrease with increasing distance from the primary source
- The depth of sampling will affect results

Further discussion on appropriate sampling and analysis methods is provided in the Methodology Statement in Appendix B.

The generation, transport and ultimate destination of microplastics (i.e. source-pathway-receptor linkages) are dependent upon a range of site characteristics, including drained area; traffic volume, vehicle type and behaviour; seasonal influences (such as rainfall volume and intensity); drained area antecedent conditions and location (urban vs rural). These are analogous to a similar set of characteristics that influence the concentration and type of runoff derived contaminants (particularly sediments) as identified in previous Highways England research and that inform current Highways England policy.

The impacts from microplastics (such as the toxicity of compounds within the plastic) are not clearly established, though known toxic materials can also be sorbed onto microplastics (see further below) which may act as a carrier.

Discussion

Although there is an increasing body of evidence regarding the presence of microplastics in the water environment, much of the research is disparate in its approach and it has been difficult to compare results across different bodies of research. Many studies are based on modelling rather than specific and quantitative measurement. Studies based specifically on road generated microplastics are available in the international literature, although these experiences cannot necessarily be readily applied to the SRN due to, for example, differing site characteristics, climate and traffic conditions. The lack of a standard approach to sampling and analysis is a particular constraint. Highways England's past evaluation of pollution generated by road runoff has demonstrated that contaminant distribution and concentration is influenced by a wide set of site-specific factors (traffic, drained area, rainfall etc). It is evident similar factors apply to the distribution of microplastic pollution. However, without more empirical evidence, such as a robust field sampling programme, firm conclusions cannot be drawn regarding occurrence of microplastic generated on the SRN or transported through the drainage networks.

What is evident from the literature review is that microplastics generated from road runoff appear to constitute the single greatest contributor (perhaps 40% or even more) to microplastics in the water environment. What is less clear is how much of this is captured, or could be captured, within the road drainage network.

On this basis, specific, SRN based and focussed research is needed to establish the full scale, nature and potential impact of microplastic pollution on or from the network.

Context and setting – pollutants of concern

Highways England invested significantly in research between 1990 and 2010 to determine the polluting potential of road runoff to both ground and surface water. This programme of research formed the basis of HE policy and standards for example, the current standards: CG501 - Design of highway drainage systems (Highways England 2019a) and LA113 Road drainage and the water environment, (Highways England 2019b)³ with respect to protection of the water environment from pollutants generated from road runoff. Alongside research into the accumulation and dispersal of suspended solids from runoff, concentrations of significant pollutants led to the development of the Highways Agency (now HE) Water Risk Assessment Tool (HAWRAT/ HEWRAT) which continues to form a fundamental part of HE standards and guidance for the assessment of the potential water quality impact of road runoff.

Since this research was completed over a decade ago, the Environment Agency has noted that some contaminants, not previously identified, may warrant further evaluation, both in water and sediments associated with road runoff.

Pollutants of concern in road runoff

Pollutants of concern (not necessarily associated with microplastics)

Complementary to earlier Highways England research (as above) it is widely accepted that highways remain sources of a number of contaminants and pollutants, whether or not these have a direct source association with microplastics. This can include; a wide variety of heavy metals (e.g., Al, As, Cd, Cr, Cu, Pb, Pt, Pd, Ni, Sb, Zn); organic pollutants containing high levels N, P and Mn; hydrocarbons (e.g., PAHs), oils and greases; pesticides and high total suspended solids (TSS) (Kibblewhite, 2018, Robertson et al., 2019).

Potential sources of contaminants are identified (in no particular order):

- Integrated vehicle components (undercoatings, paints)
- Fuels and lubricants
- Combustion products
- Catalytic converters
- Brake pads
- Vehicle cleaning products
- Roadside pesticides and herbicides
- Road surface emissions

Generically, these sources have not changed significantly since the HE research identified above, however there are a variety of chemicals, in part associated with these activities and not previously targeted by the earlier research.

A list of over 200 potential chemicals that could be in runoff were identified from literature and proposed by the Environment Agency for consideration in this study. The following steps were used to derive a realistic shortlist of chemicals:

- Remove UKWIR Chemical Investigation Programme (CIP) determinands as this programme of monitoring was designed to look for wastewater contaminants and not focused on road runoff sources
- Separate cells containing multiple chemical entries
- Eliminate duplicated chemicals
- Remove vague terms (e.g. waxes, mineral oils)
- Remove commonly occurring and widespread elements (e.g. carbon from carbon black)
- Identify important chemicals (key pollutants) established in previous Highways England research as these have already been assessed (and consider whether these need to be “re-visited”)
- Verification of the current HE pesticide/ herbicide usage and those identified removed where subjected to previous Highways England testing and analysis

³ Subsequent references to these documents will be simply as CG 501 and LA 113

- Rule out chemicals that would be included in the term “microplastics” (e.g. thermoplastics)
- Review of chemicals that are unlikely to be derived from road runoff based on literature or expert judgement (e.g. tributyl tin – an antifouling agent)
- Evaluate sources (e.g. specific to a manufacturing/ industrial process) / conceptual link with road-drainage (i.e. not routinely associated with roads or road transport)
- Identify where there is a lack of Environmental Quality Standards (EQS) (determining their level of impact on a water receptor is in need of further investigation)

As a result of this process, the following shortlist (Table 3.1) of pollutants of potential concern to environmental risk from highway runoff discharges on the SRN were identified as a priority for further analysis / consideration. Some chemicals (particularly PAHs) identified from previous research were also recommended to provide a comparison with previous research these are presented in the Methodology Statement (Appendix B).

Table 3.1. Pollutants of potential concern

Determinand	Presence in Water (EQS available)	Presence in sediment
<i>Metals</i>		
Antimony	Yes (No)	Yes
Arsenic	Yes (Yes)	Yes
Manganese See note 1	Yes (Yes)	Yes
Mercury	Yes (Yes)	Yes
<i>Organics</i>		
<i>Pesticides and herbicides</i> See note 2		
Glyphosate	Yes (Yes)	No
Mecoprop	Yes (Yes)	No
<i>Miscellaneous Organics</i>		
Benzothiazoles (including 2-benzothiazolesulfenamide) See note 1, note 5	Yes (No)	No
Aniline See note 1	Yes (No)	No
Bisphenol A (BPA) See note 3	Yes (No)	No
Cyclohexylamine See note 1	Yes (No)	No
Dicyclohexylamine See note 1	Yes (No)	No
Perfluoroalkyl substances (PFAS) - PFOS / PFOA See note 4	Yes (No)	No
Phthalates/ DEHP See note 3	Yes (Yes)	No
Steranes See note 1	Yes (No)	No
<i>Note 1: Potentially tyre derived contaminants</i> <i>Note 2: May have been subject to previous HE testing and analysis</i> <i>Note 3: Potentially derived from a range of sources including vehicle treatments, paints and road surfaces</i> <i>Note 4: Potentially association with vehicle cleaning products</i> <i>Note 5: Benzothiazoles have been considered as a potential marker for tyre derived microplastics (e.g. Bye, N. H. and Johnsen, J. P., 2019); Parker Jurd et al., 2019)</i>		

Pollutants of concern (potentially associated with microplastics)

A parallel review was undertaken of pollutants of concern associated with microplastics. Increased knowledge about microplastics has highlighted that they are typically hydrophobic and have large surface areas, allowing them to act as carriers and accumulate a wide range of other pollutants e.g. heavy metals (Cd, Cr, Pb, Ni), pesticides, hydrocarbons including polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenylethers (PBDEs) and polychlorinated biphenyls (PCBs,) (Nobre et al., 2015; Anderson et al., 2016; Auta et al. 2017; Massos & Turner, 2017; Robin et al., 2020). This is additional to, e.g., tyre-derived microplastics consisting not only of the original rubber core but various other additives (e.g., Al, Ti, Fe, Zn, Cd, Sb, or Pb) as well as

potentially hazardous metals and metalloids contained in the attached brake-abrasion particles (e.g., Al, Fe, Cu, Sb, or Ba) (Sommer et al., 2018). As it is now acknowledged that persistent organic pollutants (POP) have been shown to sorb onto microplastics (Robin et al., 2020) this research has uncovered more sources of contaminants from road runoff than have been previously considered.

Given their long-lived nature in the environment, other pollutants sorbed onto microplastics could have far reaching environmental effects, e.g., detrimental effects to biodiversity/food webs in certain ecosystems (Auta et al., 2017), however the full extent will not be known until larger (greater temporal length) datasets are collected.

Discussion

The potential for pollutants generated in road runoff has been recognised by Highways England for over 2 decades and their previous research, undertaken in close collaboration with The Environment Agency, has led to the currently adopted design guidance and standards. The Environment Agency has established that, over time, other pollutants of concern, potentially generated from, on or via the road network may be identified. This led to the generation of a long list of contaminants that could potentially reach the water environment via the road network. From evaluation of this long list of pollutants of concern, a shortlist has been developed that warrant further evaluation regarding their occurrence and concentration on the SRN. This includes revisiting some chemicals identified as key pollutants in previous research and that form the basis of existing guidance. This shortlist for proposed future monitoring has been provided in the Methodology Statement (Appendix A).

The literature review has also identified chemicals associated with microplastics. These may be “within” the plastics themselves (such as chemicals within the composition of tyres) or may sorbed on to plastic surfaces. As a result of the literature review being completed in parallel with the Methodology Statement there are a number of chemicals associated with microplastics (including some metals and some persistent organic pollutants) listed here for which monitoring has not currently been proposed. This requires further review along with determining a list of typically sorbed chemicals that should also be subject to sampling and analysis. As analysis of sorbed chemicals (which potentially may also sorb onto other surfaces, such as other particulate matter) is likely to require different analytical techniques to separate them from the microplastics, this might be something to evaluate further into the future.

Evidently there are pollutants of concern that may be generated on the road network and potentially released to the water environment. However, beyond the work previously undertaken by Highways England, there is little evidence to determine whether the generation and transport of these pollutants represents a real threat to the quality of receiving waters.

As with microplastics, SRN based and focussed sampling and analysis is needed to establish the nature and potential impact of these recently recognised pollutants of concern on or from the network.

3. Existing HE guidance

Primary guidance and standards

As noted above, with respect to the SRN, the key standards that Highways England use to assess the need for and the design of mitigation to protect the water environment are set out in LA 113 and CG 501. These are the standards most appropriate for the assessment and management of microplastics and other pollutants of concern. Further means to address these potential pollutants are applied through specification documents set out in the Manual of Contract Documents for Highways (MCHW). Asset management and maintenance requirements, delivered by managing agents and other network service providers, set out the specifications for the maintenance of the drainage network, which may include, for example, the frequency of “clean- up” of sediment retention structures (such as ponds or other sediment traps).

Roadside litter, identified as one source of microplastics, is addressed as part of Highways England's litter strategy (itself a subset of Defra strategy).

None of these current standards or policies specifically address microplastics and do not necessarily directly address emerging pollutants of concern.

Is current Highways England guidance and policy adequate to address microplastics and other emerging pollutants?

It is not proposed here to consider policy measures (such as remedial clean-up operations) that might be applied to the water environment receptor (generally freshwaters and groundwaters), but to identify, what, if any measures might be applied to the source and pathways of these pollutants which would eliminate or reduce their transport from the SRN to the water environment.

Management of pollutant sources

As noted above, the key sources of microplastic pollutants from the SRN are tyre wear, wear of road markings (often grouped together as TRWP); litter (which may include airborne plastics carried onto the network) and indirect sources from soils adjacent to the road network. Roadside soils may be a significant receptor of microplastics generated from the road surface (Parker- Jurd et al., 2019) and sewage sludge applied to agricultural soils, and other agricultural plastics use, such as break down products from polytunnels, may also be a source of microplastics (Horton et al., 2017a). Both these indirect sources may be re-mobilised into road drainage. The scale and nature of these direct and indirect sources remain ill-defined.

Evidence from the literature review suggests the contribution from tyre wear depends on a number of factors, for example, driver behaviours (speed, braking etc.); vehicle type, traffic density; urban vs rural environments, the nature (particularly abrasiveness) of the road surface. Whilst there may be measures (such as traffic management) that might reduce tyre wear these might compromise other areas of policy (such as journey times, safety). Furthermore, there is an insufficient evidence base to suggest where such measures might have the greatest impact. At this stage, development of such control measures through revised Highways England policy or guidance are not considered viable.

The scale of the overall contribution of road markings to road borne microplastics pollution remains unclear, however, they are a significant source e.g. Boucher and Friot., 2017 suggest they contribute up to 7% of all microplastic emissions to the world's oceans and the transport of road marking paint particles from road surfaces to freshwaters has been identified in the UK (Horton et al., 2017b) . The adoption and use of low wear road markings, different paint materials, markings inset into the road surface (as is being adopted in Norway) and other measures to reduce wear, warrant further investigation. However there is no specific information regarding the influence on microplastic sources of the type of road markings, their position (e.g. parallel or perpendicular to traffic flow) or their relationship with traffic (high speed routes, braking areas etc). Further investigations as to where these sources offer the greatest risk (of microplastic pollution) are required in order to inform any change in Highways England guidance with respect to road marking.

Indirect sources from soils adjacent to highways may contain microplastics. These sources might include, for example, those deposited by treated sewage spreading on agricultural soils (Fahrenfeld et al., 2019) from the breakdown of roadside litter, or from airborne litter (Dris et al., 2017). Soils may also include plastics generated from the road itself. Recent evidence from the UK (Parker-Jurd et al., 2019), suggests that tyre particles are “abundant” within 50m of motorways. Although not compliant with current design standards (CG 501), which precludes draining of third-party land, existing (“legacy”) drainage adjacent to the SRN may discharge into the road drainage network, providing another potential source of microplastics.

Provisions for the drainage of natural catchments adjacent the SRN may also be required. The current Highways England design standard, CD 522 Drainage of runoff from natural catchments (Highways England 2020) also states that such drainage should be kept separate from the road drainage network, however again there may be legacy systems where this approach is not applied. While the CD 522 guidance is more focussed on the management of flooding than pollution control, it does recognise that *“Areas where the amount of silt in the runoff is expected to be very high can still be associated with a significant pollution risk”*. Given the recent research outcomes described above, there may also be microplastics pollution associated with the drainage of these natural catchments adjacent to the SRN. Further investigations as to where these sources offer the greatest risk (of microplastic pollution) are required if this source is to be addressed. Any such research effort will need to be proportionate to the level of risk (to the network and hence to potential water receptors).

Highways England littering strategy does not specifically address plastics or their degradation products, however some steps could be adopted to reduce the influence of litter as a source of microplastics. Potentially beneficial steps include identifying and addressing litter hotspots on a wider scale and adopting some methods used by the EA to reduce the incidental production of litter degradation during verge maintenance, for example, litter picking is now undertaken before strimming so that the strimming activities do not generate additional (but unintentional) microplastics. Further investigations are needed to establish whether microplastics generated from litter may be addressed “at source” before they, or their secondary products enter the road drainage network. Again, although there may be additional benefits (such as lesser impacts on biodiversity, improved visual amenity) any such research effort needs to be proportionate to the scale of the threat (to downstream water environments) represented by roadside litter.

Management of Pollutant Pathways

The road drainage network itself forms the primary pathway between sources on the SRN and the water environment. It is transport through this network and how this relates to the properties of microplastics and other pollutants that dictate whether there will be an impact on a receiving water environment. The literature review has led to a number of general findings:

- Similar to previous Highways England research, key site characteristics that influence both the sources of microplastics and their capture and transport through drainage networks include drained area, traffic volume and behavior, vehicle type, rainfall volume, intensity and antecedent conditions, location (urban vs rural)
- An understanding of these site characteristics is a vital element to understanding the generation, pathways and ultimate receptors of microplastic pollution from the SRN
- The density of microplastics is a primary property that determines their transport and ultimate fate although they tend to accumulate in/ with sediments and typically decrease away from primary sources
- Microplastics behaviour is somewhat analogous to that of suspended sediments, however there are important differences that need to be understood, these include, for example, the influence of shape and size, the nature of contaminants sorbed on microplastics surfaces and the rate of plastics breakdown into smaller particles
- Although some road drainage treatment systems (e.g. SuDS ponds, sediment traps, filter drains) have been demonstrated to capture microplastics, the efficacy of these measures, including potential re-

mobilisation, would benefit from a greater understanding

However, based on the literature review, there was insufficient detail or quantification available on transport and treatment processes to enable robust conclusions to be drawn regarding the behaviour of microplastics within the drainage networks (i.e. from drainage of the “road surface” to discharge point).

Wider policy considerations

As identified in Section 2, there are a range of broader issues that impact our understanding of the effects of both microplastics and emerging pollutants of concern. For microplastics, this includes a lack of standardised sampling and analytical measures, a rapidly evolving and changing research environment and poor (but rapidly evolving) understanding of toxicity. There are no current legislative drivers and there are no specific standards for microplastics pollution. As the generation of microplastic pollution from roads could also fall within overall Highways England policy not to pollute, irrespective of the introduction of specific legislation. Highways England need to remain informed of any emerging legislation and will need to be fully engaged in any associated consultation. With respect to emerging pollutants of concern, a number of chemicals identified 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.

Summary

While microplastics sourced from (or via) the SRN clearly form a significant part of the pollution load to the water environment, there is insufficient robust quantitative evidence regarding the sources of microplastics and their propagation and transport through road drainage networks to make recommendations regarding a change to assessment methods or design currently adopted by Highways England.

Related to current policies there are areas where further research would be beneficial which may help shape strategy and policy in the future. These policies should focus on where assessment, design, construction or intervention measures are likely to have the greatest effect.

There are few practical steps available to address sources of microplastic pollution that have been identified that can be implemented by Highways England alone. Further investigations as to where these sources offer the greatest risk are necessary so that the pollutant linkages and potential pathways to water receptors may be addressed. There may be elements of litter management which might be implemented to reduce generation of secondary microplastics from litter, however this also needs further investigation, for example to identify hot spots, so that resources may be appropriately targeted.

With respect to pathways, further details are needed regarding the behaviour and movement of microplastics before any consideration of change to either assessment methods or design standards and guidance (for example with respect to the capture of microplastics).

Until further evidence is established, and given the generally analogous behaviour of microplastics to sediments loads in road drainage, existing assessment guidance (e.g. through HEWRAT and LA 113) on the effects and capture of sediments remains fit for purpose. On the assumption that microplastics (particularly TRWP) behave in the same way as sediments, perhaps greater emphasis needs to be placed on sediment control and management (including regular de-silting of containment features to reduce remobilisation), however, there is no evidence base to suggest measures over and above those already with the standards.

Similarly with respect to sources of other pollutants of concern that may occur in road runoff, further evidence is also needed to determine their potential to cause pollution of receiving watercourses. Proposals for further research into these areas is needed, with proposals provided in Section 4. As for microplastics, until this additional evidence is gathered, it is premature to prompt any change in Highways England policy or guidance.

4. Recommendations

Key future research areas identified

Despite a wealth of ongoing research, there are gaps and shortfalls where the literature has highlighted that additional research is needed. This includes the wider context of the water environment, for example in achieving a better understanding of the measurement, distribution and behaviour and toxicity of microplastics. Specific research targeted at microplastics and other pollutants of concern derived from roads is also needed, which is the focus herein. Table 5.2 sets out the key areas for further research and Table 5.3 combines these into specific research packages and prioritises them to bring the most immediate benefit to Highways England and the SRN and potentially influence future changes in assessment, design and policy.

It is also beneficial to identify other stakeholders in these research areas, including, for example, academia, regulators, sampling/analysis providers (crudely, “labs”), the tyre/ motor industry and commercial providers of treatment solutions. Stakeholders might also include producers of road marking materials and road surfacing contractors. To consider the potential role of these stakeholders in future research, a responsibility assignment matrix, also known as RACI matrix, has been adapted and modified to help define potential participation or possible collaboration in the research. This modified RACI matrix is defined as in Table 5.1 below:

Table 5.1. RACI matrix

	Definition
Responsible (R)	Undertakes the research
Accountable (A)	Reviews and approves the research
Consulted (C)	Provides input to research based on either how it will impact their organisation or domain of expertise
Informed (I)	Needs to be kept abreast of “developments” in the research without any direct input

The wider role of other stakeholders is also considered below with respect to dissemination of the outcomes of these literature review based research proposals.

