Understanding Microplastics in the Scottish Environment

The sources, fate and environmental impact of microplastics in the Scottish terrestrial, freshwater and marine environment

Simon Hann
Olly Jamieson
Alice Thomson
Chris Sherrington
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Prepared by Simon Hann

Approved by

Chris Sherrington

Eunomia Research & Consulting Ltd
37 Queen Square
Bristol
BS1 4QS
United Kingdom

Tel: +44 (0)117 9172250
Fax: +44 (0)8717 142942
Web: www.eunomia.co.uk

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Executive Summary

This research project sets out to understand the sources, pathways, fate and environmental impact of microplastics in Scotland in three environmental contexts and the interaction between these: the terrestrial environment, including agricultural land; the freshwater environment, and the marine environment.

Large plastic items can entangle marine life, as well as be ingested by larger marine animals. Microplastics are small (<5mm) fragments of plastic which are of additional concern because of their potential to accumulate organic contaminants in increasing quantities with decreasing size. When they enter aquatic systems, microplastics can be ingested by a range of organisms and accumulate through the food web, causing harm to health and the environment.

The Scottish Government has made tackling marine litter and plastics one of its key goals, and this featured strongly in the 2017/18 Programme for Government – a commitment that has continued in the 2019/20 Programme for Government, with the aim ‘to meet or exceed the standards set out in the European Union’s Single Use Plastic Directive’. Under the Scottish Marine Litter Strategy, a number of initiatives are underway in order to bring a strategic approach to tackling this growing anthropogenic threat to our seas, the life within them and to wider society.

Further evidence is required on the sources, pathways, fate and environmental impact of microplastic pollution in the Scottish context. This will be used to inform targeted action and further investigation.

The aims of this research project are to:

- Appraise the main environmental risks posed by microplastic pollution in Scotland’s terrestrial, freshwater and marine environment;
- Determine and quantify the main sources and pathways of microplastics in Scotland’s terrestrial, freshwater and marine environment;
- Determine further work that needs to be carried out to strengthen the evidence base and propose mitigation measures.

E.1.1 Current State of Knowledge on the Environmental Risks of Microplastics in Scotland

Whilst research in the field of nano and microplastics (NMPs) has been developing rapidly over the past few years, there are still significant gaps to fill before it is possible to have a robust understanding of the risks posed by microplastics to the Scottish environment. In part, this arises from the difficulties in scaling potential impacts from the individual or sub individual level to anticipated impacts on the ecosystem. Equally, while the marine environment has been the focus of most research to date, there are major gaps in knowledge in respect of the potential risk for freshwater environments and in particular for terrestrial environments. It is also not clear from the literature whether certain types of microplastics present a greater risk than others, despite the dominance of fibres in field studies.
However, despite these unknowns there is evidence that marine species in Scotland are consuming microplastics and that this could be negatively impacting their health with field and laboratory evidence available for presence and negative impact of microplastics on the commercially valuable Norway Lobster. There is further evidence in the literature of the presence of microplastics in waters in and around Scotland, and their consumption by commercial fish species. More widely, research reports a range of negative impacts of microplastics on fish, molluscs, and other invertebrates.

Whilst the papers which have looked to use existing data to create a risk assessment for microplastics have generally concluded that harm is not expected at the environmental concentrations experienced at present, it is worth considering the persistent nature of microplastics. It is understood that microplastics are extremely persistent in the environment and will break down over time into nanoplastics. As such, whilst there are significant gaps in the research base and current understanding of risks from NMPs, these will take time to