Table 5.2. Key areas of research

	Key future research & development area	Potential research activities	Desired outcomes	Key stakeholders	HE capacity to influence research input and outcomes
	Microplastics				
1	Development of standardised sampling and analytical methods	Analytical and sampling standardisation	This would provide a consistent approach and permit direct comparison of results with other studies	Academics (R? C, I) Commercial and research labs (R?, C) Environment Agency (R, A) Defra (R, A) Tyre industry (C, I)	Consulted / Informed
2	Develop a greater understanding of sources on the SRN (including from adjacent soils and littering)	Field based monitoring on the SRN Quantitative study on the SRN	Determine defining characteristics of different sources of plastic contamination. Establish key components for “downstream” analysis Determine if microplastics in soils adjacent the SRN are primarily from road-based sources or from third party sources (e.g. sewage sludge spreading, airborne)	Academics (C) Commercial and research labs Environment Agency (C, I) Defra (C, I) Tyre industry (C, I)	Responsible Accountable
3	Develop a greater understanding of the distribution and proportions of different types of plastics generated on (and transported via) the SRN (in parallel with item 2)	Field based monitoring of plastic distribution and types Quantitative study on the SRN (refer Methodology Statement, Appendix A)	Broaden microplastic monitoring as this is lacking in current published literature. Better establish presence, distribution and concentration of microplastics within the road drainage networks. Prompt potential change in HE assessment and design guidance	Academics (C) Commercial and research labs (I) Environment Agency (C, I) Defra (C, I) Tyre industry (C, I) Commercial treatment enterprises (I)	Responsible Accountable
4	Further understanding of how site characteristics (urban/rural location, weather, road condition, drained area, driver behaviours etc.) influence the generation of microplastics from the SRN and its distribution in the drainage network	Field based monitoring for a range of site characteristics Quantitative study on the SRN	Broaden microplastic monitoring as this is lacking in current published literature. Determine if particular site characteristics dictate generation of microplastics pollution Prompt potential change in HE assessment and design guidance	Academics (C) Commercial and research labs (I) Environment Agency (C, I) Defra (C, I) Tyre industry (C, I) Commercial treatment enterprises (I)	Responsible Accountable
5	Determine to what extent is the SRN facilitating the movement of microplastics.	Microplastic mobilisation and drainage pathway studies, tied in with sources and site characteristics. Compare with sediment transport	Further evaluation of sources, pathways and receptors. Understand relationship between sediment movement and capture and that for microplastics. Do they represent similar levels of pollution? Can they be assessed managed in the same way? Prompt potential change in HE assessment and design guidance	Academics (C) Environment Agency (C) Commercial treatment enterprises (C)	Responsible Accountable
6	Evaluate the efficacy of HE drainage and treatment / mitigation systems and standards (including SuDS systems) in the entrapment/ treatment of microplastics (and their capacity for subsequent remobilisation)	Evaluation of different measures to treat/ contain/mitigate microplastics. Compare with existing measures/ guidance to contain sediments Undertake field trials?	Determine whether current measures to contain and treat sediments perform similarly for microplastics (including retention and propensity for re- mobilization). Identify preferred treatment/ containment methods	Academics (C, I) Environment Agency (C) Commercial treatment enterprises (C)	Responsible Accountable
7	Develop an understanding of the ultimate fate of microplastics (and other pollutants of concern) generated from road surfaces (e.g. within the	Ecotoxicology studies of microplastics derived from TRWP and other pollutants of concern	Establish direct link between SRN sources and potential impact in receiving waters, sediments and biota	Academics (C) Environment Agency (R, A) Defra (R? A)	Consulted / Informed

	Key future research & development area	Potential research activities	Desired outcomes	Key stakeholders	HE capacity to influence research input and outcomes
	downstream water environment or other displacement from the network)				
8	Evaluate the use of low wear road markings, alternate paint/markings materials and use of inset markings.	Materials studies	Identify potential for use of different road marking materials. Promote new standards and guidance?	Academics (C) Environment Agency (C) Defra (C) “Paint” companies (C) Road surfacing contractors (C)	Responsible Accountable
9	Review littering strategy, identify and map litter hotspots to consider plastic contribution	Mapping of litter hotspots. Determination of plastic contribution to litter volume and mass	Develop strategies to reduce plastics litter at source as well as better targeted removal from the network removal	Environment Agency (C) Defra (A)	Responsible Accountable
	Pollutants of concern				
10	A robust dataset is lacking to assess whether HE policy needs updating for chemicals of potential concern	Identification of research baseline via literature review for a targeted list of pollutants	Establishes current academic understanding	Environment Agency (C) Defra (A)	Responsible Accountable
		Focused investigation on pollutants of potential concern in road runoff to gather data.	Builds on literature review findings to provide robust evidence of whether HE policy changes are justified	Environment Agency (C) Defra (A)	Responsible Accountable

Table 5.3. Research project proposals – identification and prioritisation

	Proposed Project	Potential research packages	HE responsible or accountable?	Potential influence on HE policy and/or guidance	Timescale of benefit to HE	HE Priority/rank	Indicative budget	HE
Item (s) from Table 5.2	Microplastics							
1	Development of standardised sampling and analytical methods	Analytical and sampling standardisation	No	Indirect - regarding use of standard methods in field studies	< 3 years	n/a	n/a	
2,3,4,5	Characterisation and assessment of sources, distribution and concentration of microplastics on the SRN and how these are influenced by site characteristics. Evaluation of the transport and propagation of microplastics across the SRN and comparison of behaviours and environmental with suspended sediments Advise on need to update HE guidance with respect to the assessment of these pollutants	Field based monitoring on the SRN to determine plastic distribution and types for a range of site characteristics Quantitative study on the SRN A pilot field study programme may be required to establish and refine field procedures before undertaking a more widespread sampling and monitoring regime - refer Methodology Statement in Appendix A) Microplastic mobilisation and drainage pathway studies, tied in with sources and site characteristics. Compare with sediment transport, assessment and impact	Yes	Direct - could steer future guidance and policy	0-5 years	=1	£300K+ (depending on scale of monitoring) (To be combined with item 10, costs identified separately)	
6	Evaluation of effectiveness of treatment/containment systems within the SRN design (see Note 1)	Determine effectiveness of treatment / mitigation of microplastics, by existing systems Focused literature/ desk study? Pilot field trials Collaboration with commercial enterprises?	Yes	Direct – CG 501 guidance	0-3 years	2	Desk study £30K-£50K Field trials £100K-150K, depending on potential for collaboration	
7	An understanding of the ultimate fate of microplastics (and other pollutants of concern) generated from road surfaces (e.g. within the downstream water environment)	Ecotoxicology studies of microplastics derived from TRWP and other pollutants of concern	No	Direct e.g. if leads to revised EQS	0-5 years	n/a	n/a	
8	Evaluate the use of low wear road markings, alternate paint/markings materials and use of inset markings.	Materials and pavement studies. Focused literature study	Yes	Direct. for design and specification of marking and road materials	0-2 years	=3	£10K- £30K	
9	Mapping and evaluation of littering as a source of microplastics on the SRN. Identification of hotspots and methods to manage/ control	Desk study	Yes	Indirect	0-2 years	=3	£10K- £30K	

	Proposed Project	Potential research packages	HE responsible or accountable?	Potential influence on HE policy and/or guidance	Timescale of benefit to HE	HE Priority/rank	Indicative budget	HE
	Pollutants of concern							
10	A robust dataset is lacking to assess whether HE policy needs updating for emerging chemicals of potential concern	More detailed identification of research baseline via literature review for a targeted list of pollutants Focused site based Investigation on pollutants of potential concern in road runoff to gather data Quantitative study on the SRN to be integrated with Microplastics studies described above (refer to Methodology Statement - Appendix B).	Yes	Yes	0-1 years (Lit review) 0-5 years (site works)	=1	£20K Literature review £50K upwards depending on the scale of monitoring To be integrated with Microplastics studies. (To be combined with items 2,3,4,5, costs identified separately)	

Wider Engagement

In lieu of undertaking road runoff sampling and analysis (Task 3 of the original scope of this project) a final task has been proposed to disseminate the findings of this study via a Webinar to the wider research community. This task (5) will involve the identification of potential stakeholders to invite to the webinar based on contacts established and identified during the course of the study. Circulation of a flyer advertising the event will invite the opportunity to participate. Delivery of the webinar to disseminate the study findings and capture feedback within the webinar chat feed.

Deliverables

- Identify a list of stakeholders to invite to the webinar
- Prepare a flyer to advertise the webinar
- Deliver a webinar to disseminate the project findings, initiate relationships for future working and invite feedback

Management and evaluation of feedback from the webinar is not included in the scope of task 5, but it could, for example be used to refine views on research priorities (both for Highways England and the wider research community) or perhaps identify areas of research where collaboration between stakeholders can be encouraged and nurtured.

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APPENDIX A - Literature Review

**Specialist Professional and Technical
Services (SPATS) Framework
Lot 1**

**Task 1-902
Investigation of 'microplastics' from brake and tyre
wear in road runoff
Literature Review Report**

August 2020

Reference Number:

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This document has been issued and amended as follows:

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This report has been prepared for Highways England in accordance with the terms and conditions of appointment stated in the SPaTS Agreement. Atkins CH2M JV cannot accept any responsibility for any use of or reliance on the contents of this report by any third party or for any modifications or enhancements carried out by others.

Executive Summary

This report sets out the findings of the literature review undertaken as part of the Highways England (HE) research project to assess the potential contribution from the strategic road network (SRN) to microplastic pollution in the water environment. There has also been consideration of other forms of pollutants of concern that may have emerged subsequent to research work carried out by the Highways Agency in the two decades up to 2010.

The methodology adopted for the literature review comprised three main components: web searches; a review of “core” literature provided by HE, by members of the Project Steering Group (PSG), and through initial searches undertaken by the project team; and a series of telephone interviews with a selection of key subject matter experts. The review was given focus by selecting two primary research questions (PQ), these being:

- (PQ1) To what extent does the SRN contribute to microplastics in the water environment?
- (PQ2) What is the most appropriate sampling and analysis method to quantify microplastics of key interest to the SRN?

These primary questions were supported by supplementary secondary questions. Both primary and secondary questions were discussed and agreed with the PSG and provided a slight change of emphasis from the original scope.

The web searches were carried out using four academic literature search engines. The initial search, based on title, yielded 387 articles for PQ1 and 254 for PQ2. Core literature was added to the filtered search results to form the final evidence base used to select papers to be read in more depth and from which to extract information relevant to each of the primary questions.

It is clear that this field of research (i.e. microplastic pollution of the water environment) is rapidly evolving and is the subject to an ever increasing body of research. During the course of undertaking the review, numerous new papers have emerged. Re-running the web search terms in March 2020 (some 2 months after the initial searches were applied) provided a further 42 hits for PQ1 and 36 hits for PQ2.

Selected articles were read and information gathered against the secondary questions first, to build a body of evidence to provide a series of responses to the primary questions.

Based on the research, the main sources of microplastics from the SRN are likely to be:

- Tyre, Road and Wear Particles (TRWP) – from abrasion of tyres, and road markings via direct runoff
- Degradation of litter
- Indirect sources from microplastics found in in soils

With tyre wear being the most important contributor. While estimates vary, the literature review suggests that up to 40% of microplastics in the freshwater environment are derived from TRWP. The proportion of this total that could be attributed to the SRN is unclear, although most evidence suggest that urban sources generate greater volumes and concentrations of microplastics, recent work in the UK suggest motorways may be a more significant contributor.

For the purposes of this literature review we are using the following classifications of plastics as found in Robin et al., 2020 which appear to represent the general consensus.

- Macroplastics: >25mm
- Mesoplastics: >5mm <25mm

- Microplastics: >100nm <5mm
- Nanoplastics: <100nm

The Environment Agency has identified other pollutants of concern, potentially generated from, on or via the road network and developed a long list of contaminants that could potentially reach the water environment. From this identified list of pollutants of concern, a short list has been developed (using a filtering process) that warrant further evaluation regarding their occurrence and concentration on the SRN. This includes revisiting some chemicals identified as key pollutants in previous research and that form the basis of existing guidance. However, from the research available, firm conclusions cannot be drawn regarding changes in contaminant type or the emergence of new pollutants of concern since previous HE (formerly Highways Agency) research and there is currently insufficient empirical evidence to suggest whether changes in HE assessment processes are needed.

Microplastics, and particularly TRWP, have been shown to attract and retain materials physically bound or sorbed onto their surfaces and these include persistent organic pollutants, however, as above there is currently insufficient information to warrant changes in HE policy, assessment and standards relating to microplastic pollution derived from the road network.

Since the earlier research, there have been changes in environmental quality standards (EQS) for some key contaminants (most notably PAHs) associated with road runoff. Given that HE guidance with respect to PAHs is based on evaluation of toxicological effects undertaken in previous research programmes (both for soluble and sediment bound pollutants) it may remain appropriate; however, the implications of a significant change in the EQS values for PAHs needs to be considered more fully by HE.

The generation, transport and ultimate destination of microplastics (i.e. source – pathway- receptor linkages) are dependent upon a range of site characteristics, including drained area; traffic volume and behaviour; rainfall volume and intensity; drained area antecedent conditions and location (urban vs rural). These are analogous to the same set of characteristics that influence the concentration and type of runoff derived contaminants (particularly sediments) as identified in previous HE research and that inform current HE policy. SuDS systems, particularly ponds and grassed channels, as already identified in HE requirements and advice documents, would appear to provide significant retention of microplastics (rates of 75-90% have been reported). Heavily influenced by density, the distribution and transport of microplastics is closely linked with that of sediments, but similarities in behaviour between microplastics and sediments still warrant further investigation. There is some evidence to suggest that microplastics may be remobilised from SuDS features, although this research area is less robust and it is not clear whether microplastics are more susceptible to remobilisation than other sediments.

The process of sampling and analysis of microplastics is immature and currently there are no standardised procedures available. Typically samples are dried and sieved, subject to density separation with visual (microscopic) evaluation followed by source characterisation and quantification. A variety of different analysis methods are applied, however the spectroscopic and thermoanalytical techniques used produce results in different units (count vs. mass) which make combination and/or comparison of results difficult. Typically, different techniques are applied to (“rubber” based) TRWPs and to other forms of plastic and this makes differentiation between different types of source particularly difficult. TRWP are typified as elongate, black materials with particle size 5-250 µm and include bound road materials and while polymer composition can help identify plastic sources, analytical methods for typical tyre materials are destructive which can compromise analysis.

Sampling must take into account site characteristics (as above). Microplastics typically accumulate in sediments close to the source (e.g. in depositional areas at pond inlets) but distribution (typically within sediment) varies with depth and distance from the inlet. Event based sampling may be required to fully assess the processes by which microplastics may enter, be retained and (perhaps) leave road drainage networks.

HE policy to address microplastic pollution should focus on where assessment, design, construction or intervention measures are likely to have the biggest impact, however, at the present time, more robust research and more evidence is needed before changes in HE policy are implemented.

As well as pursuing research directly associated with the SRN, HE could contribute significantly to collaborative research including with regulators, vehicle and tyre manufacturers and other industry stakeholders (such as developers of treatment measures).

Following the literature review, the key areas of research that should be pursued in the future are identified as follows:

- Development of standardised sampling and analytical methods
- Develop a greater understanding of sources on the SRN (including from adjacent soils and littering)
- Develop a greater understanding of plastic materials on the SRN including rates of breakdown and the nature, composition and “extent” of sorbed contaminants
- Further understanding of how site characteristics (urban/rural location, weather, road condition, drained area, traffic etc.) influence the generation of microplastics from the SRN and its distribution in the drainage network
- Develop a greater understanding of the distribution and proportions of different types of plastics generated on (and transported via) the SRN
- Develop a more targeted list of other pollutants of concern and undertake focussed investigations (into these) to develop a more robust dataset for evaluation of impacts from road runoff
- Determine to what extent is the SRN facilitating the movement of microplastics.
- Evaluate the efficacy of HE drainage and treatment / mitigation systems and standards (including SuDS systems) in the entrapment/ treatment of microplastics (and their capacity for subsequent remobilisation)
- Develop an understanding of the ultimate fate of microplastics generated from road surfaces (e.g. within the downstream water environment) Evaluate the use of plasticised paints and road markings to determine if these sources might be reduced
- Determine how much roadside litter contributes to the overall load of microplastics and if there are ways of reducing this impact ?

These will be considered in more depth in the final project report.

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APPENDICES

APPENDIX A - Literature Search Results

APPENDIX B – Bibliography

1. Introduction

Scope and Objectives

The scope of the literature review was set out within the overall project scope as follows:

- I. Review of UK and international literature on aquatic pollution from microplastics. This should consider;
 - a. Sources and nature (e.g. particle size) of microplastic pollutants in the aquatic environment and the source apportionment associated with roads and the management of roads.
 - b. The relationship of microplastics with other contaminants such as PAHs and hydrocarbons e.g. adsorption.
 - c. Environmental and human health hazards associated with microplastic aquatic pollution associated with the strategic road network (SRN) corridor and any identified environmental thresholds.
 - d. Field sampling and laboratory analytical techniques for the identification of microplastics
- II. Review of UK and International literature on new/emergent pollutants of concern in road runoff – this should focus on those pollutants not previously monitored by Highways England (i.e. post 2009).
- III. Relevance and applicability of existing guidance in the Design Manual for Roads and Bridges (DMRB) HD 45 and HD 33 (now superseded by LA 113 and CG 501 respectively) in managing any potential risks from microplastics and/or new/emergent pollutants of concern identified in I & II above.
- IV. Consultation, as recommended and agreed with the Project Sponsor, with relevant external organisations in support of I-III above.

This scope was intended to address the key project objective (for the literature review) to:

- Produce a literature review assessing the risk on aquatic pollution from microplastic and other new or pollutants of concern from highway discharges

The approach adopted in undertaking the literature review (see Section 2 below) was intended to meet these requirements through the definition of primary and secondary research questions. Due to limitations of the current available literature, there has been limited scope to consider environmental and human health hazards (item I (c)), and following discussion with the Project Steering Group (PSG) this element has been given a lower priority in the literature review, as reflected in the primary and secondary research questions adopted.

The consultation process (item IV above) has been undertaken primarily through the Project Steering Group (PSG) but also through structured telephone interviews (see also Section 2) conducted as part of the project.

Report Layout

Section 2 of this report sets out the overall approach to undertaking the literature review, including the overarching methodology and establishing the research questions. It describes the techniques adopted in undertaking web-based literature searches, including the search engines and search terms utilised, and sets out how the telephone interviews were established and completed.

Section 3 provides the methods adopted to refine and filter the literature to extract the relevant information. Spreadsheets, were developed and used to identify, categorise, “rank” and order retrieved works of literature according to their relevance to the primary and secondary research questions. To retain this record, these spreadsheets will be provided separately in digital format.

Section 4 provides the findings in detail. The layout of this section reflects the approach to providing a response to the primary research questions, in that the secondary questions are addressed first,

Section 5 summarises these findings and identifies common themes and key areas of research to be promoted going forward.

Section 6 provides references and a list of acronyms. A full bibliography is provided in Appendix B.

2. Approach

Literature review methodology

At the Inception Meeting (17.10.19) it was agreed that the course of the literature review would be fundamentally driven by the selection of suitable “research questions” to provide an appropriate focus. Primary and secondary research questions were established and subject to discussion and agreement at the first PSG Meeting (21.11.19).

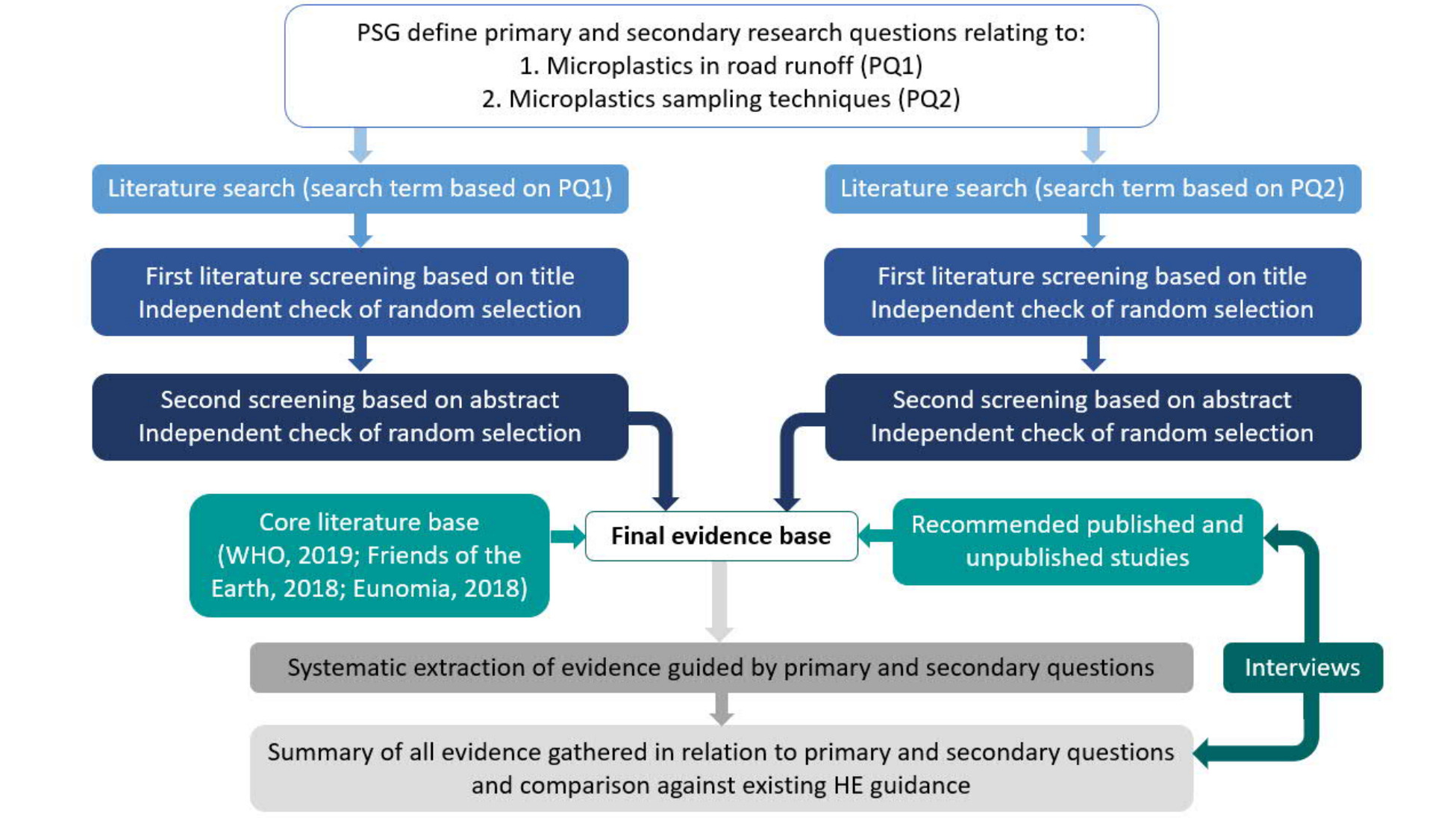
The basic approach adopted for the literature review followed a structured, tiered methodology that incorporated a check/review process as it progressed. These methods were also discussed and agreed with the PSG.

Similarly, a structured approach was adopted for telephone interviews. These were conducted with a small number of selected experts representing a cross section of academia, regulatory bodies and industry practitioners. The telephone interview process is described more fully below.

The overall output from the literature review combines evidence collected through web searches (see further below), from core literature (for example that provided by Highways England (HE) and the PSG and from the telephone interviews.

The overall approach is summarised in Figure 2.1 below.

Figure 2.1 Literature Review Methodology



Establishing the research questions

The fundamental aim of the research questions was to help meet the primary project objectives which are to:

- Assess the risk of aquatic pollution from microplastic and other new or 'pollutants of concern from highway discharges
- Establish the presence or absence of microplastics and other agreed pollutants in road runoff

In addition, evidence gathered in the literature would be used to inform methods of sampling and analysis to be proposed for the next stage of the project and to inform the associated Method Statement.

Furthermore, the research questions were intended to address other project objectives to:

- Provide recommendations on potential further Research and Development (R&D)
- Determine the need for changes to current policy in DMRB or existing HE management practices

On this basis, two primary research questions were identified, with these, in turn, supported by a group of secondary questions. After initial proposals made during project inception, these primary and secondary research questions were presented to, discussed and agreed with the PSG. Whilst some of these (agreed) questions may not explicitly correspond to some elements of the original scope (for example size of microplastics), the questions were chosen to provide the most useful results against overall project aims.

The finalised research questions are as follows:

Primary question (PQ1)

- To what extent does the SRN contribute to microplastics in the water environment?

Secondary questions (PQ1)

- What are the main sources of microplastics on the SRN?
- What has changed in terms of pollutants in road runoff since 2010?
- What are the implications for HE policy?
- What essential future research activities can be identified and what would be their indicative budget?

Primary question (PQ2)

- What is the most appropriate sampling and analysis method to quantify microplastics of key interest to the SRN?

Secondary questions (PQ2)

- Are robust and repeatable techniques under development for quantifying microplastics?
- What are key site characteristics and conditions for sampling microplastics on the SRN?
- To what extent can the SRN as a source of microplastics be differentiated from other (e.g. airborne) sources?

Web searches

The primary research questions, identified in the previous section, were converted into search terms which were used in the following four search engines in order to extract relevant literature:

- Web of Science
- Science Direct
- Scopus
- Google Scholar

A number of different search terms were trialed, with different combinations used to constrain the number of hits obtained. These varied significantly from over 5000 hits for more wide-ranging search terms to less than 10 for more constrained searches. Some of the searches were producing large numbers of clearly irrelevant results. The final selected search terms, identified below, were derived iteratively and through discussion within the team.

The selected search terms used were:

- Primary question 1: ((microplastic\$ OR plastic\$) AND (road\$ OR runoff OR highway\$ OR tire\$ OR tyre\$) AND (source\$ OR contribut* OR origin*))
- Primary question 2: (microplastic\$ OR plastic\$) AND (sampl* OR analys* OR detect* OR quantif*) AND method* AND (road\$ OR runoff OR highway\$ OR tire\$ OR tyre\$)

The Boolean operator '\$' allows for both the singular and plural version of a word to be included within the search, whereas the wildcard '*' allows for that word/text to be completed with any combination of letters. The search terms were built up based on the key terms within each primary question. For example, with primary question 1 (To what extent does the SRN contribute to microplastics in the water environment?):

- The first section of the search means that microplastic, microplastics, plastic or plastics must be present
- The second section of the search means that road, roads, runoff, highway, highways, tire, tires, tyre or tyres must be present
- The final section of the search means that source, sources, contribute, contribution etc., origin, origins or originates etc. must be present

As the sections are linked together with an 'AND' a term must be found within each of the elements in order to return a hit. American and British terms (highway/road, tire/tyre) have both been used to avoid excluding any research.

The Science Direct search engine restricts the number of Boolean operators and does not accept wildcards, therefore the searches had to be altered and split for this search engine, and results combined. The search was restricted to the last five years for all search engines, as this is a new science and techniques are developing readily, and results were ordered by relevance. All results from the search engines for each of the primary questions are shown in Appendix A, along with the exact search terms used and the number of hits from each search engine.

The Scopus search engine resulted in many hits (340 for primary question 1 and 443 for primary question 2). For primary question 2, a spot check of 10 hits beyond the top 150 hits (ranked by relevance) indicated that these results were not at all relevant to the selected primary questions. Therefore, for primary question 2 only the top 150 hits from Scopus were carried through to the next step in the process.

Google Scholar allows searches to be undertaken either anywhere in the article, or in the title of the article only. Searching anywhere in the article resulted in thousands of hits and searching in the title of

the article only resulted in zero hits for both primary question 1 and primary question 2. This is not unexpected and has occurred in other literature searches and is due to the breadth of the first search and the restriction of the second search, rather than search terms being looked for in title, abstract and key words as for other search engines. Therefore, it was not possible to use Google Scholar in this literature review.

The results from each search engine were combined and duplicate results removed to give the final full record, which formed the basis for subsequent filtering (see Section 3). This resulted in 387 articles for primary question 1 and 254 articles for primary question 2 (Table 2.1).

Table 2.1. Number of hits from each search engine (undertaken 6th/7th/9th/10th January 2020)

	Number of hits for each search engine				Full Record
	Web of Science	Science Direct	Scopus	Google Scholar	
Primary question 1	170	66	340	0	387
Primary question 2	141	79	443 (capped at top 150)	0	254

A limitation of using search terms is that potentially relevant literature may not be picked up since the search terms are strictly defined and there is a chance that potentially relevant literature may not include these terms and meet the criteria. However, other (core) sources of literature were included within this study, i.e. those:

- Recommended by the PSG
- Identified during the telephone interviews
- Found during a general internet search early on in the project (see Section 3)

Hence there were numerous sources of literature used within this project that increased the likelihood of picking up most of the relevant literature.

A further limitation to the searches is that irrelevant literature is also picked up using the selected search terms (for example plastic surgery associated with road accidents was often found). However, as noted above, when very large numbers of hits were returned, ordering the literature by relevance, and then capping the searches at the top 150 where relevant, helped to provide focus.

The searches were re-run towards the end of the review period (5th March 2020, approximately two months after the first searches) and the number of hits for each search engine were noted to provide an indication of how 'active' this research area is for literature publication (Table 2.2). The results indicated that there has been additional literature published in the intervening two months, with an additional 42 hits for primary question 1 and an additional 36 hits for primary question 2, although some of these hits may be duplicated literature between the different search engines.

Table 2.2. Number of hits from each search engine on 5th March 2020

	Number of hits for each search engine			
	Web of Science	Science Direct	Scopus	Google Scholar
Primary question 1	184	67	367	0
Primary question 2	149	83	467	0

Telephone Interviews

To complement the literature review and with the aim of gathering additional information, the project team undertook a series of telephone interviews with selected contacts. A list of potential interviewees was produced with the assistance of the PSG, selected due to their known involvement in microplastic research and/or being key stakeholders affected by issues related to the prevalence of microplastics in the environment.

From this initial list, six people were shortlisted to be contacted formally and invited to take part in a telephone interview. This shortlist was selected to represent an even distribution of knowledge on the sources, pathways and receptors of microplastics as well as the analytical perspective to gather unpublished information from the microplastics community. Four accepted the invitation and were interviewed (see Table 2.3). All four interviewees were asked the same primary and secondary research questions (PQ1 and PQ2) that formed the basis of the Literature Review.

Table 2.3 Telephone interviewees

Name of Interviewee	Organisation	Sector	Justification for selection
Joanna Bradley	SDS Ltd	Manufacturer of Water Infrastructure Systems	Practical insight on pathways and possible treatment options (also former EA water quality specialist in road drainage)
Judy Proctor	Environment Agency	Regulation	Environment and Business (E&B) Future Regulation Plastics Strategy Lead
Hasmitta Stewart	Defra	Regulation	Senior Scientific Adviser for Priority substances in surface waters.
Richard Thompson	University of Plymouth	Academia	Lead author on Defra funded project investigating microplastics from tyre wear in the environment (yet to be published) and subject matter expert on sampling and analysis techniques for microplastics.

Each interview conducted lasted 1 hour, after which a typed transcript of the discussion was sent (via email) to each of the interviewees for review and agreement. This provided the opportunity to make changes before a final version of the transcript was produced. This final version was emailed to each interviewee explaining information in this 'approved' document would be used to inform our Literature Review. Copies of all four approved telephone interview transcripts have been retained for project records.

3. Filtering, Extracting and Recording Information

Filters applied

A two-stage filtering process was undertaken on the identified literature in order to select the most appropriate works to read in more depth and to extract information. This filtering process was undertaken on both the literature identified through the web search (as above) and additional literature, (herein referred to as 'core literature'), that had been identified through others means (i.e. telephone interviews, Project Steering Group, early project "general searches").

In the first step, titles were read by members of the research team and categorised into 'relevant (R)', somewhat relevant (SR) and not relevant (NR). The literature identified as 'relevant (R)' and 'somewhat relevant (SR)' was then taken on to the second step, whereby the abstracts were read. These were further categorised as 'relevant (R)' or 'not relevant (NR)'. Only literature identified as 'relevant (R)' at this second stage was read in depth and used to form the basis of information extraction.

A sub-section of the filtering process was checked by another member of the research team to ensure consistency in applying these "rules" (as per guidelines in Collins et al. 2015). This resulted in 82 pieces of literature for primary question 1 (comprising 49 from the web search and 33 from the core literature) and 50 pieces of literature for primary question 2 (comprising 18 from the web search and 32 from the core literature). The literature in each category in the filtering process is shown below in Table 3.1.

Table 3.1. Literature filtering

	Pieces of literature		
	Relevant (R)	Somewhat relevant (SR)	Not relevant (NR)
Primary question 1			
Web search			
Stage 1: Title filtering	63	73	251
Stage 2: Abstract filtering	49	N/A	87
Core literature			
Stage 1: Title filtering	34	31	10
Stage 2: Abstract filtering	33	N/A	32
Primary question 2			
Web search			
Stage 1: Title filtering	15	8	231
Stage 2: Abstract filtering	18	N/A	5
Core literature			
Stage 1: Title filtering	25	38	12
Stage 2: Abstract filtering	32	N/A	31

Extracting information

After all filters had been applied, papers marked as "relevant" were sourced. Once a copy of the paper/article/report had been obtained this was read in full, picking out pertinent information related to answering primary and secondary questions. Notes made for each paper/article/report were then distilled and findings presented in Section 4. Where pertinent information extracted from "relevant" sources was credited to other author(s) then it is this original author that has been cited in the literature review and subsequently documented in the reference list.

A table of all paper/article/reports read and used to compile our Literature Review are presented in the bibliography provided in Appendix B.

4. Findings

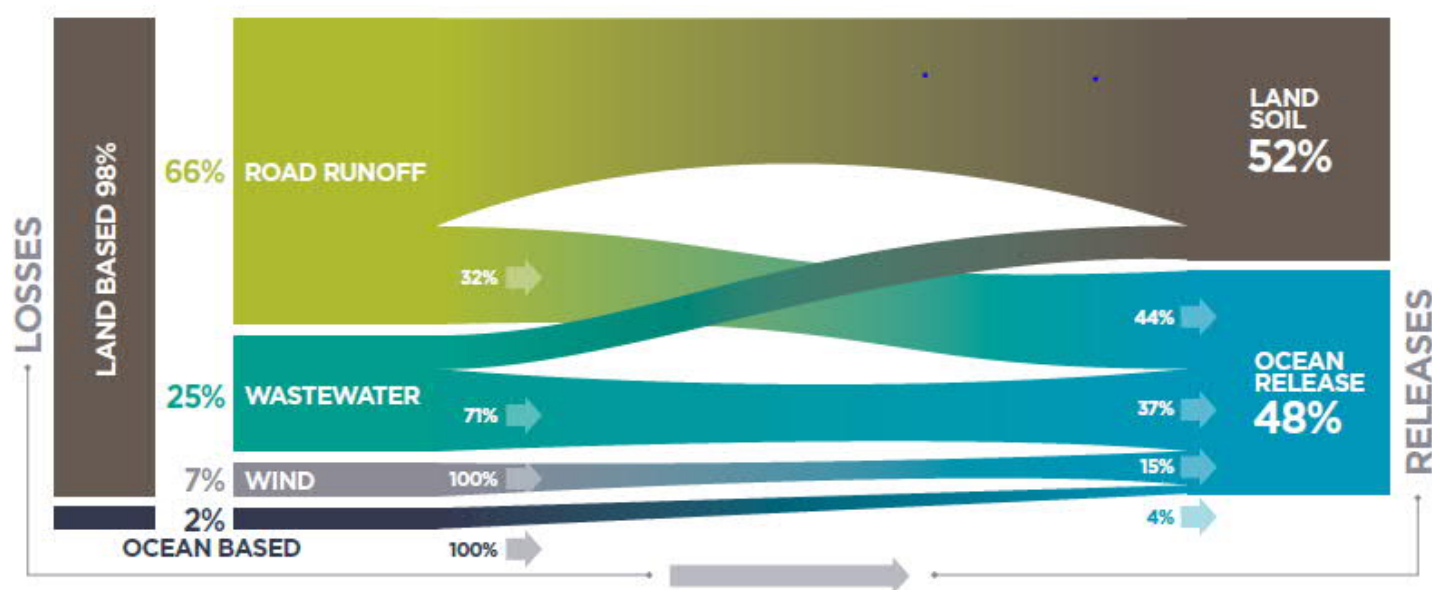
Introduction and background

Plastic production has risen substantially over the last ~65 years during which 6300 million metric tons have been produced (as of 2015) (Geyer et al., 2017). Best estimates suggest of this plastic total only ~9% has been recycled, 12% incinerated and 79% ends in landfills or is discarded into the natural environment (Geyer et al., 2017). Consequently, due to often taking hundreds of years to degrade, the vast majority of plastic produced to date is still present in the environment in some form (Barnes et al., 2009; Thompson et al., 2005).

Most plastic and rubber types have low water solubility as a common general characteristic, which means that components made of these materials will not dissolve, disappear, or dilute in aquatic environments (Verschoor, 2015). Although broadly outside of the scope of this study, it is worth noting that this longevity poses a threat to numerous animal species across multiple and variable food chains, as ingesting plastic pollutants slow growth and increase morbidity (Browne et al., 2013; Rochman et al., 2013; Fu & Wang, 2019). Plastics can leach toxic chemicals and bioaccumulate in food therefore their environmental risk threat extends to higher trophic levels, including human ones (Karbalaie et al., 2018). Globally each year over 322 million tonnes of plastic are produced, and this is increasing (European Commission, 2018) therefore the issue of plastic pollution for society (for reasons outlined above) is likely to continue for generations to come (Vaughan et al., 2017).

Plastic pollution in the world's oceans has received a lot of popular media attention over the last few years, however 70-80% of sea litter originates from land (Horton et al., 2017b; Galafassi et al., 2019) and annual plastic release to terrestrial environments is estimated to be 4-23 times that released to oceans (Horton et al., 2017b). Modelling studies (i.e. not based on direct sampling and analysis) by the International Union for Conservation of Nature (IUCN) (Boucher and Friot, 2017) suggest that the global contribution of microplastics from the land mass is even greater (98%), with road runoff acting as the most important pathway (see Figure 4.1 below).

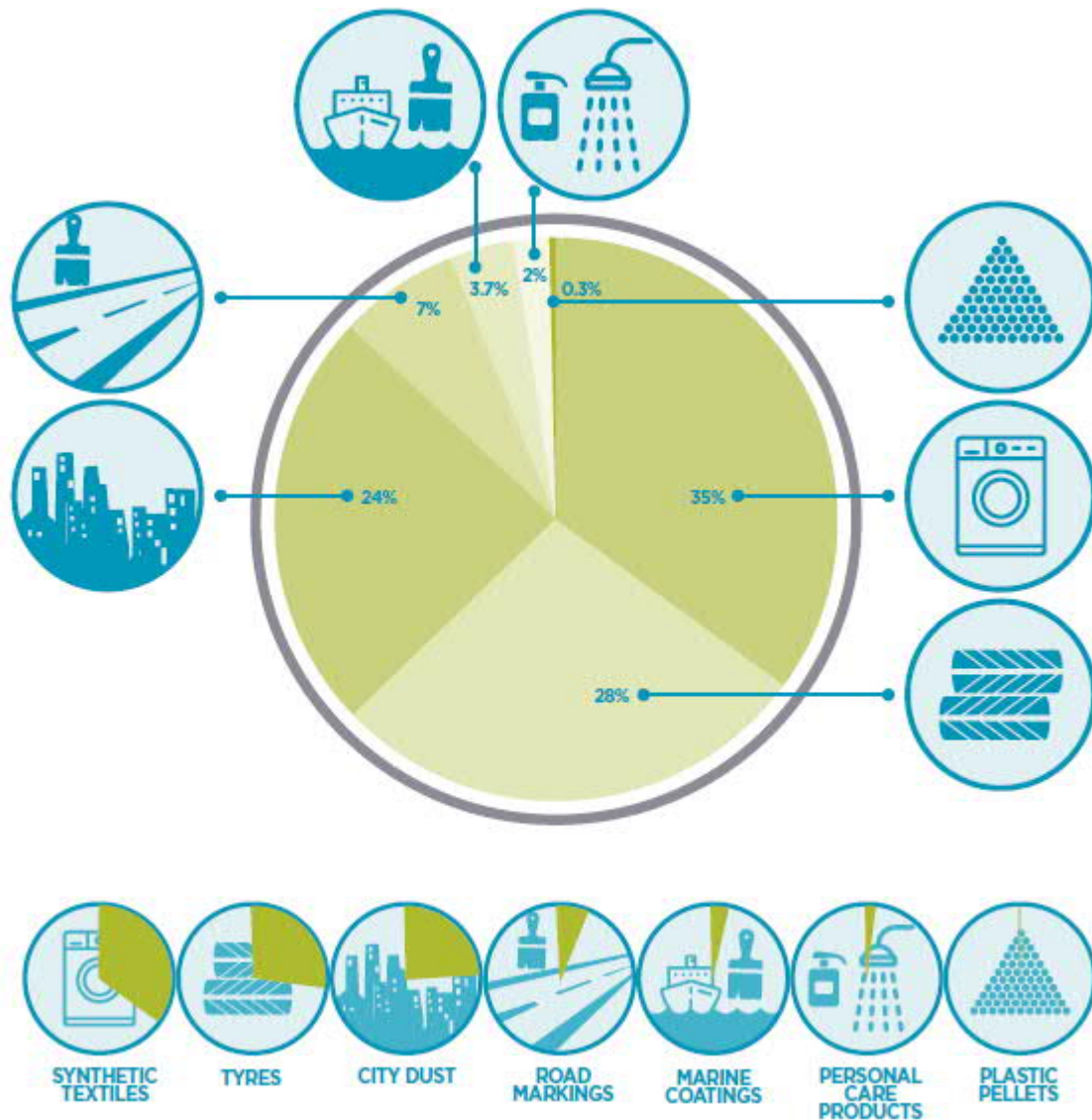
Figure 4.1 Global microplastic release and pathways to the world's oceans (Boucher and Friot, 2017)



Studies are now consistently reporting evidence that the most significant sources of plastics in the environment originate from laundry fibres (Dris et al., 2017) and abrasion of tyres, brakes and road markings (Sundt et al., 2014; Lassen et al., 2015; Sherrington et al., 2016; Boucher and Friot, 2017; Bondelind et al., 2019). Based on their modelling studies, the IUCN (Boucher and Friot, 2017) provide

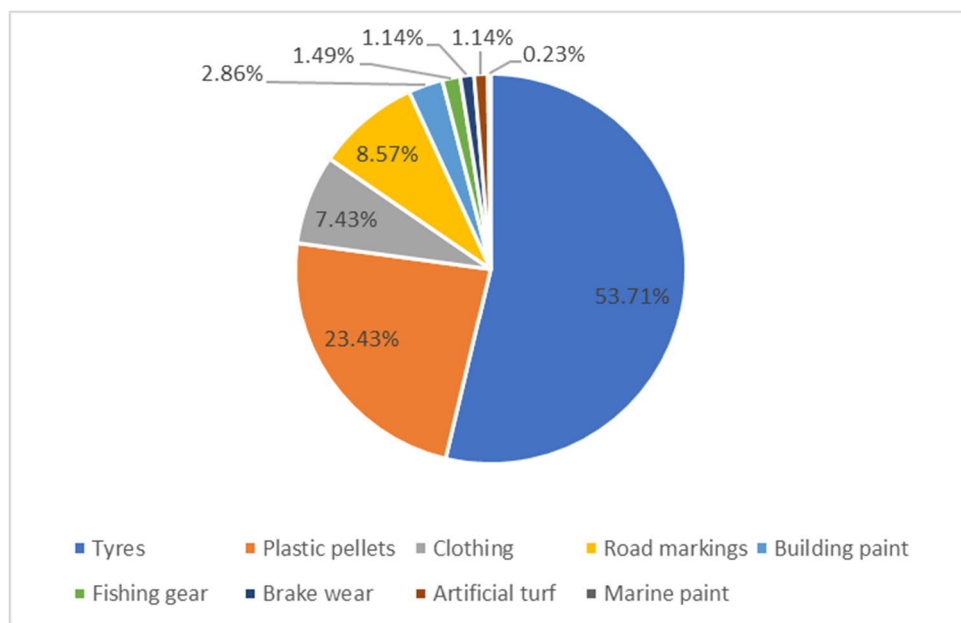
an illustration (Figure 4.2 below) of the contribution of different sources of microplastics to oceans, with tyre wear and road makings making up a significant contribution (28% and 7% respectively)

Figure 4.2 Global releases of primary microplastics to the world's oceans (Boucher and Friot, 2017)



Similarly, The Eunomia report (Hann et al. ,2018) used pathway modelling to draw together source data for microplastics emitted by different products to the aquatic environment (with seas as the ultimate receptor). This study attributed a greater proportion of the sources to tyre wear (see Figure 4.3 below) than the IUCN study and more than in most of the literature reviewed, but otherwise provides a useful breakdown of sources.

Figure 4.3 Annual (2017) microplastic emissions to surface waters (after Hann et al 2018)



Of particular interest to this study are plastics sourced from tyre and brake wear and associated other sources such as road markings. To describe this group of sources collectively, the term Tyre Road and Wear Particle (TRWP¹) is used and describes hetero-aggregates of abraded tyre material with road material and other particles deposited on the road (Kreider et al., 2010).

Like all plastics, TRWPs can breakdown into smaller particle sizes without degradation. These 'secondary' plastics (those generated by the breakdown of larger plastics) are believed to be the main source of plastic particles in aquatic environments (Eerkes-Medrano et al., 2015). This is backed up by studies in urban areas which concluded that the majority of microplastics found were of a "secondary" nature (Horton et al., 2017a; Pinon-Colin et al., 2019). Mechanisms enabling this breakdown range from mechanical degradation and physical weathering, to chemical degradation (exposure to acids and alkaline substances and UV radiation) and biological transformation (ingestion and degrading by organisms) (Auta et al., 2017; Horton & Dixon, 2017).

Commonly TRWPs are referred to as 'microplastics' based on their size and it is important to establish definitions of various plastic sizes. However, there is currently no uniform plastic classification and sizing guide with researchers using different definitions (Bondelind et al., 2019; SAM, 2018; Kole et al., 2017; Martinelli et al., 2018; Robin et al., 2020; Vogelsang et al., 2019). A good summary of these differences is presented by Blair et al., 2017. For the purposes of this literature review we are using the following classifications as found in Robin et al., 2020.

- Macroplastics: >25mm
- Mesoplastics: >5mm <25mm
- Microplastics: >100nm <5mm
- Nanoplastics: <100nm

These were also the most commonly used size ranges identified during our literature research when referring to different sizes of plastics.

¹ This acronym is in regular use and is used throughout this report

For this study, the term 'microplastic(s)' is perhaps the most crucial to define. The term microplastics, herein, will be used to describe any particle <5mm in diameter and >100nm. Where necessary, the term large microplastics will cover particles sized between 1-5mm and small microplastics will refer to particles <1mm in diameter (CIWEM, 2017).

Whilst it is widely acknowledged research needs to be increased to improve the understanding (and identification) of sources and impacts of microplastics (European Commission, 2018), accurately quantifying these sources remains a significant scientific challenge (Kole et al. 2017; Halle et al., 2020). Based on this literature review, there is a clear need for (international) standardised methods for analysis, quantification and units used for microplastics (Horton et al. 2017b; Sutton et al., 2019). This is covered further in the responses to primary question 2 below. Taking this step would facilitate more direct comparison of results from different studies (Fu & Wang, 2019; H Stewart 2020, pers.com. 29th January). This will require wider cross-sector collaboration to develop consistent and effective methodologies for sampling and analysis (J Proctor 2020, pers.com. 30th January).

Presentation of results

This section presents the findings of the literature review. This information has been collated and summarised, drawing upon all methods of data gathering used for this project ("core" literature provided by the PSG, specific literature web search results and subsequent filtering processes and telephone interviews).

The secondary questions are explored in turn before a collated summary is presented addressing each primary question. In addition, common themes identified whilst conducting this literature review are outlined.

Primary research question 1

As set out in Section 2, primary question 1 and its associated secondary research questions are as follows:

Primary question.

- To what extent does the SRN contribute to microplastics in the water environment?

Secondary questions.

- 1a. What are the main sources of microplastics on the SRN?
- 1b. What has changed in terms of the types and occurrence of predominant pollutants in road runoff since 2010?
- 1c. What are the implications, of the changes discussed in question 1b, for Highways England policy (most specifically related to microplastics)?
- 1d. What essential future research activities can be identified to better understand the contribution of road runoff to *microplastic pollution* and what would be their indicative budget?

Note: Italicised terms were added for greater clarity

Secondary question 1a. What are the main sources of microplastics on the SRN?

Road runoff is documented globally as a direct pathway for land based microplastics entering watercourses (Lozoya et al., 2016; Horton et al., 2017a&b; Pinon-Colin et al., 2019; Vaughan et al., 2017; Kibblewhite, 2018; Li et al., 2018; Tang et al., 2018; Bauer-Civiello et al., 2019; Boucher et al., 2019; Dikareva & Simon, 2019; Ziajahromi et al., 2020). Road runoff via drainage ditches (storm drains from roads including networks receiving agricultural runoff) contains vehicle derived microplastics which represents a significant source of riverine microplastic load (Browne et al., 2010;

Eriksen et al., 2013; Galgani et al., 2015; Tibbetts, 2015; Horton et al., 2017a; Robin et al., 2020). It has recently been estimated, from urbanised watersheds, that 29% of microplastics are sourced from tyres with road markings contributing an additional 7% (Birch et al., 2020), see also Figure 4.4 below.

Plastic contamination is highly dynamic and is largely controlled and influenced by surface runoff during rainfall events (Hillenbrand et al., 2005; Cheung et al., 2019). The start of any rainfall event is more important than the end as the debris load will be higher as it has had a chance to build up in antecedent conditions prior to the 'first flush' of rainfall (Cheung et al., 2019;). Hence the 'first flush', in the early part of a storm event on the rising limb of a hydrograph, can see the biggest concentration of microplastics being re-suspended and mobilised (Cheung et al., 2019; Kibblewhite, 2018; Ziajahromi et al. 2020). However, earlier research for the Highways Agency (Crabtree et al., 2008) suggested that "first flush" may not be an appropriate model for contaminant generation and migration from road drainage (including of suspended sediments) and it is the peak hydrograph that is associated with the highest contaminant load, albeit at lower concentration. However, requirements within current HE design standards (i.e. Design of highway drainage systems. CG 501²; Highways England 2019a) advise that drainage design should be undertaken to address the first flush to capture the maximum amount of potential pollutants generated within a storm event.

When the make-up of microplastics in road runoff solutions is examined the main/direct sources can be attributed to: tyres and brake wear, road markings (TRWPs), and litter degrading (Horton et al., 2017a; Fahrenfeld et al., 2019; Kole et al. 2017; Blasing & Amelung, 2018; Sommer et al., 2018; Wagner et al., 2018; Boucher et al., 2019; Rhodes, 2019). Although of less significance (than the above), paint from road signs and accidental spillage of pre-production plastic pellets (Galafassi et al., 2019) have also been acknowledged as a direct source of microplastics from the SRN.

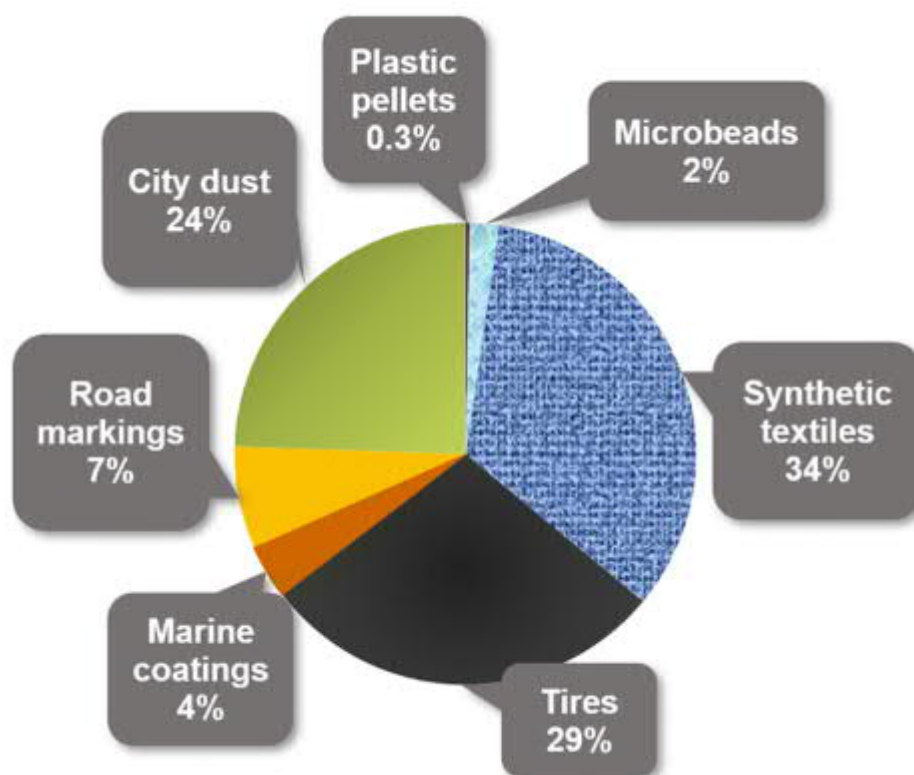
In determining the proportion of sources attributable to road runoff, it is not wholly appropriate to synthesise results from different papers in that many adopt different approaches (e.g. modelling), and sampling and analytical techniques so combining results from different literature sources is a little unrealistic.

Some examples of the percentage contribution from different sources of microplastics are available, as provided in the introduction to this section, although these are not specific to road runoff. As a further example (again not specific to road runoff) it has recently been estimated, from urbanised watersheds, 29% of microplastics are sourced from tyres, with road markings contributing an additional 7% (Birch et al., 2020), with textiles and city dust identified as other major sources (see Fig 4.4 below). However, urban and rural road sources may differ (and bearing in mind the SRN is predominantly rural) so this may not properly represent source distribution from the SRN.

Despite this distinction between urban and rural environments and contrary to previous reports, in recent work in the UK (Parker-Jurd et al., 2019), it has been suggested that motorways may provide a greater contribution to tyre wear derived microplastics than that from urban environments.

² Subsequent references to this document will simply be as CG 501

Figure 4.4 Sources of microplastics in urban watersheds (after Birch et al 2020)



TRWP

Estimates vary but evidence suggests that globally, between ~30-40% of microplastics passing from freshwater systems to oceans are sourced from TRWPs (Boucher & Friot, 2017; Siegfried et al., 2017). For many studies, TRWP also represented the majority (i.e. largest source) of microplastics deposited in the environment (Brate et al., 2014; Lassen et al., 2015; Boucher & Friot, 2017; Kole et al., 2017; Wagner et al., 2018; Halle et al., 2020).

Of all TRWPs produced, ~2% is thought to be <10µm and probably sourced from atmospheric deposition, the remaining 98% is distributed between direct runoff (49%) and roadside soil (49%) (Unice et al., 2018 a&b). TRWP emissions vary with vehicle type (car, bus, truck) driving characteristics, including average speed and road type (urban or highway) (Sommer et al., 2018; Unice et al., 2018a&b; Sieber et al., 2020). Despite this evidence, there is limited consistent, robust and quantitative knowledge of TRWP concentrations (and consequently accurate flux budgets) released from road networks (Unice et al., 2018a&b). This is partly due to limitations in the sampling and analytical methods available for their determination (Klockner et al., 2019).

With particular relation to tyres, studies have suggested anything between 10-30% (by mass) of the synthetic rubber in the tyre is lost over the tyre's lifetime (Wik and Dave, 2009; Grigoratos & Martini, 2014; Boucher & Friot, 2017). With an annual consumption of about 7 Megatonnes (a megatonne (Mt) is equivalent to 10⁶ metric tonnes) of synthetic rubber for tyres (ETRMA, 2011) and assuming that the annual consumption is constant over time, an annual loss of 1.4 Mt of microplastic to the environment has been estimated (UN Environment, 2018). These figures compare well with other research which estimate a total of ~3.0 Mt of microplastics are lost globally with losses primarily derived from abrasion of polymer-containing products, 47% attributed to tyres (Ryberg et al., 2019). In relation to specific figures for road markings, it is estimated 0.59Mt per year of microplastic pollution can be attributed to this source (Boucher & Friot, 2017) and this matches well with Ryberg et al.,

(2019) who calculated that 19% of the total ~3Mt of microplastics are associated with sources from road markings.

An extensive summary table of quantified sources (worldwide) is available in Table 2 of Galafassi et al., 2019) but in Europe much of work quantifying microplastic pollution from roads has been undertaken in Scandinavia the Netherlands and Germany. In Denmark, it is estimated TRWPs contributed up to 5.6k tonnes to annual microplastic pollution, representing 26% of total plastic loads (Auta et al., 2017). A study in Sweden indicated inputs from tyres and road abrasion proved to be a dominant source of microplastic pollution contributing to 13k tonnes of microplastics being released annually (Magnusson et al., 2016). In Germany, the mass of TRWPs emissions was higher still at 48k tonnes per year (Wagner et al., 2018).

There is generally little evidence of extensive research into microplastic pollution from UK roads (whether urban or rural). However, a recent report prepared for Defra (Parker-Jurd et al., 2019), investigated sources and pathways of vehicle tyres from roads in south west of England. It found the most important pathway for tyre particles entering the aquatic environment were storm water discharges from road networks. Tyre particles were abundant within 50m of motorways and the report comments they represent a substantial source of total microplastics export compared to other known sources, (e.g., fibres and microbeads from cosmetics). Although the report does not quantify or apportion the contribution from tyre particles, it concludes that previous studies have likely underestimated the total load of microplastics that have been exported / accumulated in the environment, including those derived from tyre particles sourced from road networks.

As another indicator of the scale of the contribution from TRWPs as a source of microplastics, it has been estimated that plastic waste from TRWP that ends up in the sea is comparable to the total amount of plastic bottles, bags and fibres (Boucher & Friot, 2017; Kole et al., 2017; Sutton et al., 2019). Furthermore, as more roads are built and car ownership increases (worldwide), microplastic pollution from TRWPs will most likely increase (Galafassi et al., 2019). As a consequence, TRWP pollution “should sit higher on political agenda and emission reduction of tyre wear should be given a higher priority than it currently receives” (Kole et al., 2017).

Indirect Sources

Soils, next to roads could be a source of microplastic pollution. There is evidence that suggests that approximately 80% of all TRWPs are deposited within 5m of the road (Fauser et al., 1999) with up to 75% of this total remaining within roadside soils (Wagner et al., 2018). Evidence from the UK, (Parker-Jurd et al., 2019), cited above, also suggests microplastics are prevalent adjacent to roads. TRWPs are generally held in the upper 1cm of the soil and there is no downward migration (Fauser et al., 2002) so microplastics within the soil are readily available to be mobilised during storm events, if that ground is disturbed. On this basis, the permeable areas adjacent to road drainage networks may constitute a significant source.

In many cases, agricultural land surrounding the SRN will be subject to spreading of sewage sludge, a material that is generally highly contaminated with microplastics (Tang et al., 2018; Fu & Wang, 2019, Fahrenfeld et al., 2019). Microplastics in sewage sludge are not yet considered contaminants under environmental regulations (Galafassi et al., 2019) but the quantities of plastics in sludge application may exceed 430k tonnes annually – which is higher than the mass currently estimated present in global ocean (estimated upper limit of 236k tonnes) (Nizzetto et al., 2016). Other agricultural plastics use, such as break down products from polytunnels, may also be a source of microplastics (Horton et al., 2017b). Therefore, if they ultimately discharge into road drainage, for example via land drains, the sheer volume of microplastics in soils surrounding the SRN, can make soils a significant potential source of microplastics entering road drainage systems (Horton et al., 2017a&b; Blasing & Amelung, 2018).

The other main indirect sources of microplastics to the SRN are deposited via air deposition. Examples of these air-borne particles deposited include clothing fibres and synthetics, sources from landfill or fumes from incineration of waste (Dris et al., 2017).

Role of the SRN drainage infrastructure

Drainage infrastructure on the SRN, such as retention ponds and sediment basins, can act as sinks for microplastics. Sedimentation is identified to be the most important mechanism for trapping microplastic (and other suspended contaminants) pollution (Vogelsang et al., 2019; Robertson et al., 2019). Retention ponds / sediment basins can act as a sink for microplastic and have a critical role in managing microplastic transport in the environment (Olesen et al., 2019). The settling tendency of microplastics is largely controlled by their density (similarly to sediments) so not all particles will sink/settle and not all will be trapped by settlement systems, and those that do settle may be remobilised by more intense water flow. Whilst this will clearly depend on the nature and source of the microplastics and the design of the retention system, in general terms the proportion of particles which settle to those which do not, remains unclear.

The current HE design standard, CG 501, provides a range of potential treatment efficiencies for suspended solids (amongst other contaminants). For suspended solids these vary from 40% for sedimentation tanks, 60% for wet (retention) ponds up to 80% for grassed channels and swales.

Various studies provide estimated retention efficiencies. For microplastics in ponds (Olesen et al., 2019; Sieber et al., 2020) there is a suggested rate of 85-90% and this is similar to that (albeit a little higher) of suspended solid treatment efficiencies quoted for retention ponds (70%) in the CIRIA SuDS Manual (Woods Ballard et al 2015), and also higher than that (for suspended solids) suggested in the HE standard (CG 501). In other studies, swales/grassed channels and detention basins showed removal (effectively retention) efficiencies of TRWP of up to 75% (Unice et al., 2018; Wagner et al., 2018) and in some cases generic efficiencies were up to 90% (Besseling et al. 2017; Siegfried et al., 2017).

The physical characteristics of microplastic particles including size, and in particular density, are the most important factors influencing microplastic settling tendency, i.e., how easily are they retained in or with sediments, (Horton et al., 2017b, Besseling et al., 2017). Perhaps intuitively, bigger heavier particles tend to settle faster and are generally found in large abundances in sediment at inlets of basins (or further upstream in the drainage network) whereas smaller sized particles were found in the water column at basin outlets (Besseling et al., 2017 & Unice et al. 2018 a&b; Ziajahromi et al. 2020). It has been noted, basins associated with road drainage have the potential to capture, retain and potentially degrade up, to 90% of the TRWPs prior to eventual “export” (Unice et al. 2018).

Through appropriate design, monitoring the retention efficiency and managing sediment removal appropriately, SuDS can help ensure these drainage assets remain sinks for microplastic pollution (Liu et al 2019 a&b; Olesen et al., 2019). However, if the basins are not designed appropriately (for example by insufficient storage or retention time) or are not regularly maintained (allowing a build-up of retained microplastics that may be subsequently re- mobilised) there is potential that SuDS basins could cease being effective sinks of microplastic from the SRN and merely act as a pathway to the wider environment (Liu et al., 2019a).

Other factors affecting concentration of microplastics deposited on SRN

Evidence suggests the scale of inputs of microplastics from the sources outlined above are controlled by the spatial position of any road network. Positive correlations have been found between microplastics concentration and areas of increased urbanisation (Dris et al., 2017; Horton et al., 2017a; Tang et al., 2018; Yukoika et al., 2019; Sieber et al., 2020). A study in Denmark concluded surrounding land use influenced the types and quantities of microplastics captured (Liu et al., 2019).

Other studies have shown microplastic pollution has a clear spatial signal with distance from urban centres (Wang et al., 2017; Tang et al., 2018; Robin et al., 2020), traffic flows (Abbasi et al., 2017; Sommer et al., 2018) and industrial land use (Pinon-Colin et al., 2019). Still, in many studies microplastic content from road runoff treatment systems and surrounding soils are found to be highly variable. Factors contributing to (or determining) microplastic concentrations in runoff and soils need to be better understood and these include surrounding land use, traffic volumes/density and driving behaviours (e.g., more congestion leads to more acceleration and braking leading to more tyre abrasion) (Klockner et al., 2019).

Secondary question 1b. What has changed in terms of the types and occurrence of predominant pollutants in road runoff since 2010?

HE Research to 2010

In the two decades to 2010, The Highways Agency (HA, now HE) invested significantly in research (e.g. Gaskell, P., et al, 2007; Crabtree et al., 2008; Scott Wilson, 2010) to determine the polluting potential of road runoff both to surface water and groundwater. These research programmes, which included extensive monitoring and testing of road runoff from wide ranging sample sites, have formed the basis of HE policy and standards with respect to protection of the water environment from pollutants generated from road runoff, particularly the current standards CG 501 and LA 113 - Road drainage and the water environment (Highways England 2019a,b³).

Initial reviews identified sediments, hydrocarbons, metals, salts and nutrients, bacteria and other chemicals (such as herbicides) as potential contaminants within road runoff. Subsequent runoff water sampling studies undertook analyses for a wide range of metals (Cu, Zn, Cd, Al, Ni, Cr, Pb, Pt); organics including total hydrocarbons, PAHs (the “EPA 16 priority PAHs”), MTBE; Na, Cl, CN (de-icing salts); suspended solids and NO₃. Subsequent analyses included these chemicals plus COD and BOD.

The sampling and analytical programmes led to the development of a list of “significant pollutants,” namely dissolved and total Cu, dissolved and total Zn, total Cd, total Pyrene and total Fluoranthene (Crabtree et al., 2007) developed from potential ecological impacts (runoff specific thresholds, RSTs) based on associated HA studies. Subsequent statistical analysis of the factors (e.g. climatic zone/ rainfall; traffic density, drained area etc) influencing the concentration of these significant pollutants and led to the development of the Highways Agency (now HE) Water Risk Assessment Tool (HAWRAT/ HEWRAT) which continues to form a fundamental part of HE standards and guidance for the assessment of the potential water quality impact of road runoff.

In parallel, research was undertaken to evaluate the accumulation and dispersal of suspended solids from runoff (ECUS Ltd and University of Sheffield, 2007) and the effects of sediment bound contaminants on the ecology of receiving waters. The study evaluated the impacts on in-stream biota for a range of metals (Al, Cu, Cd, Zn) and PAHs (anthracene, fluoranthene, pyrene, phenanthrene, and total PAHs). The work led to the development of unique Threshold Effects Levels (TELs) and Probable Effects Levels (PELs) for concentrations of metals (Cu, Zn, Cd) and PAHs in sediments, also incorporated into the HEWRAT tool.

Pollutants associated with Microplastics

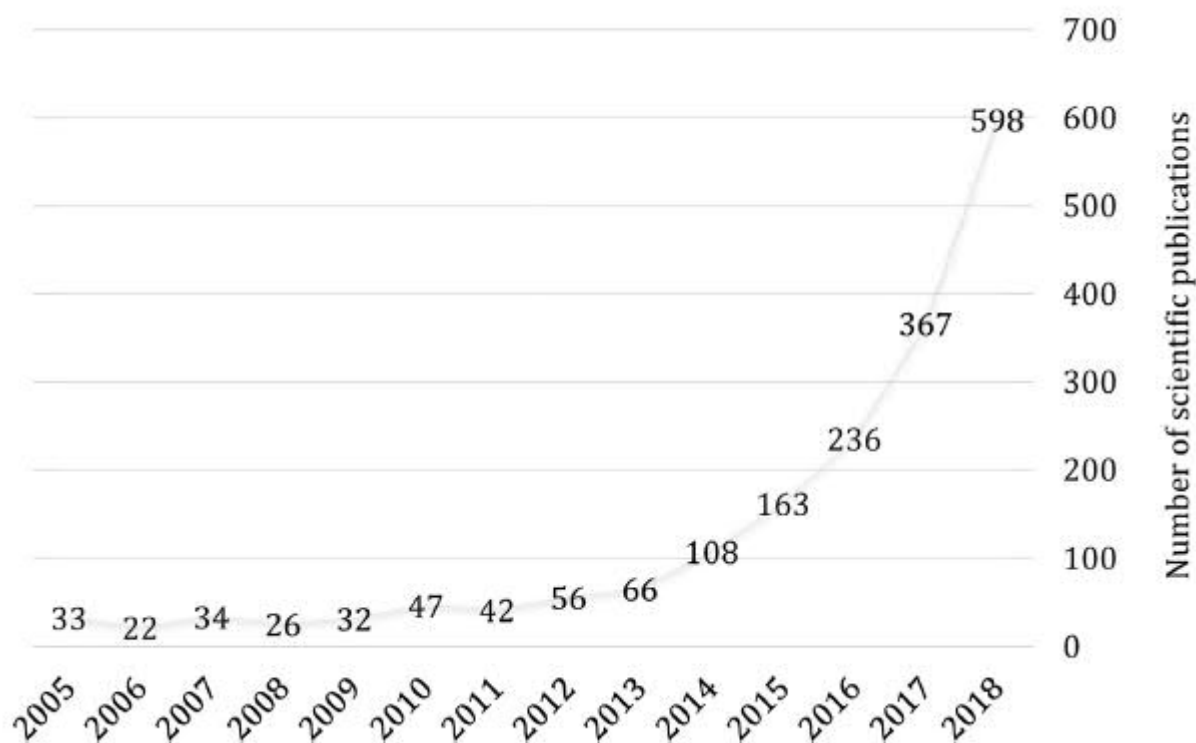
These HA/HE research programmes did not evaluate the potential impacts of microplastics but subsequently interest in (and knowledge of) microplastic pollution has increased significantly. This is demonstrated in the number of academic papers published on the topic. From the first paper on microplastic published in circa 2004, research accelerated almost exponentially from about 2012/ 2013. This trend (see Figure 4.5 below) was demonstrated by Galafassi et al 2019, based on a

³ Subsequent references to this document will be simply as LA 113

search of the term “microplastic” the Scopus research database (although see above in section, with reference to the difficulties in using such simple search terms).

Furthermore, there has been a substantial learning curve to be overcome to understand how best to sample roads for these microplastic contaminants (Horton, 2017b; Parker-Jurd et al., 2019).

Figure 4.5 Increase in interest in microplastics research (Galafassi et al., 2019)



Urban and highway stormwater runoff is widely known to be land-to-sea pathway for microplastic, but definitive experimental studies are lacking (Auta et al., 2017). Quantification issues persist with current analytical techniques for assessing microplastic concentrations. This is partly due to presence of black material in (road) samples which absorb all light decreasing reflection and transmission used to measure and determine polymer type in Fourier Transform Infra-Red (FTIR) and Raman analytical methods (Halle et al., 2020) - see also the response to research question 2a below. In addition, there is a need for better flux estimates of microplastics from highways (Wanger et al., 2018; Boucher et al., 2019) and this will be improved when factors contributing to, or determining, TRWP concentrations in runoff (also see PQ2 responses), are better understood (Klockner et al., 2019; Sieber et al., 2020). Furthermore, the lack of homogeneity in the presentation and interpretation of results makes comparisons difficult across different studies and in understanding historical change (Martinelli et al., 2018; Halle et al., 2020).

Increased knowledge about microplastics has highlighted that they are typically hydrophobic and have large surface areas, allowing them to act as carrier and accumulate a wide range of other pollutants e.g., heavy metals (Cd, Cr, Pb, Ni), pesticides, hydrocarbons including polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenylethers (PBDEs) and polychlorinated biphenyls (PCBs,) (Nobre et al., 2015; Anderson et al., 2016; Auta et al. 2017; Massos & Turner, 2017; Robin et al., 2020). This is additional to, e.g., tyre-derived microplastics consisting not only of the original rubber core but various other additives (e.g., Al, Ti, Fe, Zn, Cd, Sb, or Pb) as well as potentially hazardous metals and metalloids contained in the attached brake-abrasion particles (e.g., Al, Fe, Cu, Sb, or Ba) (Sommer et al., 2018). As it is now acknowledged that persistent organic pollutants (POP) have been shown to sorb onto microplastics (Robin et al., 2020) this research has uncovered more sources of contaminants from road runoff than have been previously considered.

Given their long-lived nature in the environment, other pollutants sorbed onto microplastics could have far reaching environmental effects, e.g., detrimental effects to biodiversity/food webs in certain ecosystems (Auta et al., 2017), however the full extent will not be known until larger (greater temporal length) datasets are collected. For example, although some cosmetic products still contain microplastics, given the ban introduced in June 2018, a decrease in their abundance is expected to be recorded in years to come, provided appropriate temporal datasets exist or are developed (Auta et al., 2017).

Other pollutants of concern

Complementary to earlier HE research (as above) it is widely accepted that highways remain sources of a number of contaminants and pollutants, whether or not these have a direct source association with microplastics (such as TRWPs or road markings). This can include; a wide variety of heavy metals (e.g., Al, As, Cd, Cr, Cu, Pb, Pt, Pd, Ni, Sb, Zn); organic pollutants containing high levels N, P and Mn; hydrocarbons (e.g., PAHs), oils and greases; pesticides and high total suspended solids (TSS) (Kibblewhite, 2018, Robertson et al., 2019). Other than TRWPs, potential sources of contaminants are identified (in no particular order) below:

- Integrated vehicle components (undercoatings, paints)
- Fuels and lubricants
- Combustion products
- Catalytic converters
- Brake pads
- Vehicle cleaning products
- Roadside pesticides and herbicides
- Road surface emissions

Generically, these sources have not changed significantly since the HE research identified above, however there are a variety of chemicals, in part associated with these activities and not previously targeted by the earlier research. Furthermore, the Environment Agency has identified that it is important to update the list of pollutants of concern periodically as newer compounds and processes become more prevalent and has expressed concern that some contaminants, not previously identified, may warrant further evaluation, both in water and sediments associated with road runoff.

A selection of other pollutants of concern is identified in Table 4.1 below.

Table 4.1 Other pollutants of potential concern

Determinand	Presence in Water (EQS available)	Presence in sediment
<i>Metals</i>		
Antimony	Yes (No)	Yes
Arsenic	Yes (Yes)	Yes
Manganese See note 1	Yes (Yes)	Yes
Mercury	Yes (Yes)	Yes
<i>Organics</i>		
<i>Pesticides and herbicides</i> See note 2		
Glyphosate	Yes (Yes)	No
Mecoprop	Yes (Yes)	No
<i>Miscellaneous Organics</i>		
Benzothiazoles (including 2-benzothiazolesulfenamide) See note 1, note 5	Yes (No)	No
Aniline See note 1	Yes (No)	No
Bisphenol A (BPA) See note 3	Yes (No)	No
Cyclohexylamine See note 1	Yes (No)	No
Dicyclohexylamine See note 1	Yes (No)	No
Perfluoroalkyl substances (PFAS) - PFOS / PFOA See note 4	Yes (No)	No
Phthalates/ DEHP See note 3	Yes (Yes)	No
Steranes See note 1	Yes (No)	No
<i>Note 1: Potentially tyre derived contaminants</i> <i>Note 2: May have been subject to previous HE testing and analysis</i> <i>Note 3: Potentially derived from a range of source including vehicle treatments, paints and road surfaces</i> <i>Note 4: Potentially association with vehicle cleaning products</i> <i>Note 5: Benzothiazoles have been considered as a potential marker for tyre derived microplastics (e.g. Bye, N. H. and Johnsen, J. P., 2019); Parker Jurd et al., 2019)</i>		

A number of these chemicals lack Environmental Quality Standards (EQS) which means that determining their (level of) impact on a water receptor will require additional study.

The Water Framework Directive (WFD) Article 16 provides a list of 45 priority hazardous substances, for which EQS values are derived. A number of these substances (e.g. the metals Cd; Pb; Ni, PAHs) featured in earlier sampling programmes for Highways England, however some of the EQS values (notably for PAHs) have been updated subsequent to these research programmes. In particular the EQS for PAHs is now 1000 times smaller (0.00017µg/l) than it was when previous Highways Agency research was produced.

Run off specific threshold (RST) levels were developed in previous Highways Agency research based on measured toxicological effects (Johnson. I. and Crabtree. R., 2008). These included RSTs for the PAHs pyrene and fluoranthene, which had been identified as key pollutants in road runoff. The research also found that event mean concentrations (measured in road runoff) for fluoranthene and pyrene (as well as the metal cadmium) were always markedly lower than the derived RSTs and it was concluded that these substances were not likely to contribute to the impact from soluble pollutants

(Johnson. I. and Crabtree. R., 2008). On this basis HE assessment methods (in LA 113) do not consider PAHs in the assessment of acute impacts from soluble contaminants in road runoff.

However, EQS values for pyrene and fluoranthene are now 0.00017µg/l and 0.00063µg/l (respectively), these values being below the Limits of Detection (LOD) used in the Highways Agency research and also notably lower than average and median event mean concentrations (for these substances) measured in road runoff at the time of the research (Crabtree et al., 2008).

Given that current HE guidance is based on toxicological effects (derived from road runoff), it may remain appropriate, however the implications of a significant change in the EQS values for PAHs (and how these are derived and for what purpose) needs to be considered more fully by HE.

Secondary question 1c. What are the implications, of the changes discussed in question 1b, for Highways England policy (most specifically related to microplastics)?

Overview

From the above although it is apparent that investigation of microplastics generated from roads is in its infancy, it is evident that:

- Roads generate a significant proportion of microplastics that enter the water environment, mainly from tyre wear
- Other sources, such as road markings, secondary microplastics from litter are also significant
- Indirect sources from soils may also contribute to microplastics in road runoff (e.g. via land drains discharging to road drainage networks) - these could be from agricultural sources (such as sewage sludge) or from road generated microplastics captured by adjacent soils
- The impacts from these microplastics (such as toxicity) are not clearly established, though known toxic materials can be sorbed onto microplastics which may act as a carrier.
- There are some other contaminants, not necessarily related to microplastics that have emerged since previous HE research, although the most significant contaminants probably remain metals and PAHs which have been previously investigated by HE
- The behaviour of microplastics may be somewhat analogous to suspended sediments generated from road surfaces, but no clear or direct relationship has yet been established for UK roads.
- Highway drainage features, particularly elements that lead to deposition of materials (such as sedimentation traps, retention ponds, swales etc) may retain microplastics, but the effectiveness of these measures is not fully understood nor is the (amount of) potential re-mobilisation from these features

Legislative setting

Currently there is no specific legislation that addresses pollution from microplastics although the literature review has identified that new legislation are significant priorities (e.g. Fahrenfeld et al., 2019). New or updated legislation and policy, supported by increased public engagement, will be needed to deal with not only existing microplastic pollution, but also as a deterrent to control the sources of pollution (e.g. through managing production of plastic based products) (Auta et al., 2017, Li et al., 2019).

Similar to the ban of microbeads in cosmetics in June 2018, Nordic countries are currently leading efforts to introduce legislation, in the form of a global treaty, to tackle ocean plastics pollution (Chemical Watch, 2019; Maritime Executive, 2019). These same countries are also leading research into microplastic pollution from road runoff and are at the forefront of developing new techniques to mitigate against it.

On the basis of these emerging global efforts, it seems likely that microplastics will eventually be included as pollutants in future updates to requirements of other legislation, for example in European Community WFD and waste management directives.

Given the prevalence of microplastics generated from roads, HE need to remain informed of any emerging legislation, and will need to be fully engaged in any associated consultation. The generation of microplastic pollution from roads could also fall within overall HE policy not to pollute, irrespective of the introduction of specific legislation. Similarly if links between microplastics and (sorbed) known pollutants are fully established, this potentially may fall within the existing legislative regime for water quality.

Existing environmental quality standards (EQS), both with respect to metals and PAHs have changed since HE assessment tools were originally established. Recent changes to the HE assessment process (in LA 113) have taken into account changes with respect to metals, but further evaluation (of these tools) is needed to determine if changes are needed to respond to the significant lowering of EQS values for PAHs.

Assessment and design

Design guidance and standards for the assessment of (impacts on) the water environment are clearly set out in LA 113, CG 501 and associated HE standards. These do not specifically address microplastics as a pollutant derived from the SRN. Whilst the legislative setting with respect to microplastics remains unclear, the need to amend these with respect to microplastics would seem premature, even taking into account HE policy not to pollute. Furthermore, as noted above, the behaviour and characteristics of microplastics (in road runoff) are not yet sufficiently understood to implement suitably robust changes to current practice, and only when this becomes available should a change be considered.

However, there may be considerable benefit in understanding the relationship between the behaviour of microplastics and sediment bound pollutants, as it may be possible to demonstrate that standards intended to address sediment management of the network may also address microplastic pollution.

The main mechanisms identified for the removal of microplastics from road drainage are sedimentation and deposition (Liu et al. 2019a). The installation of effective methods of treating road runoff therefore remains central to controlling microplastic pollution (Sieber et al., 2020) as well as other potential contaminant sources (Robertson et al., 2019).

However, similar to the assessment process, further research is needed to investigate the effectiveness of current drainage treatment system design standards (i.e. as set out in CG 501) before developing any new techniques.

Construction and maintenance

The nature of road construction and maintenance clearly has an influence on the generation of microplastic pollutants, both through materials used (such as road marking paint) and (the degree and rate of) wear on tyres and other vehicle components.

In keeping with HE sustainable development strategy, the use of recycled materials in construction provide a more “environmentally friendly” approach (Fu & Wang, 2019). For example, in Norway, road markings are now regularly incorporated into the fabric of the road rather than being painted on the surface. This reduces erosion and abrasion of paint materials, an identified source of microplastics (J Proctor 2020, pers.com. 20th January). Work previously presented, suggests road markings are estimated to be 7% of all microplastics sourced derived from urban watersheds and

although this is approximately a quarter of 29% estimated from tyres in the same studies, (Boucher & Friot, 2017; Birch et al., 2020). Road markings remain a noteworthy source of microplastic pollution.

Using materials that abrade less and/or are biodegradable may also reduce wear and tear impacts. The addition of plastic waste content (optimally 6% by mass) to bitumen at high temperature (i.e. 135 °C), increases the viscosity of the road building material. The high viscosity reduces the tendency to rutting of the road surface and results show surfaces can better withstand not only increased use of heavy goods vehicles but also large changes in daily temperatures (Abdullah et al., 2017).

Recent innovations in road surfacing introduced on parts of the SRN have incorporated the use of recycled, materials such as recycled tyres (<https://www.highwaysmagazine.co.uk/Highways-England-trials-rubber-asphalt-5069>) or a larger proportion of recycled asphalt, augmented with polymer modified binder (PMB) in within the road surface (<https://www.highwaysmagazine.co.uk/50-reclaimed-asphalt-pavement-used-on-SRN-for-the-first-time-5212>).

However, the sustainability benefits of these innovations may need to be offset against their potential to generate microplastics. A study in Norway (Vogelsang et al., 2019), where it is understood PMB is used more extensively (on 2770km of public roads), suggest that these form a source of microplastics, albeit a relatively small one (<1%) from road surfaces. Any plastics used within road construction in the future, (e.g. rubberised asphalt), could become a potential “new source” and this needs to be considered before adoption of any policy to take up such materials (Ziajahromi et al. 2020).

While, as noted above, appropriate assessment and design are needed to manage microplastic pollution, in common with the management of other road borne pollutants (such as suspended solid loads), on-site management and maintenance are essential. For example, the potential for remobilisation (of microplastics) needs to be recognised and appropriate measures adopted to remove (and appropriately dispose of) such pollutants. As with assessment and design, HE maintenance policy needs to recognise this need, but more information is needed to understand how microplastics accumulate in drainage systems in order to develop appropriate policy.

The wider context which might affect policy

Climate change predictions currently suggest more intense rainfall events are likely. This will influence mobilisation and transport of all contaminants and it is also evident that microplastic concentrations (by mass and particle number) are linked to hydraulic loading (Amamiya et al., 2019; Liu et al., 2019; Pinon-Colin et al., 2019). Intense storm events can resuspend/remobilise microplastics which have previously been deposited (e.g. in sedimentation basins or retention ponds) (Dris et al., 2017; Martinelli et al., 2018; Scheurer & Bigalke, 2018) and may generate greater runoff from roadside soils. In Sweden, after periods of snowmelt microplastics from tyre wear and road paints were measured to have increased (Vijayan et al., 2019). On this basis, for example, more regular inspection and emptying of drainage features such as sediment retention structures may be needed after large storm events and maintenance policy may need to take this into account.

Similar to other contaminants, traffic flows and behaviour (e.g. increased braking and accelerating in areas of traffic congestion) have a large influence on tyre and brake wear and hence microplastic deposition. On this basis, targeted traffic management, to keep traffic speed to a constant rate can potentially help significantly reduce the volume of microplastics abraded from tyre and brake wear (Sommer et al., 2018).

The future increase in the use of electric vehicles on the SRN will have implications for microplastic pollution. Due to their generally increased weight over equivalent internal combustion engine vehicles, electric vehicles are expected to produce more tyre wear and tear (Simons, 2013 & Timmers et al., 2016; Rhodes, 2019; R Thompson 2020, pers.com. 18th February).

However, in these cases, (i.e. traffic flow, behaviours and a changing vehicle fleet) without a full understanding of the actual impacts on microplastic generation, it is difficult to envisage policy revisions that might specifically address the issue. It could, for example, be a requirement for more robust containment / treatment at “sensitive” locations, but this is dependent upon being able to identify where these may occur, which is not possible with the current understanding.

Defra’s “Litter Strategy for England (Defra, 2017) includes general litter removal from the SRN, and HE litter strategy forms a part of this wider strategy. Within the HE strategy there are no specific references to the composition of litter material (i.e. whether plastic or not), although it sets out a strategic goal to reduce the need for litter picking and deliver an effective litter cleaning service. This focuses on workstreams influencing littering behaviour; improving operational delivery and asset maintenance; seeking and responding to customer feedback and improving partnership working. In 2017, the Defra strategy identified 25 priority litter hotspots on the HE network that aimed to achieve lasting local improvements. Wider adoption of similar measures, i.e. identifying and prioritising hotspots, could enhance the removal of all litter (including plastics) from verges and other areas of the network and reduce a primary source. Plastic litter degradation (including size reduction and breaking down from a single article to multiple particles) is such that it becomes far harder to remove and manage, so any policy that encourages reduction or enhanced removal of litter would lessen this impact. The EA have adapted their maintenance activities to minimise unnecessary generation of microplastics, for example, litter picking is now undertaken before strimming so that the strimming activities do not generate additional (but unintentional) microplastics. HE should consider whether there are any similar actions they can undertake related to litter picking strategy/protocols.

Secondary question 1d. What essential future research activities can be identified to better understand the contribution of road runoff to microplastic pollution and what would be their indicative budget?

Better understanding of the sources and fate of microplastics on the SRN

From secondary research question 1a it is apparent that the key sources of microplastics on the SRN are:

- Tyre wear
- Road markings
- Litter degradation
- Indirect sources (such as from soils adjacent to roads)

Much of the evidence for this is based on broad ranging studies evaluating deposition to the wider water environment (and often to marine waters), and often may depend on modelling with little or no direct study incorporating environmental sampling of road runoff.

Fate and transport mechanisms of microplastics to and from the SRN are largely unknown and need to be better understood (Rochman, 2018; Liu et al., 2019a; Liu et al., 2019b), for example: where and at what rates are microplastics deposited in or lost from stormwater drainage pathways?. Currently, the rate and scale of the breakdown of macro / meso (scale) plastics into micro / nano plastics, or indeed how important this is on the SRN, is unknown.

Specific analysis of microplastics sources from UK roads is lacking, although a recent study (Parker-Jurd et al., 2019) undertook direct sampling from storm water discharges from roads. The scope of this study was necessarily constrained but, without quantification, suggests that tyre wear forms a major component of water environment microplastic pollution. Similarly, direct UK based evidence is lacking to support the volume/ mass (“load”) or concentrations of the other identified key sources

(road markings, litter, indirect) or how degradation of primary plastics (e.g. from roadside litter) to secondary microplastics occurs.

Hence, the actual quantum (of each source) from UK roads is difficult to determine and will need to be established through a comprehensive sampling and analysis programme, specific to the SRN, to provide suitable empirical evidence for the scale of the issue on the SRN. This would need to include an understanding of how these might be influenced by site characteristics (see research question 2b, below)

Despite apparent similarities in behaviour (refer secondary question 1a) during this review, no literature was found detailing an explicit correlation in behaviour between microplastics and suspended solids. However, generally, settling rates for microplastics should follow principles set out in Stoke's law (Parker-Jurd et al., 2019), i.e., particles with larger densities settle faster, and it has been well documented that particle density strongly influences the settling rates of microplastics (Andrady, 2011). Typically, densities of microplastic particles from tyres suggest they would have tendency to sink but can be resuspended at higher discharges and/or turbulence (Verschoor et al., 2016). Similarly, coarser particles are more likely to be retained in sediments than fine ones but, due to a current lack of data, definitive relationships between size, shape and density of microplastics and how they settle out requires further investigation (Wagner et al., 2018).

Parker-Jurd et al. (2019) suggests tyre wear particles greater than 50 µm settle close (<1km) to where they are sourced, whereas particles between 15 – 50 µm could potentially travel up to 15km before settling. Laboratory experiments also suggested particles between 4 – 15 µm could be transported many 10s of kms from where they are sourced as results ~15 % of particles remained at the water's surface after a 1 week settling period (Parker-Jurd et al., 2019).

More in depth comparisons of these data with the findings in earlier HE research into the movement of sediments from road drainage would be worthwhile. These HE studies (ECUS Ltd and University of Sheffield, 2007) identified that 97% of particulate material discharged from roads during storm events was less than 63 µm in size, so on this basis it may be that it is these finer particle sizes that constitute the most significant issue.

Such relationships also warrant further consideration as they may identify parallels between the efficacy of existing road runoff treatments for suspended solids and microplastics.

Analysis of microplastics from the wider environment remains challenging as it is unclear how the chemical properties of particles change over time under different environmental conditions (Ryberg et al., 2019; Ziajahromi et al., 2020). Establishing the typical rates of breakdown and how this is influenced by ambient conditions will be useful in determining long-term average concentrations of microplastics in the environment (Kole et al., 2017; Li et al., 2019; Unice et al., 2018a&b). Further understanding of these processes will also help establish the importance of site characterisation when sampling microplastics. Developing techniques to differentiate between primary and secondary plastics (i.e. breakdown products) will be critical to understand sources of microplastics in road runoff (Horton et al., 2017b; Li et al., 2018). Whilst developing this broader understanding of microplastics in the environment is not the responsibility of HE, it would be worthwhile keeping a watching brief on any such wider research programmes.

Measuring effectiveness of mitigation measures

The effectiveness and efficiency of mitigation measures, e.g., retention ponds, need further research, although these will be dependent upon first developing a better understanding of sources on the SRN and key site characteristics (as noted above). Also as noted above, research into correlation of behaviour between microplastic and suspended solids would be beneficial in identifying the effectiveness of mitigation. These steps could form part of future HE research.

It has generally been demonstrated SuDS features (in their broadest sense) are effective at retaining microplastics, but retention times remain unclear as does the ultimate fate of microplastics (Liu et al., 2019a). This uncertainty increases during periods of high through flow / storm events (Unice et al., 2018a&b). Since diameter and density of particles are key to retention in drainage ponds/basins then methods for in-situ measurements of these parameters (for TRWP) need to be developed (Unice et al., 2018a&b). There appears to be no evidence available on the distribution of microplastics within a road drainage network (e.g. gully pots, pipes, or other drainage “structures”).

It has been suggested that in-situ studies looking at the impact of urban surface runoff on plastic pollution should target storm event sampling (see also response to secondary question 2b below), targeting a range of different flow levels (Cheung et al., 2015). For non-event sampling (also see 2b), technology and techniques are available (e.g., electro-separation using Korona-Walzen-Scheider (KWS)) which can separate microplastics particles from large heterogeneous (sediment) samples (Felsing et al., 2017) and this could help contribute to assessing abundance of microplastics from SRN assets, e.g., drains, ponds etc.

In addition, more investigations could be targeted on the potential use (and effectiveness) of microbes to breakdown microplastics and other pollutants (heavy metals, pesticides, hydrocarbons) (Auta et al., 2017), however, such research is probably something only to be considered after more fundamental information is gathered.

Other considerations - the wider research agenda and implications for the SRN

More than half of microplastics deposited in the environment will remain within soils (as a sink) so microplastic sources, quantities and pathways to and from soils need further investigation, including the effect of spreading sewage sludge on agricultural lands (CIWEM, 2017).

To quantify actual concentrations of TRWPs in water, sediment and soil, work from Sieber et al. 2020 (estimating weight of microplastics released from tyres per year and per capita) needs to be coupled with models predicting environmental fate of microplastics /rubber. First fate models for microplastics in surface water have already been published (Besseling et al., 2017) as has a geospatial model for TRWP transport from land to sea (Unice et al. 2019a&b). Coupling the time-resolved modelling presented in this work with spatially-resolved models for transport and environmental fate of microplastics (Unice et al., 2019a) would enable researchers to obtain more complete accounting of current and previous flows of microplastics and the amounts accumulated so far in environmental compartments. (Sieber et al., 2020).

However, roads also contribute to microplastics in soils. Tyre and road marking derived microplastic concentrations will likely be higher in soils closest to roads than those further away (see “indirect sources” in question 1a, which suggests the greatest concentrations of TRWPs occur within 5m of the road). Parker-Jurd et al., 2019 identify more work is needed to investigate this distribution: *“More research is also needed to consider a mass balance approach to evaluate a wider range of sources and transport pathways. This should consider quantifying tyre particles and fragments along their entire transport pathways and at greater distances, 1, 10 and 100 km from roads and urban areas”*.

Currently, concentrations of microplastics in soils close to roads are not generally available, especially in the UK and where such studies do exist, values (mass, concentrations etc.) that are reported are not in a standardised format or unit of measure making it difficult to compare and contrast different study areas.

Whilst such research is beyond the scope or sole responsibility of the HE, understanding the distribution of microplastics in the soil environment (e.g. from agricultural sources and /or originating from the road derived sources) will ultimately be of benefit (to the HE) in identifying those sources directly attributable to roads and provide further insight into how, and in what form, microplastics may

be transported (e.g. washed off from soils) into highway drainage systems. This may be an area where collaboration with other research programmes may be warranted.

Long-term implications of microplastic pollution on environment, biodiversity and human health is unknown and longer-term studies are needed (Horton et al., 2017a&b; Bauer-Civiello et al., 2019; Pinon-Colin et al., 2019). As noted above, the capacity for microplastics (including TRWPs) to sorb harmful, potentially toxic substances (e.g. heavy metals, PAHS and other persistent organic pollutants) has been recognised, however there is little work available that investigates the ultimate toxic effects of such “composites.” As noted in the introduction, environmental and human health implications of microplastics in road runoff have not been fully reviewed herein due to a general lack of available literature (and particularly specific to road runoff) or definitive outcomes.

As plastics are so long lasting in the environment (100s of years) (Barnes et al., 2009) the potential toxic effects of microplastics will remain an environmental issue for a long time and further assessment is needed by the wider research community (Horton et al., 2017b). However, such research is not realistic for the HE to pursue in isolation.

Research funding costs

Timeframes to complete research, sampling, monitoring and development of new analytical techniques can be long (i.e. ~5 years) and therefore tend to be expensive. The key to managing cost is to have clearly defined objectives, to identify, separate and package out different workstreams and to identify the most appropriate research teams for each package.

Masters and PhD research may be a cost-effective way of gathering research information however, academic research comes with the premise of a year to multiple year timescales for final results to be published.

Pooling sources and collaborating with different stakeholders is also an effective way of investigating common themes of common interest. Having a small working group of key experts would be beneficial to engage with people who understand the subject and could provide opportunities for co-funding (R Thompson 2020, pers.com. 18th February). In the case of microplastic research linked to SRN; Defra, Department for Transport, Environment Agency, subject-matter experts (i.e. academics) and tyre manufacturers are all organisations who have an interest in this topic. Dialogue between HE and these organisations should be initiated, although the Environment Agency are already working with the HE on the issue of microplastics originating from tyre wear particles (H Stewart 2020, pers.com. 29th January).

It is difficult to estimate costs with any certainty as they will be heavily influenced by the scope of the work commissioned. For example, the addition of field work / sampling to any projects can increase the costs substantially, mainly due to costs of logistics for collecting samples.

Primary research question 2

As set out in Section 2, primary question 2 and its associated secondary research questions are as follows:

Primary question.

- What is the most appropriate sampling and analysis method to quantify microplastics of key interest to the SRN?

Secondary questions

- 2a Are robust and repeatable techniques under development for quantifying microplastics?
- 2b. What are key site characteristics and conditions for sampling microplastics on the SRN?.
- 2c To what extent can the SRN as a source of microplastics be differentiated from other (e.g. airborne) sources?

Secondary research question 2a – Are robust and repeatable techniques under development for quantifying microplastics?

Numerous publications identified during our literature search detailed the techniques used for quantifying microplastics from environmental samples. However, it was clearly evident that, as had been identified at the outset of this research, there is no standardised methodology for the identification and quantification of microplastics. This can create significant difficulties in comparing results between different studies (Blair et al. 2019; Olesen et al. 2019; Stock et al. 2019; Blasing & Amelung, 2018; Horton et al. 2017b). The most appropriate techniques for quantifying microplastics in the SRN is discussed in secondary research question 2c.

Defra are currently working with the British Standards Institute (BSI) and the International Organisation for Standardisation (ISO) to develop standards relating to microplastics and their sampling and analysis, however this is still at a very early stage and it takes a minimum of three years for ISO to confirm standards for an emerging pollutant (Hasmitta Stewart, pers. com.; Judy Proctor, pers. com.). There will also need to be a range of protocols developed for different environments (water, sediment, soils) (Hasmitta Stewart, pers. com.).

Current methods being used for microplastics and other contaminants, are expensive and time consuming (Boucher et al., 2019; Halle et al., 2020) and lack the ability to monitor and test microplastics concentrations in solutions (Li et al., 2019). However, as identified, advances are being made e.g., thermal extraction desorption gas chromatography–mass spectrometry (TED-GC-MS) allowing the fast identification and quantification of microplastic in environmental samples without sample preparation (Eisentraut et al., 2018). However, in general the current situation limits the ability of organisations, stakeholders and scientists to monitor the concentrations of microplastics (and other contaminants) in the environments, especially in developing countries (Anh et al., 2018).

Although there are differences in the methodologies undertaken, there are common steps undertaken for sample preparation, processing, microplastic identification and quantification for environmental samples. These steps are summarised in a figure in the Blair et al. (2017) journal article, reproduced below (Figure 4.6). At each step, different techniques are available for selection, summarised in Table 4.2 and detailed further below. The first step of sample collection is not discussed here, but with secondary research question 2b.

The first three steps of drying/sieving, sample digestion and density separation all reduce the sample volume and separate microplastics from the sample matrix (purification).

Figure 4.6. Generalised steps for sample processing for microplastics (Figure 3 from Blair et al. 2017).

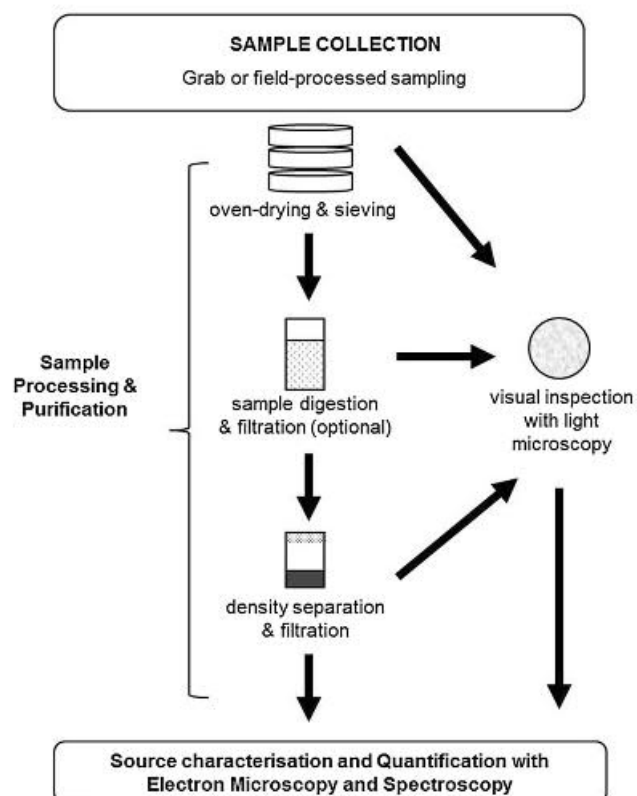


Table 4.2. Summary of steps in sample processing for microplastics

Step	Processes
Oven-drying and sieving/filtering	Reducing sample volume.
Sample digestion	To remove organic matter: Acidic Alkaline Oxidising Enzymatic
Density separation	High-density solutions (e.g. NaCl, ZnCl ₂ , NaI) so microplastics float to surface Alternatives (1) Munich or MicroPlastics Sediment Separator (2) electrostatic separator (3) Elutriation
Visual inspection	Microscopes
Source characterisation and quantification	Electron microscopy Spectroscopy Thermo analytical Melt test

Oven-drying and sieving/filtering

Oven-drying and sieving of samples is usually the first step in reducing the sample volume and separating microplastics from the sample matrix. Oven-drying of sediment samples removes excess water content and sieving/filtering of sediment and water samples processes the sample down to the size fraction of interest. There is variation in this process between different studies, and although the size cut-off chosen for sieving/filtering will have an effect upon the size-fraction from within which the microplastics are being quantified, and there is no standardised cut-off point for sieving/filtering.

Some examples of the variety of different oven-drying and sieving/filtering methodologies used in microplastic studies are shown below in Table 4.3. These illustrate the range of methodologies that are used between studies and therefore the difficulty in comparing results between studies which have prepared samples differently. The differences in grain size to which sediment samples are sieved will also potentially impact upon the quantity of microplastics found in the sample (i.e. the larger sieve size may miss finer microplastics).

Table 4.3. Examples of oven-drying and sieving/filtering methods used in microplastic studies.

Reference	Study context	Oven-drying and sieving/filtering method used
Fu & Wang (2019)	Review of studies in China with water and sediment samples.	Water samples filtered in range 5 µm to 1.6 mm. Sediment samples dried in range 50°C to 70°C for 12 to 72 hours.
Liu et al. (2019)	Sediments from storm retention pond in Denmark.	Wet sieve <2 mm. Left for a week to settle and remove high water content.
Olesen et al. (2019)	Sediment and water from stormwater retention pond in Denmark.	Water samples sieve <10 µm. Sediment wet sieve <2 mm, effluent settle, decanting and filtering supernatant (liquid lying above a solid residue) to <10 µm.
Yukioka et al. (2019)	Road dust from Japan, Vietnam and Nepal.	Sieve <100 µm.
Hurley et al. (2018)	River sediments in Northwest England.	Wet sieve to 63 µm to 5 mm. Oven dried 40°C.
Scheurer & Bigalke (2018)	Floodplain soils in Switzerland.	Dried 65°C. Sieved <1 mm.
Horton et al. (2017a)	Sediments from the River Thames.	Wet sieve to 1-2 mm and 2-4 mm. Oven dried 80°C.

Sample digestion

Sample digestion is undertaken on either sediment or water samples to destroy the organic matter content. The digestions are commonly undertaken with either acidic, alkaline, oxidising or enzymatic solutions (Blasing & Amelung, 2018; He et al. 2018; Blair et al. 2017; Stock et al. 2019). Depending upon the solution chosen for undertaking the digestion, there may be incomplete digestion of organic material (e.g. hydrochloric acid) and there is also a risk of some polymers being degraded by the solution, (e.g. NaOH) which may negatively impact upon the later stages of sample characterisation. Although the use of enzymes is advantageous in that no polymers are degraded or dissolved (which is a risk with acidic, alkaline and oxidising solutions), there is a long processing time due to the differing optimal temperature and pH for each enzyme (Stock et al. 2019). Table 4.4 summarises commonly used digestion solutions and their advantages and disadvantages.

Table 4.4. Commonly used digestion solutions (Table 1 from Stock et al. 2019)

Sample digestion	Advantages	Disadvantages
Acidic: nitric acid (HNO ₃) hydrochloric acid (HCl)	HNO ₃ – most organics destroyed.	HNO ₃ – dissolution of polystyrene (PS) and polyethylene (PE) possible. HCl – incomplete destruction of organics.
Alkaline: sodium hydroxide (NaOH) potassium hydroxide (KOH)	KOH – Most polymers resistant. Both - Most organics destroyed.	NaOH – Some polymers degraded (e.g. polycarbonate (PC), polyethylene terephthalate (PET), polyvinyl chloride (PVC)).
Oxidising: hydrogen peroxide (H ₂ O ₂)	Most organics destroyed.	Polymers might be affected.
Enzymatic: Cellulose Lipase Chitinase Protease (proteinase-K)	Most organics destroyed, not hazardous.	Time-consuming, partly expensive, different enzymes for different samples.

Below are some examples of where different digestion solutions have been used in published studies.

Nitric acid (HNO₃) was used for sample digestion by Scheurer & Bigalke (2018) looking at microplastics in floodplain soils in Switzerland.

Hydrogen peroxide (H₂O₂) was used for sample digestion in the following studies:

- Ziajahromi et al. (2020) looking at microplastics in both sediment and water samples from a stormwater treatment wetland in Australia.
- Yukioka et al. (2019) looking at microplastics in road dust samples from Japan, Vietnam and Nepal
- Blair et al. (2019) whilst developing a protocol for determining microplastics in wastewater treatment water samples
- Wang et al. (2017) looking at microplastics in water samples from urban lakes and rivers in Wuhan, China.

Fu & Wang (2019) reviewed the methodologies used in published studies looking at microplastics in water and sediment in China and found that both hydrogen peroxide (H₂O₂) and potassium hydroxide (KOH) was used.

An alternative which has been used is Fenton's reaction (a combination of hydrogen peroxide (H₂O₂), sodium hydroxide (NaOH) and iron sulphate (Fe₂(SO₄)) (Liu et al. 2019; Olesen et al. 2019; Ball et al., 2019).

Density separation

Density separation is a simple technique used to separate microplastics from the rest of the sample matrix, based on the principle of the 'lighter', less dense microplastic particles floating in a denser solution and the microplastics being extracted from the supernatant. This reduces the volumes of the sample. A range of different solutions, of different densities, have been used for this separation technique (Fu & Wang 2019; Blasing & Amelung, 2018; He et al. 2018; Stock et al. 2019). Table 4.5 summarises commonly used density separation solutions, their densities, advantages and disadvantages. The density of the solution needs to be chosen based on the density of the microplastics which are being separated, with the most common plastics being <1.4 g/cm³ (Table 4.6).

Table 4.5. Commonly used density separation solutions (Table 1 and Table 3 from Stock et al. 2019, * = approximately)

Density solution	Density (g/cm ³)	Advantages	Disadvantages
Sodium chloride (NaCl)	1.0-1.2*	Low cost & toxicity	Density of saturated solution too low to detect all polymer types
Sodium tungstate dihydrate (Na ₂ WO ₄ ·2 H ₂ O)	1.4	Cost-effective, high density	None cited
Sodium polytungstate (3 Na ₂ WO ₄ ·9 WO ₃ ·2 H ₂ O)	1.4	High density	Expensive
Potassium formate (K(HCOO))	1.6*	Cost-effective, high density, not hazardous	Hygroscopic
Zinc chloride (ZnCl ₂)	1.6-1.8	Not expensive, high density	Corrosive, hazardous
Sodium iodide (NaI)	1.8	High density	Expensive

Table 4.6. Common polymers and their densities (Table 2 from Stock et al. 2019)

Polymer	Abbreviation	Density (g/cm ³)	Plastic demand in Europe (%)
Polystyrene	PS	0.01 – 1.06	6.7
Low- and high-density polyethylene	PE	0.89 – 0.98	29.8
Polypropylene	PP	0.85 – 0.92	19.3
Polyurethane	PUR	1.2 – 1.26	7.5
Polyethylene terephthalate	PET	1.38 – 1.41	7.4
Polyvinyl chloride	PVC	1.38 – 1.41	10.0
Others (polycarbonate, polymethyl methacrylate, polytetrafluoroethylene, Acrylonitrile Butadiene Styrene)	PC, PMMA, PTFE, ABS	N/A	19.3

In general, the chosen high-density solution is added to the sample and the sample/solution mix is shaken (either manually or mechanically) for a period time before being left to settle. The floating particles are then extracted from the supernatant (often by filtration). This process is often repeated a few times.

Below are some examples of where different density solutions have been used in published studies.

Zinc chloride solution (ZnCl₂) was used for density separation by Horton et al. (2017a) looking at microplastics in river sediments of the River Thames, UK and by Olesen et al. (2019) looking at microplastics in sediments of a stormwater retention pond in Denmark.

Sodium iodide solution (NaI) was used for density separation by Ziajahromi et al. (2020) looking at microplastics in sediments of a stormwater treatment wetland in Australia and by Yukioka et al. 2019, looking at microplastics in road dust samples from Japan, Vietnam and Nepal.

Blair et al. (2019) undertook density separation for microplastics from river bank sediments from the River Kelvin in Glasgow, UK using sodium chloride (NaCl). Hurley et al. (2018) sampled river sediments from rivers in Northwest England and undertook a three-step density separation using three solutions of differing densities: sodium chloride NaCl 1.2 g/cm³; higher density sodium iodide, NaI, 1.8 g/cm³; and finally, lower density sea water solution. NaCl 1.025 g/cm³.

Horton et al. (2017a) analysed the particles which did not float after density separation and a number were identified to be dense composites of road-marking paints, aggregates, painted coating on dense particles or high-density mineral-polymer mixtures. This shows the importance of ensuring that the density solution chosen is appropriate to allow all microplastics of interest to float.

Alternative methods to density separation for separating microplastic particles from the sample matrix include the Munich/MicroPlastic Sediment Separator, electrostatic separator and elutriation.

The Munich/MicroPlastic Sediment Separator is essentially a constructed device for undertaking density separations with higher-density solutions for large sediment samples (up to 6 l) (Stock et al. 2019), which was developed by Imhoff et al. (2012).

Electrostatic separators (commonly used in recycling centres) divide non-conductive material (plastics) from conductive materials (metals) and could be used to reduce sample size, although only in sediments (Stock et al. 2019; Felsing et al. 2018). Felsing et al. (2018) tested an electrostatic separator using spiked river sediment samples and found good recovery rates.

An elutriation device uses an upward stream of gas or liquid to isolate lighter particles (microplastics) from heavier ones (Blair et al. 2017 and Eerkes-Medrano et al. 2015). Bottolfsen (2016) used an elutriation device on river sediments from Oslo, Norway to reduce the volume of the samples, and then undertook density separation afterwards.

Visual inspection

Samples are often initially inspected under microscopes in order to identify, categorise and count/quantify microplastic particles (Blair et al. 2017). A range of different microscopes and techniques are used which are discussed further below with examples from published studies. A summary of techniques, and their advantages and disadvantages, are shown in Table 4.7.

Table 4.7. Commonly used visual inspection techniques

Technique	Advantages	Disadvantages
Microscope with a range of magnifications	Simple technique. Can simply categorise microplastics based on size, type, shape and colour.	Not automated, therefore susceptible to human error. The smaller the particle, the more prone to error in identification. Rubber can be difficult to identify visually.
Stains – Rose-Bengal, Rhodamine B and Nile Red	Aid visual identification under a microscope.	Tyre particles do not take stain. Rhodamine B and Nile Red rely on removal of all organic matter from sample.

Prior to density separation, Horton et al. (2017a) used a binocular light microscope with 6x magnification to inspect the sieved sediment samples from the River Thames, UK. Particles were sorted as potentially being microplastics based on the criteria of no visible cellular or organic structures; particles/fibres being non segmented; and, if fibres, being of equal thickness throughout their entire length and not tapered at the end. After density separation, visual inspection using the same criteria was repeated under the binocular light microscope with 6-40x magnification.

Schessl et al. (2019) visually inspected river sediments from the New York State for microbeads based on spherical shape, colour, and texture under a 2x magnification dissecting microscope. Santilo et al. (2019) collected surface water samples from 13 rivers across the UK and under a 3x magnification illuminated lens microscope identified any suspected plastic items, including large and small fragments, fibres, pellets and pieces of film. Blair et al. (2019) sampled water at wastewater treatment works and, using a stereo microscope with x10 – x32 magnification, visually sorted for suspected microplastics into four categories based on morphology (pellets, fibres, fragments, and films). Vaughan et al. (2017) visually identified microplastics in sediments from an urban pond in Birmingham, UK under a binocular microscope (x40 magnification) using physical properties as well as colour and structure. They were then categorised into size, type, shape, colour, pliability and degradation stage.

Stains can be used to help aid the visual identification of microplastics under microscopes. Ziajahromi et al. (2020) sampled water and sediment from a stormwater treatment wetland in Australia and used Rose-Bengal to stain the suspected microplastic particles. Particles which take on the stain are natural fibres and were therefore removed whilst inspecting the samples under a dissecting microscope. The microplastics were counted and classified based on colour and form (fibre, fragment and granular (bead)). Nile Red and Rhodamine B dye have been identified as another staining method which causes microplastics to fluoresce, which can aid microplastic identification (Darbo, 2019; Ball et al., 2019). However, this relies on all organic matter having been removed from the sample (Ball et al., 2019), and tests have shown that tyre particles do not take the stain (Darbo, 2019) and therefore this may under-represent microplastics in a sample.

Tyre road wear particles are often visually identified on the assumption of an elongated shape, being black, inclusion of mineral road samples and being in the size range 5-250 µm (Jekel, 2019; Vogelsang et al., 2019). Similar shapes, size distributions and densities as tyre road wear particles have been associated with polymer-modified bitumen wear particles, with road wear marking particles having a wide range of particle sizes (Vogelsang et al., 2019). However, Vogelsang et al., 2019 note that rubber is not shiny, smooth and 'plastic-like', and therefore virtually impossible to detect visually which could result in underestimation of microplastics within a sample.

Visual identification and counting can result in errors of quantification. Blair et al. (2019) visually identified microplastics in river bank sediments under a stereo microscope from the River Kelvin, Glasgow and noted that it was increasingly difficult in the fractions smaller than 0.125 mm due to decreasing resolution and may have resulted in overestimation.

Source characterisation

Generally, there are three different analytical techniques (Table 4.8) used for characterising the microplastics particles, to provide more information on their polymer type (and therefore potential source):

- Electron microscopy
- Spectroscopy
- Thermoanalytical

Table 4.8. Source characterisation techniques (Blair et al 2017)

Source characterisation	Technique	Quantification
Electron microscopy	Scanning electron microscopy (SEM) or Transmission electron microscopy (TEM) sometimes with added Energy-dispersive X-ray (EDS)	Particle counts
Spectroscopy	Raman or Fourier Transform Infra-Red (FT-IR)	Particle counts
Thermoanalytical	Pyrolysis (Pyr) or Thermal extraction desorption (TED) with either Gas chromatography mass spectroscopy (GC-MS) or Gas chromatography flame ionization detection (GC-FID)	Particle mass
Other	Melting test	N/A

Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are often used during analysis of microplastics. Electron microscopy techniques provide clearer images (x50-10,000 magnification) which can characterise surface morphology (Li et al. 2019) and therefore can be considered part of the visual identification techniques. However, when coupled with energy-dispersive x-ray (EDS) to produce images and spectra for determination of electron composition, this can be used to differentiate carbon-based particles (such as plastics) from non-polymers, as plastics are made of carbon and shown spectra different to non-plastics materials (Blair et al. 2017). When electron microscopy is used alone, it still relies on visual inspection which can result in inaccuracies, requires a lot of time, is relatively expensive and requires other coatings in the preparation which may also result in inaccuracies (He et al. 2018).

The two main spectroscopic techniques used are Raman and Fourier Transform-Infra Red (FT-IR), which provide information on polymer type and crystalline structure (Blair et al. 2017). Infrared radiation is passed through a sample and a spectrum is produced which is different for different materials and therefore the compound can be identified (Blair et al. 2017). The spectra produced are compared to those provided in a spectral library in order to identify the polymer compound. Spectroscopic techniques are not suitable for identifying tyre wear particles as carbon black (which is added to tyres) absorbs the infra-red light and there are strong interferences with other materials in tyres (Jekel, 2019; Olesen et al. 2019; Eisentraut et al. 2018). Spectroscopic techniques can provide information on quantities (counts) of microplastics within a sample and dimensions of particles (Scheurer & Bigalke, 2018; Richard Thompson, University of Plymouth, pers.com). However, Olesen et al. (2019) note that particles can be brittle and disintegrate over time (i.e. particle concentration in terms of numbers is not a conserved quantity) and therefore the use of mass is preferable. Spectroscopy can also be used to quantify/count the number of particles (e.g. Liu et al. 2019).

A variation of this technique is the identification of markers (rather than polymers) within the sample via spectroscopy, which are indicative of tyre and road wear particles, for example zinc (Zn) and additives such as benzothiazoles (Klockner et al. 2019; Redondo-Hasselerharm et al. 2018; Wagner et al. 2018). However, there are other sources of Zn in the environment, which may limit its use as a marker (Vogelsang et al., 2019). Additionally, Klockner et al. (2019) whilst identifying a methodology for using Zn as a marker noted that it is a less sensitive method than thermoanalytical techniques, and therefore more applicable for environments with high traffic loadings.

Thermoanalytical methods include pyrolysis (Pyr) and thermal extraction desorption (TED) (Eisentraut et al. 2018). In these methods samples are heated to high temperatures (and thus destroyed) and the volatile products produced are analysed by gas chromatography (either GC-FID (gas chromatography flame ionization detection) or GC-MS (gas chromatography mass spectrometry)) (Wagner et al.

2018). This enables quantification of polymer contents on a scale of mg/kg (Eisentraut et al. 2018). These methods are suitable for identifying tyre wear particles in samples (Parker-Jurd et al., 2019). There is a standardised method for determining the concentration of tyre and road wear particles in soil and sediments via Pyr-GC-MS (PD ISO/TS 21396:2017 Rubber – Determination of mass concentration of tyre and road wear particles (TRWP) in soil and sediments – Pyrolysis-GC/MS method, ISO, 2018). An alternative thermoanalytical technique is thermogravimetric analysis, whereby the loss of mass at different (high) temperature bands indicates the composition of the particle (Redondo-Hass et al. 2018).

It is worth noting that spectroscopic and thermoanalytical techniques produce results in different units (count vs. mass) which can make combination and/or comparison of results difficult.

Studies looking into microplastics in environmental samples use a range of these techniques.

Wang et al. (2017) sampled water samples from urban lakes and rivers in Wuhan, China and analysed a sub-sample of microplastic particles (fibre, granule, film and pellet) under an SEM to look at their surface characteristics. Additionally, the number, shape, colour and size of microplastics for each sample were recorded. A set of items were then selected and confirmed as plastic by identifying their polymer composition using FT-IR and an associated spectral library, which identified polyethylene terephthalate (PET, 18 particles), polypropylene (PP, 13 particles), polyethylene (PE, six particles), polyamide (nylon, five particles) and polystyrene (PS, two particles). PET and PP were the main polymer, with PET typically used in the production of textiles, such as clothes, blankets and fleeces and PP the most widely produced polymer around the world and commonly applied in fishing nets and ropes. However, they note it was far-fetched to determinate the origin of plastics by identifying the polymer-types of such a small number of subsamples.

Eriksen et al. (2013) sampled water from the Great Lakes, USA. After sieving, individual pieces of plastic were divided into categories (fragment, foamed polystyrene, line, pellet, film) and then counted. The surface characteristics of the identified microplastics were determined using SEM and elemental composition determined using EDS. Many particles were identified as non-polymeric through SEM/EDS analysis (paint chips from the ship used for monitoring and aluminium silicates, coal ash and coal fly ash) showing that visual observation alone is insufficient to separate microplastic from other debris.

Horton et al. (2017a) used Raman spectroscopy to analyse a sub-sample of the river sediments collected from the River Thames, UK, and the collected spectra were compared to a database of known compounds (BioRad KnowItAll® Informatics System - Raman ID Expert (2015) software). They found only 33% of the tested particles could be identified due to poor quality spectra. Of those which could be identified by their polymer composition, polyester/polyethylene terephthalate (PET, 14 particles), polypropylene (PP, five particles), polyarylsulphone thermoplastic (five particles), polyethylene (PE, two particles), polystyrene (PS, one particle), and poly vinyl chloride (PVC, one particle), with the remaining (six particles) being grouped under 'other'.

Ziajahromi et al. (2020) sampled water and sediment from a stormwater floating treatment wetland in Australia. Suspected microplastics were counted after being identified visually under a dissecting microscope and the suspected microplastics were characterised using micro(μ)FT-IR with the spectra being compared to a library of known spectra (library set included the Nicolet polymer, forensics and common materials set in addition to the Hummel polymer library). The most frequently detected microplastics across all water samples were polystyrene-co-ethylacrylate (black fragments) followed by polypropylene, nylon and polyester, which could be attributed to industrial and commercial applications as well as atmospheric depositions. Unlike water samples, a greater amount of fibrous particles (>60% of the total microplastics) were detected in sediment samples. Black microplastic fragments were also found in both sediment inlet and outlet samples, which comprised 15 to 38% of the total detected microplastics in the sediment samples, the majority of which were confirmed by

FTIR as synthetic rubber-carbon filled isobutylene (or butyl rubber), likely originating from car/truck tyre.

Hurley et al. (2018) sampled river sediments from Northwest England and a subsample of suspected microplastic particles had their polymer composition identified using FT-IR and spectra compared to a standard Attenuated Total Reflectance Polymers library in order confirm the particles were polymers.

Klockner et al. (2019) developed a method for using Zn as a marker for detecting tyre and road wear particles from environmental samples and elemental analysis was undertaken using an ICP-MS (inductively coupled plasma mass spectrometer) and chromatography undertaken using TED-GC-MS.

An alternative method used for confirming that suspected microplastics are actually composed of plastic is by undertaking a 'melting test' (i.e. testing whether the particle melts under heat, which plastic does), which Vijayan et al. (2019) used for suspected microplastics from snow banks alongside roads in Sweden.

It has been noted that environmental conditions (such as pH, salinity and temperature) may have an effect on the composition of car tyre particles, which may cause the chemical properties of these particles to change over time and needs to be investigated further to ensure the characterisation of microplastics from environmental samples is undertaken appropriately (Ziajahromi et al. 2020).

Secondary research question 2b – What are key site characteristics and conditions for sampling microplastics on the SRN?

There were a few articles identified during the literature search which specifically looked at sampling and analysing for microplastics from urban/road runoff. Eisentraut et al. (2018) collected a street runoff sample (3 litres, water) from the influent channel of a soil retention filter system after a rainfall event and a sediment (sludge) sample was taken from the sedimentation basin after drainage of the supernatant from the basin itself.

Liu et al. (2019) sampled sediments from seven stormwater retention ponds (of differing catchment land uses) during dry weather with at least two days of antecedent dry weather. The samples were taken in locations where the pond had 1 m water depth, which is a water depth at which deposited sediments are not prone to wind-induced re-suspension, and therefore were assumed to represent the long-term average of 3-7 years of sediment accumulation. Sediments were collected on the same day from each pond, at three random locations, and then combined into one composite sample.

Olesen et al. (2019) collected sediment and water samples from a stormwater wet retention pond in Denmark from September to December. Water samples were collected 5 times during dry weather (10 litres each time) with at least 14-days in between sampling, to compensate for short-term variations. Samples were collected 2-3 m from the "shoreline" in at least 0.5 m water depth. Sediment was collected once (October) in the littoral zone (2 m from shore), midway between the inlet and outlet of the pond. The top 5-8 cm of sediment was collected, and multiple samples taken to create a bulk sample of 1-2 kg.

Ziajahromi et al. (2020) collected sediment and water samples from a floating stormwater treatment wetland in Australia in December. Sediment was collected at both the inlet and outlet (with two replicates), with the top 5 cm collected from an approximately 20 x 30 cm area, resulting in approximately 1 kg from each location. Water samples were also collected at both the inlet and outlet (with two replicates) after a heavy rainfall event (approximately 34 mm/day) from the middle of the pond, approximately 50 cm below the water surface.

Based on the responses to this research question and those in question 1a (which considered the main sources of microplastics on the SRN), those site characteristics that influence the quality, type and concentration of road runoff derived contaminants, as identified in previous HE research, also, for

the most part, dictate the generation of microplastic pollution, these include:

- Traffic volume and behaviour (e.g. congestion, speed, braking)
- Rainfall volume and intensity and subsequent flow off the road to the drainage network
- Drained area, ambient and antecedent conditions
- Spatial position (i.e. rural vs urban)
- Peaks in microplastic concentrations are likely to be seen during the 'first flush' of rainfall events and associated with the peak hydrograph

Also, in common with other contaminants derived from the SRN, SuDs systems (particularly retention ponds and swales/grassed channels) may trap and contain microplastics. Retention rates of 75-90% have been identified. However, although evidence is sparse, such systems may also provide a secondary "source" through re-mobilisation of microplastics following storm events.

More general information on the considerations that need to be undertaken when sampling for microplastics (not necessarily SRN related) were noted from the reviewed literature and the telephone questionnaires :

- In the water environment microplastics tend to accumulate in sediments (Wagner et al, 2018) due to the high density of some microplastics (e.g. tyre and road wear particles, ETRMA, 2019) and increases in density due to heteroaggregation with suspended solids (Unice et al. 2019, Part I) and biofouling (Horton et al. 2017a)
- Sediment distribution and transport processes will influence the distribution and transport of microplastics within the water environment (Blair et al. 2017)
- Concentrations of microplastics will decrease with increasing distance from the primary source, whilst the complexity of the matrix (which may affect sampling preparation and analysis) and importance of other sources increases (Wagner et al. 2018)
- The season and antecedent conditions will affect runoff, water levels, flows, which will have an impact upon sampling (Santillo et al. 2019; Stock et al. 2019). Road runoff only occurs when it rains, otherwise water sampled could be land drainage (Joanna Bradley, SDS Limited; pers.com.). If there has not been any rainfall in weeks, the runoff that results from subsequent rainfall will be especially polluted, however, if it has been raining for some time the pollution will be more distributed and will have less of an immediate impact on the water quality of nearby waterbodies (Joanna Bradley, SDS Limited; pers.com.). Currently it is not known how much rainfall is needed to liberate particles from the road, how far they travel and how long it takes for the road surface to become 'clean' (Richard Thompson, University of Plymouth; pers. com.)
- The depth of the sediment or water, from which the sample is taken needs to be considered, due to sedimentation and the different densities of plastics (Table 4.4).
- The type of road, road gradient, how often a driver is braking, weight of vehicles (HGV vs. car), urban vs. rural roads and traffic density are also very influential on the level of pollution coming from roads (Joanna Bradley, SDS Limited; Hasmita Stewart, Defra; Judy Proctor, Environment Agency; Richard Thompson, University of Plymouth pers.com.)

Microplastics are highly diverse in shape, size, colour and density, resulting in high variability in their distribution in space and time (Blair et al. 2019). Furthermore, differences in sampling method and equipment may lead to inconsistencies that prohibit the comparability of datasets (Horton et al. 2017b).

Secondary research question 2c – To what extent can the SRN as a source of microplastics be differentiated from other (e.g. airborne) sources?

From secondary question 2a it seems apparent that there are some techniques and methods which can be used to help identify which microplastics within a sample are derived from the SRN.

As detailed within secondary question 1a the main/direct sources of microplastics in the SRN are tyre and brake wear, road markings and degradation of litter. As noted in secondary question 1a, tyre wear, brake wear and road markings (collectively known as TRWP) represent the largest source of microplastics deposited in the environment for many studies, indicating they are the likely the most important source of microplastics on the SRN. Visual and source characterisation methods can be used to identify some of these sources of microplastics within a sample and hence to identify SRN sources from other non-SRN sources.

Visually, tyre road wear particles are frequently identified under microscopes. As noted above, this is based on the assumption that they can be characterised as having an elongated shape, are black, include mineral road materials and are in the size range 5-250 μm (Jekel, 2019; Vogelsang et al. 2019). Also as noted above, polymer-modified bitumen wear particles (i.e. road surfaces) have similar visual characteristics.

Road markings can be identified visually due to their colouring from the paint (white/red/yellow) and the incorporation of glass beads (Horton et al. 2017a). However, Horton et al (2017a) noted that these road marking particles were dense composites, and did not float during density separation, and therefore there is the potential for these particles to be missed during sample analysis methodologies.

For source characterisation, tyre wear particles cannot be analysed using spectroscopy methods as the carbon black absorbs the infra-red light and there are strong interferences (Jekel, 2019; Olesen et al. 2019; Eisentraut et al. 2018). Therefore, to ensure the inclusion of tyre wear particles (which are presumed to be an important source of microplastics from the SRN), then a thermoanalytical method must be used.

Additionally, the polymer composition of the identified microplastics, which can be determined through spectroscopy and thermoanalytical techniques, can be interpreted to understand the possible sources (SRN or not) of the microplastics. For example, polyester can be assumed to be derived from a non-SRN source and synthetic rubber-carbon filled isobutylene (or butyl rubber), likely originating from a car or truck tyre. The identification of dyes within particles can help identify road markings, Horton et al. (2017a) identified chrome yellow dye in Raman analysis of road marking particles.

Although no studies were identified during this literature review which specifically described visual identification or polymer composition of litter on the SRN, with some further research, there is the potential for microplastic litter to be identified visually due to its visual characteristics and polymer composition. For example, plastic shopping bags, which are typically made of polyethylene, could be identified by polymer composition and visually may be identifiable under a microscope due to the colour and shape. Many forms of microplastic litter on the SRN will be secondary microplastics, i.e. have broken down to the smaller micro size ($>100\text{ nm}$ $<5\text{ mm}$, Robin et al. 2020), which may help in the visual identification process.

5. Summary

Primary and secondary questions 1

Secondary question 1a. What are the main sources of microplastics on the SRN?

The main sources of microplastics from the SRN are:

- Tyre Road and Wear Particles (TRWP) – from abrasion of tyres, brakes and road markings via direct runoff
- Degradation of litter
- Indirect sources from microplastics concentration in soils (which may originate from road generated microplastics or from agricultural soils use)

Of these, tyre wear is the single biggest contributor. Primary plastics break down via physical, chemical and biological transformation to form smaller secondary plastics, which are the most prevalent in the environment.

1b. What has changed in terms of the types and occurrence of predominant pollutants in road runoff since 2010?

Microplastic pollution was not considered in earlier HE research efforts. The literature survey has clearly established that roads form a major source of such pollutants, however quantification of these and the impacts they may have on the environment remain unclear.

The literature search has not generated firm conclusions regarding the change in contaminant type since the previous tranche of HE research, although the search terms used may not have identified all emerging substances not associated with microplastics. However, it is evident that many contaminants are either present in tyre materials (e.g. Zn; PAHs;) or are sorbed onto and carried by tyre wear materials (this may include heavy metals, and a number of persistent organic pollutants) and that these warrant further investigation. The toxic effects of these “composites” are not clearly understood.

Discussions during this research programme have identified a number of other pollutants of concern (not previously identified in earlier HE research) that warrant further attention, these include some metals and a number of organics, some of which are derived from tyres. Future sampling and analysis programmes should seek to evaluate the potential harm from these substances, although many lack environmental quality standards (EQS) which may influence judgements regarding their capacity to cause harm in the water environment. The value of monitoring pollutants of concern that have no associated EQS will need to be considered further. Proposals for the sampling and analysis of specific pollutants of concern are provided in the Final Project Report.

Although recognised in previous HE research programmes, and indeed incorporated into HE assessment tools, the fate and concentration of PAHs in particular has been identified as a (continued) cause for concern, particularly as they are now (i.e. post 2010) subject to more stringent environmental quality standards.

Current HE standards (in LA 113) have recognised changes in EQS for metals. The change in EQS values for PAHs have not led to any change in HE assessment methods (for PAHs) as these were based on direct, evidence based toxicological evaluation undertaken in earlier HE research (Gaskell, P., et al, 2007; Johnson. I. and Crabtree. R., 2008) and hence were not influenced by EQS values (or any subsequent change). However given their identification as key pollutants in road runoff, further evaluation of the implications of the change in EQS values for PAHs is warranted.

Given the apparent sorption of PAHs onto highly prevalent tyre derived microplastics (and the tyre “content” itself) and that these microplastics may make up a (potentially significant) part of the sediment load, developing a better understanding in terms of the distribution of PAHs within the sediment load is necessary before any recommendations could be made regarding changes to current HE assessment methods.

1c. What are the implications, of the changes discussed in question 1b, for Highways England policy (most specifically related to microplastics)?

Although there are changes in the sources and nature of pollutants of contaminants derived from road runoff there needs to be more evidence on their effects (including toxicity) before significant changes in HE policy should be considered.

With respect to assessment and design, it would be premature to alter guidance and standards until a greater understanding is obtained of the sources, pathways and receptors of these pollutants. Exploring any analogous behaviour between microplastics and suspended sediments would be a particular area to address, as this might demonstrate that some aspects of existing policy remain relevant and appropriately robust.

Similarly with respect to construction and maintenance policy, the current evidence base is insufficient to justify significant change, although a greater emphasis on the maintenance of drainage infrastructure may address some of the issues raised in the literature review (e.g. re-mobilisation of microplastics from retention structures such as ponds). In the adoption or use of new innovative road surfacing methods incorporating recycled materials (such as recycled tyres) sustainability benefits need to be balanced against the potential for these (non-standard) road surfaces to act as (additional) sources of microplastics.

HE littering strategy does not specifically address plastics or their degradation products, however some steps could be adopted to reduce the influence of litter as a source of microplastics. Potentially beneficial steps include identifying and addressing litter hotspots on a wider scale and adopting some methods used by the EA to reduce the incidental production of litter degradation during verge maintenance. The contribution of such hotspots to the overall microplastic load (for example as discharged to road drainage) might also be subject to investigation.

1d. What essential future research activities can be identified to better understand the contribution of road runoff to microplastic pollution and what would be their indicative budget?

The primary research needs to better understand the contribution of road runoff to microplastic pollution are as follows:

- An improved understanding of the key sources of microplastics (particularly the main source, tyre wear) through specific site sampling and analysis.
 - These identified sources need to be better quantified not only in concentration but total flux/load
- An understanding of the degradation of primary plastics (and the controls on this) to quantify the magnitude of ‘secondary’ microplastic pollution.
- Evaluate the use of plasticised paints and road markings to determine if these sources might be reduced or eliminated

- Further investigations into the link between site characteristics (traffic volume and behaviours, climate, road materials etc.) and how these influence fate and transport mechanisms of microplastics.
- More investigations are needed monitoring microplastic pollution through storm events, particularly in the early part of storms, as this is likely when concentrations will be the highest (the most important pathway for microplastic being transported from the SRN is surface runoff).
- The relationship (if any) between suspended/ sediment load and deposition and that of microplastics requires greater clarity... are they analogous. Can treatment/ containment of suspended solids (and current standards) also address microplastic pollution?
- (following the above) Investigate the efficacy of runoff treatment systems to capture and retain microplastics requires additional investigation, as well as management techniques, for example de-silting of ponds.
- How are road derived microplastics distributed in soils adjacent the SRN and can they be re-mobilised into drainage systems and the aquatic environment?
- How much does roadside litter contribute to the overall load of microplastics and are there ways of reducing this impact ?

Primary question 1 - To what extent does the strategic road network (SRN) contribute to microplastics in the water environment?

As much as 40% of microplastics (and possibly more) flowing from freshwaters to oceans are sourced from TRWPs and these likely represent the largest single source of microplastics deposited in the water environment. There is no research available to determine the proportion of these sources attributable to the SRN, and there is evidence to suggest urban sources of road drainage (i.e. predominantly off the SRN) represent a larger part of the overall contribution from roads (although recent UK research appears to suggest this may not be the case and that motorways provide a greater contribution).

Although understanding of microplastic sources from road networks has improved exponentially over the last decade, future research should still seek to improve the understanding of the sources, fates and impacts of microplastics. After identifying sources, accurately quantifying these sources remains a significant scientific challenge, both in concentration and total flux.

Cross-sector and cross-company collaboration is needed to develop faster, cheaper, more portable techniques to measure and quantify microplastics in-situ.

Future research needs will require a wide collaborative approach with, for example, regulators, vehicle and tyre manufacturers, road materials contractors and designers and treatment providers.

Primary and secondary questions 2

Secondary research question 2a – Are robust and repeatable techniques under development for quantifying microplastics?

- Currently there is no standardised methodology for the identification and quantification of microplastics
- The common steps undertaken for sampling processing and microplastic identification and quantification are:
 - o oven-drying and sieving/filtering
 - o density separation
 - o visual inspection
 - o source characterisation and quantification

- However, there are variations within each of these steps
- Spectroscopic and thermoanalytical techniques produce results in different units (count vs. mass) which make combination and/or comparison of results difficult
- Sampling techniques and analysis need to be further developed to allow for this quantification, including in-situ analysis. This needs to be faster, cheaper and more portable

Secondary research question 2b – What are key site characteristics and conditions for sampling microplastics on the SRN?

- Only a few studies identified in the literature sampled and analysed for microplastics from urban/road runoff
- General considerations that need to be undertaken when sampling for microplastics are:
 - o microplastics tend to accumulate in sediments
 - o sediment transport processes will influence microplastic distribution
 - o microplastics occurrence will decrease with increasing distance from the primary source
 - o the season and antecedent conditions will affect presence of microplastics and sampling method adopted
 - o the depth of sampling will affect results
 - o the type of road, road conditions, vehicle types and driving conditions will affect sampling results.

Secondary research question 2c – To what extent can the SRN as a source of microplastics be differentiated from other (e.g. airborne) sources?

- Visually tyre road wear particles appear as an elongated shape, are black, have the inclusion of mineral road samples and are in the size range 5-250 µm.
- Polymer-modified bitumen wear particles (i.e. from road surfaces) have similar shapes, size distributions and densities as tyre road wear particles
- Road markings can be identified visually from their colouring (red/yellow/white) and the incorporation of glass beads.
- Thermo-analytical techniques are needed to identify tyre wear particles
- Polymer composition can help identify the possible sources (SRN or not) of the microplastics

Primary question 2 - What is the most appropriate sampling and analysis method to quantify microplastics of key interest to the SRN?

There is currently no standardised methodology for both the sampling and analysis of environmental samples for microplastics derived from the SRN. Therefore, until a standardised approach is agreed, it is important that the chosen sampling and analysis protocol is appropriate for the research being undertaken. Mirroring previous sampling and analysis methodologies may also be appropriate to allow comparison of results.

Sampling – for the sampling sites it is important that the site characteristics are considered and sampling is undertaken where microplastics are most likely to accumulate (in sediment, close to the source and in depositional areas). The timing of when samples are taken will also have an impact upon what results are obtained, so consideration of antecedent conditions needs to be included. Additionally, the type of road, road conditions, vehicle types and driving conditions will affect sampling results.

Sample preparation – sample preparation needs to be adequate and appropriate to ensure accurate results are obtained from the samples - dry/filter/sieve to the appropriate size range, removal of organic matter via digestion (but select an appropriate chemical which will reduce the risk of impact on plastic particles from digestion), density separation to isolate the microplastics

(select appropriate density of solution to ensure all microplastics float in the supernatant) and visual inspection (at high enough magnification to reduce human errors).

Analysis - parallel analysis via both spectroscopy and thermoanalytical techniques will be needed in order to ensure tyre wear particles are captured. However, the output of these two techniques will be different, as discussed in secondary research question 2a. Comparison of spectral signatures to spectral libraries will allow polymers to be identified, and potential sources of microplastics to be determined. Tyre and road wear particles may be retained in SRN drainage systems for a considerable period of time and the environmental conditions in which they are retained may affect their chemical properties and thus their characterisation.

Common themes identified

Whilst looking at each primary research question, which provided different “hits” in the web searches, there are clearly common themes emerging. These are summarised as follows:

- There is an emerging understanding that TRWP form one of the most significant (if not the most) contributors to microplastics pollution in the water environment (40% or possibly greater from TRWP)
- TRWP form the main sources of microplastics on the SRN with roadside litter and microplastics from roadside soils additional (and notable) contributors
- Microplastics behaviour is somewhat analogous to that of suspended sediments, however there are important differences that need to be understood, these include, for example, the nature of contaminants sorbed on microplastics surfaces and the rate of plastics breakdown into smaller particles
- Density of microplastics is a primary property that determines their transport and ultimate fate although they tend to accumulate in sediments and typically decrease away from primary sources
- Similar to previous HE research, key site characteristics include drained area, traffic volume and behaviour; rainfall volume, intensity and antecedent conditions; location (urban vs rural)
- Understanding these site characteristics is a vital element to understanding the generation, pathways and ultimate receptors of microplastic pollution from the SRN
- Sampling techniques, analysis and units used to record microplastic fluxes need to be standardised so results from different studies can be compared and verified
- The adoption of cheaper, quicker (and preferably field based) methods of analysis, would contribute significantly to our understanding of the scale of the issue
- TRWP are typified as elongate, black materials with particle size 5-250 µm and include bound road materials
- Polymer composition can help identify plastic sources, but analytical methods for typical tyre materials are destructive which can compromise analysis
- A number of other pollutants of concern have been identified that warrant further attention, these include some metals and a number of organics
- Future sampling and analysis programmes should seek to evaluate these pollutants of concern, although many lack environmental quality standards (EQS) which may influence judgements regarding their capacity to cause harm in the water environment
- The future increase in the use of electric vehicles on the SRN will have implications for microplastic pollution due to their generally increased weight (and hence wearing characteristics) over equivalent internal combustion vehicles
- Although some SuDS treatments (such as ponds) of road drainage have been demonstrated to capture microplastics, the efficacy of these measures, including potential re-mobilisation, would benefit from a greater understanding
- HE policy to address microplastic pollution should focus on where their assessment, design or intervention measures are likely to have the biggest impact, however, at the present time, more robust research and more evidence is needed before changes in HE policy are implemented.

- As well as pursuing research directly associated with the SRN, HE could contribute significantly to collaborative research including with regulators, vehicle and tyre manufacturers and other industry stakeholders (such as developers of treatment measures).

Key areas for future research

Based on the above the key areas of research are as follows:

- Development of standardised sampling and analytical methods
- Develop a greater understanding of sources on the SRN (including from adjacent soils and littering)
- Develop a greater understanding of plastic materials on the SRN including rates of breakdown and the nature, composition and “extent” of sorbed contaminants
- Further understanding of how site characteristics (location, weather, road condition, drained area, traffic etc.) influence the generation of microplastics from the SRN and its distribution in the drainage network
- Develop a greater understanding of the distribution and proportions of different types of plastics generated on (and transported via) the SRN
- Develop a more targeted list of other pollutants of concern and undertake focussed investigations (into these) to develop a more robust dataset for evaluation of impacts from road runoff
- Determine to what extent is the SRN facilitating the movement of microplastics.
- Evaluate the efficacy of HE drainage and treatment / mitigation systems and standards (including SuDS systems) in the entrapment/ treatment of microplastics (and their capacity for subsequent remobilisation)
- An understanding of the ultimate fate of microplastics generated from road surfaces (e.g. within the downstream water environment or by atmospheric dispersion)
- Evaluate the use of plasticised paints and road markings to determine if these sources might be reduced
- Determine how much roadside litter contributes to the overall load of microplastics and if there are ways of reducing this impact?

A more in -depth discussion of the key areas for research will be developed in the Final Project report.

6. References and Acronyms

References

The Reference list below contains details of all papers/articles/reports that are cited in this report. A wider Bibliography is given in Appendix B and provides the full list of papers viewed to support the compilation of the Literature Review. The bibliography includes both referenced sources and works not specifically cited herein.

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Acronyms

Acronym	
ABS	Acrylonitrile Butadiene Styrene
BSI	British Standards Institute
Defra	Department for Environment, Food and Rural Affairs
DMRB	Design Manual for Roads and Bridges
EA	Environment Agency
EDS	Energy-dispersive x-ray
FT-IR	Fourier Transform Infra-Red
GC-FID	Gas chromatography flame ionization detection
GC-MS	Gas chromatography mass spectroscopy
HE (HA)	Highways England (Highways Agency)
ISO	International Organisation for Standardisation
PAHs	Polycyclic aromatic hydrocarbons
PC	Polycarbonate
PE	Polyethylene
pers.com.	Personal communication
PET	Polyethylene terephthalate
PMMA	Polymethyl methacrylate
POP	Persistent organic pollutants
PP	Polypropylene
PS	Polystyrene
PSG	Project Steering Group
PTFE	Polytetrafluoroethylene
PUR	Polyurethane
PVC	Polyvinyl chloride
Pyr	Pyrolysis
SEM	Scanning electron microscopy
SRN	Strategic road network
SuDS	Sustainable drainage systems
TED	Thermal extraction desorption
TEM	Transmission electron microscopy
TRWP	Tyre and road wear particles
WFD	(European) Water Framework Directive

APPENDIX A - Literature Search Results

Literature research results have been supplied separately as separate excel files comprising:

- 'Primary Question 1 Literature Search Results'; and
- 'Primary Question 2 Literature Search Results'.

APPENDIX B – Bibliography

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APPENDIX B – Methodology statement

1 Background

Highways England (HE) has commissioned research into the Strategic Road Network's (SRN) potential contribution to microplastics in the water environment. The aim of this initial research is to identify if runoff from the SRN is contributing to microplastics in the water environment. Following a review of the literature, interviews of experts in the field and best practice techniques, this methodology statement sets out the sampling and analysis requirements to establish the presence or absence of microplastics in road runoff and in addition to establish concentrations of emerging contaminants. These emerging contaminants have been identified primarily as those substances of interest not captured by previous HE research into road runoff.

Although this methodology statement has been informed by the outcomes of the literature review, it remains evident that the occurrence of microplastics in the water environment is a developing field of research and proposed approaches are based on the current best available information. This is illustrated by the lack of a standard approach to sampling / analysis of microplastics and, as is recognised in the literature, more work needs to be done to develop a robust and repeatable methodology for quantification of microplastics.

2 Site selection

Previous research by the Highways Agency (now HE) into the quality of runoff broadly followed three key research "streams" each of which identified and utilised a number of different sampling sites derived from a long lists of candidate sites:

<i>Research Stream</i>	<i>Main research contractor</i>	<i>No. of sampling sites identified/ utilised (see Note 1)</i>	<i>Primary sampling purpose</i>
"Improved determination of pollutants in highway runoff"	WRC (1997 - 2008)	4 "Group A " sites 20 "Group B" sites (see note 2)	Sampling focussed on quality of road runoff and resultant watercourse quality. ("A" sites were those with a high traffic volume; "B" sites have lesser traffic)
Fate of highway contaminants in the unsaturated zone	Scott Wilson/ Highways Research Group (2007-2010)	4 sites (from a shortlist of 8/9)	Sampling focussed on discharges to ground and underlying geology / ground conditions
Accumulation and dispersal of suspended solids in watercourses	ECUS Ltd and University of Sheffield (2003-2007)	6 sites	Sampling focussed on sediment discharge to water courses

Note 1 : Only those sampling sites used "long term" are identified here

Note 2 : 6 other sites had been sampled in earlier work; 2 of which became Group B sites.

In each of these research streams, slightly different site selection criteria were applied depending on the primary research purpose, however it was considered that sampling site(s) for this (current) project should be a subset of these sites identified in previous research, for a number of reasons, including:

- The previously selected sites should offer safe access
- Site characteristics (e.g. road catchment, traffic load etc) should be well documented and understood

- There should be readily identified sampling points

Available project documentation for these previously sampled sites offered differing levels of detail regarding the sample sites. For example, site details for the WRC Group B sites were not available (being in separate report appendices, not now available), although details from 2 sites previously monitored by WRC were available. As information on the sampling sites was variable in quality, a number of other sources of information were examined to provide some corroboration. This included:

- Aerial imagery (Google Earth)
- Highways England drainage data (on HADDMS)
- OS mapping

This also helped to identify sites that may have changed significantly (e.g. loss of safe access) as a result of developments (whether of the highway or other developments).

The selection of previously sampled sites also provides some “backward compatibility”, although traffic volumes, for example, will clearly have changed and there may have been changes to the drainage characteristics,

Further “filters” were applied. Sites were eliminated:

- That previously required significant installation of pipework, chambers or similar “structures.”
- Where traffic management was required or where there are other significant safety and access constraints.

There was a presumption against sites that drained road runoff into open ditches (which might collect plastic litter, unrepresentative of road runoff).

There was a presumption for sites with good drainage data on HADDMS (to provide some clarity before any site visit), with a positive drainage input (pipes or similar) to a well -defined pit, pond or tank from which samples could be taken. There was also a presumption for higher trafficked roads (e.g. WRC “Group A sites”) which might be expected to offer a “worst case” for microplastics. [Note that evidence from the literature review suggests (on the assumption of other factors being equal) that microplastic generation increases with increased road traffic, although flow, speed and traffic behaviours such as braking are also important (Sommer et al., 2018; Vogelsang et al., 2019)]

On the basis of the above criteria, 2 potentially suitable sites have been identified as follows:

Site	Road/ Location	“Source”	Key site characteristics
1	M1 J9 Luton	WRC Group A site	Good access, catchpit and sediment pond for sampling, high traffic
2	M25 Abbots Langley	Scott Wilson monitoring site	Good access, soakaway lagoon for sampling, high traffic

An initial site visit will be needed to confirm suitability (site 2 may not be favoured for collecting water samples), however these sites are relatively close to each other (circa 20km) and it is possible, depending on costs, that both sites could be subject to sampling. Brief site details are given in Annex A below.

3 Sample collection and analysis

3.1 Microplastics

The study currently plans to collect three sediment and three water samples for the analysis of microplastics from the sites identified above. These samples would be collected as close as possible to the discharge point from the “road drain.” It is proposed that the sediment samples are composite and taken from the top layer of sediment combining sediment from at least three locations across the pond inlet, ideally at a depth of >0.5m. The practicalities of this sampling method will be discussed with the contractor. Water samples would ideally be collected during a runoff event and follow an antecedent dry weather period of 24 hours. Samples would be taken from a point immediately below the surface of standing water. It is not presently proposed to use auto-samplers or other more sophisticated techniques, although other sampling approaches, if proposed by the monitoring contractor, will also be considered, subject to agreement.

Records taken on site will include measurements of temperature and pH, reference to antecedent conditions and comments on site characteristics. It is understood from the literature survey that factors that could influence microplastic contamination include, but are not limited to:

- Seasonal conditions
- Frequency and rate/rapidity of braking
- Road type,
- Tyre type,
- Vehicle weight

However, an analysis of these factors are beyond the scope of this sampling study.

Microplastics from the SRN may be derived from tyre wear and from other types of microplastics, such as road marking paint. To ensure these are represented in the analysis, two analytical techniques are required. A thermo-analytical technique such as Pyrolysis Gas Chromatography Mass Spectrometry (GCMS) will be required to determine the weight of tyre particles and types of plastic polymers present. In addition, a spectroscopy technique such as Fourier Transform Infrared Spectroscopy (FTIR) will be needed to provide particle numbers, dimensions and types of plastic polymers.

Specifics of the size fractions and analytical approaches for oven-drying, sample digestion, density separation and visual separation are to be determined by the contractor. However, sample preparation needs to be adequate and appropriate to ensure accurate results are obtained - this might include, for example:

- Dry/filter/sieve to the appropriate size range
- Removal of organic matter via digestion (but select an appropriate chemical which will reduce the risk of impact on plastic particles from digestion)
- Density separation to isolate the microplastics (select appropriate density of solution to ensure all microplastics float in the supernatant)
- Visual inspection (at high enough magnification to reduce human errors)

There should be the facility to store a sub-sample for a period of up to 5 years for future analysis. Permission is to be agreed with HE before this sub-sample is destroyed.

Careful consideration to be taken by the contractor regarding quality assurance with appropriate measures taken both for sampling and analysis to avoid plastics contamination. Information to be provided on blank correction of analytical techniques.

3.2 Chemicals

The collection of sediment and water quality samples would be from the same locations as the microplastics samples, and ideally at the same time. The sampling procedure adopted would broadly follow that identified for microplastics above, with site conditions and characteristics similarly recorded.

Sample analysis will be undertaken by a UKAS accredited lab for the determinands listed below. The colour codes in the Table are as follows:

- green: chemicals identified from previous research
- blue: likely to be subject to analysis
- orange: under consideration.

Deteminands	Water (EQS available?)	Sediment
INORGANICS		
Metals		
Antimony	Yes (No)	Yes
Arsenic	Yes (Yes)	Yes
Cadmium (total and dissolved)	Yes (Yes)	Yes
Copper (total and dissolved)	Yes (Yes)	Yes
Lead	Yes (Yes)	Yes
Manganese	Yes (Yes)	Yes
Mercury (dissolved and total)	Yes (Yes)	Yes
Zinc (total and dissolved)	Yes (Yes)	Yes
Inorganics		
Biological oxygen demand (BOD)	Yes (Yes)	No
Hardness	Yes (No)	No
Orthophosphate	Yes (Yes)	No
Sulphide	Yes (No)	No
Suspended solids	Yes (Yes)	No
ORGANICS		
Polynuclear Aromatic Hydrocarbons (PAHs)		
US EPA 16 PAH's(Speciatiated) - Naphthalene - Chrysene - Benzo (b) fluoranthene - Benzo (k) fluoranthene - Benzo (a) pyrene - Indeno (1,2,3,c,d) pyrene - Dibenzo (a,h) anthracene - Benzo (g,h,i),perylene - Acenaphthylene - Acenaphthene - Fluorene - Phenanthrene - Anthracene - Fluoranthene - Pyrene - Benz(a)anthracene	Yes (Yes – recent change)	Yes
Pesticides and herbicides		

Deteminands	Water (EQS available?)	Sediment
Benzothiazoles (including 2-benzothiazolesulfenamide)	Yes (No)	No
Glyphosate	Yes (Yes)	No
Mecoprop	Yes (Yes)	No
Miscellaneous Organics		
(Aromatic) mineral oils	Yes (No)	No
Aniline	Yes (No)	No
Bisphenol A (BPA)	Yes (No)	No
Cyclohexylamine	Yes (No)	No
Dicyclohexylamine	Yes (No)	No
Perfluoroalkyl substances (PFAS) - PFOS / PFOA	Yes (No)	No
Phthalates – DEHP	Yes (No)	No
Steranes (ltd suite)	Yes (No)	No

Note that some PAHs were identified as a key contaminant in previous HA ((HE) research and, in part, form a basis of the HEWRAT tool assessment of the sediment fraction in road runoff. However, advances in analysis methods have now led to lower limits of detection for these PAHs, and since the original research programmes there has been a significant lowering of EQS values for PAHs (and some of which were not previously defined have been “added”). On this basis a revisit of PAHs is considered relevant.

4. Outputs

The sampling and analysis contractor would need to provide onsite measurements and comments, analytical results, interpretive report relating the microplastic types to source, and details of the analytical techniques applied.

Onsite access would be arranged via Highways England but the contractor would need to implement appropriate health and safety measures including risk assessments for the sample collection.

5. Programme

It is expected to complete sampling, analysis and reporting by 30th April 2020.

6. Assumptions and limitations

Due to the aim of this research being to establish the presence or absence of microplastics in road runoff, groundwater and replicate samples are not requested. It is acknowledged that the collection of one sample for emergent contaminants will not necessarily be representative of the temporal variability in concentrations at the site and that such snapshot samples cannot be realistically be compared with results recorded in previous research. It has also been necessary to limit the scope of this investigation meaning it is not possible to consider variables such as seasonality or first flush. It is acknowledged that there remains a steep learning curve to understand how to sample and analyse the occurrence of microplastics in road drainage, therefore the storage of a sub-sample provides the opportunity for future analysis techniques continue to develop.

Annex A - Potential sampling site brief details

Site 1- Luton M1 /J9

The WRC site summary states:

- Traffic flow - 146000 vehicles per day (two way)
- Carriageway - drainage concrete channel
- Catchment area - 43375m², Northbound carriageway only, 4 lanes
- Monitoring location - 4500mm pipe, manhole upstream of oil interceptor in balancing pond compound.

Though traffic (in particular) is now probably significantly higher.

The location is shown on the Google screen shot (imagery date 7/5/2018) below. It is understood this part of the M1 now has all lane running (which would have not applied when previously sampled), however otherwise site characteristics are believed to be relatively unchanged. Site access (off the A5183) is good.

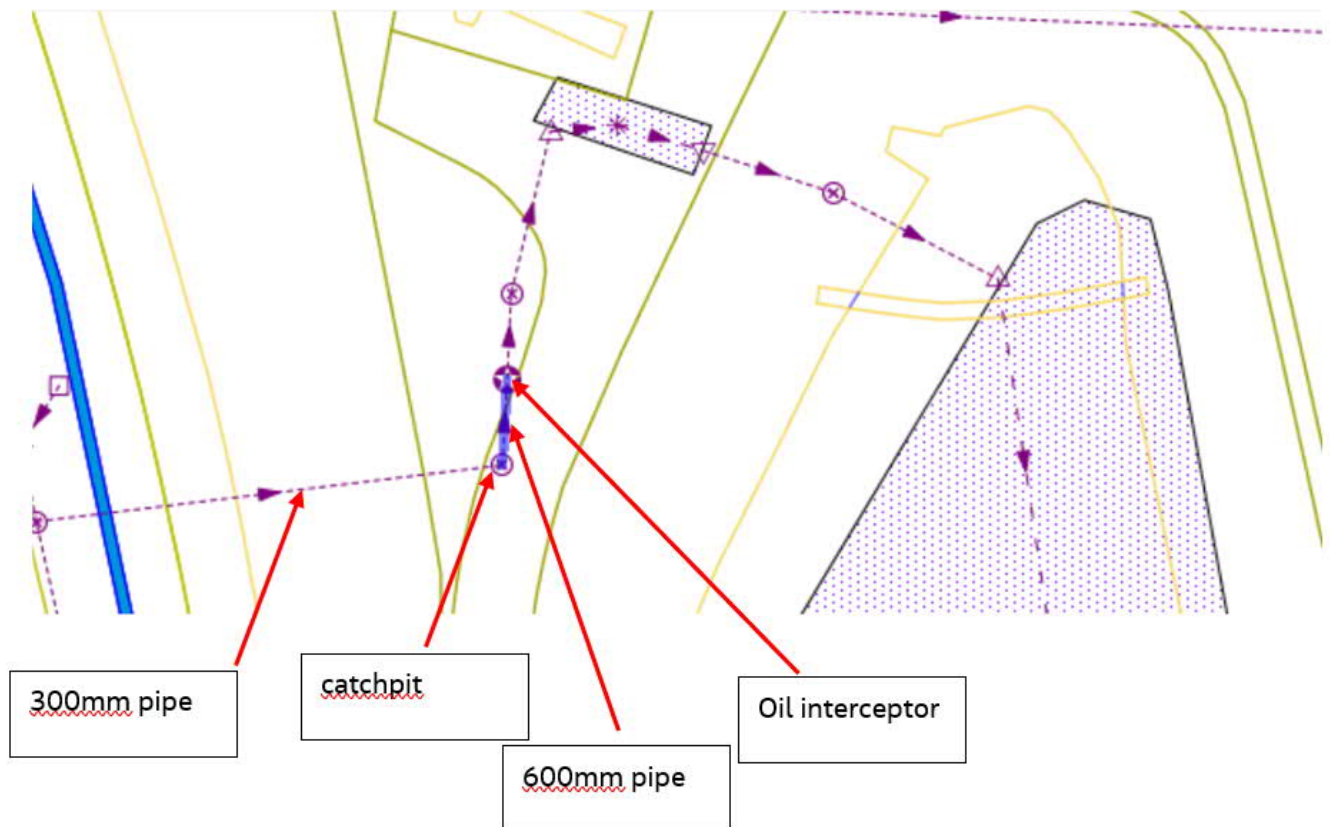


The WRC Report map shows the monitoring location approximately at point marked X above, though based on imagery and HADDMS mapping (see below) this is probably incorrect

The circle shows a large pollution attenuation chamber prior to discharge to a large pond. The previous sampling point was a catchpit prior to the pollution attenuation chamber. (see below).

This site provides a number of possible sampling locations

Site 1- Luton M1 J9 – annotated extract from HADDMS

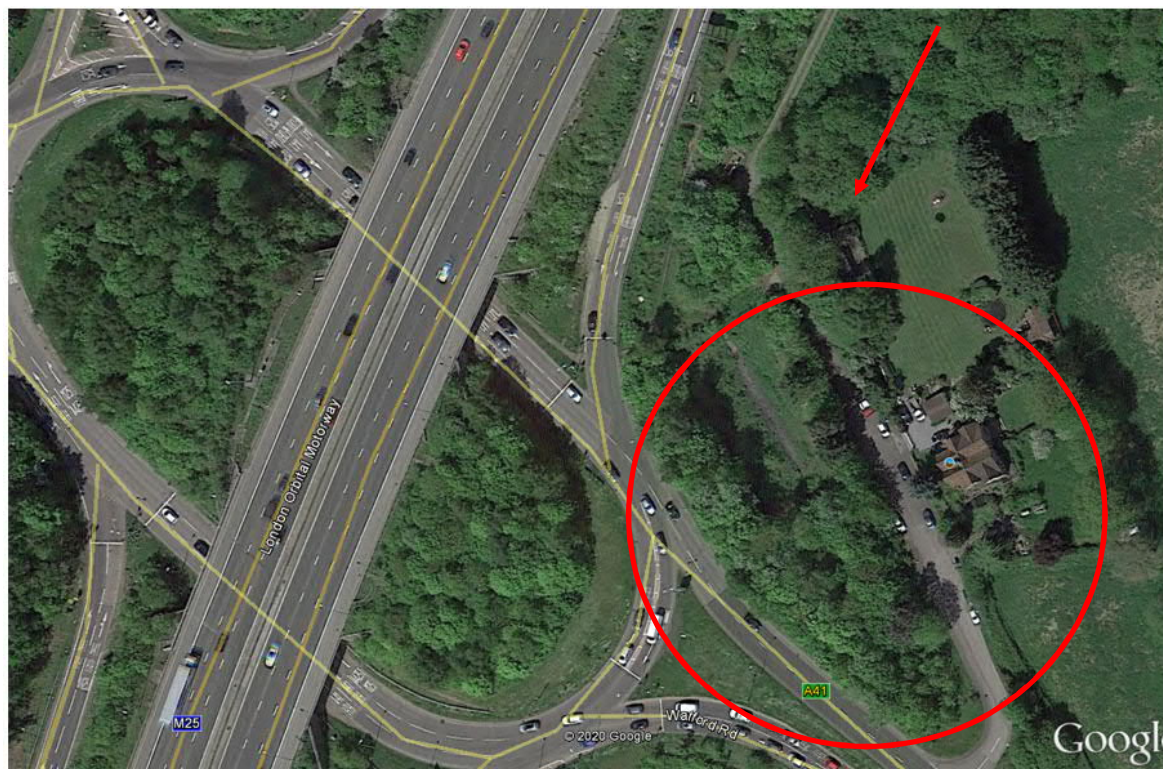


Site 2- Abbots Langley M25 J 20

Discharge is to a soakaway lagoon (NGR 507663 201367)

Access is good off a no through road adjacent the M25.

Further details of the monitoring location are provided in the source research document.

**Site 2 - Annotated extract from HADDMS**



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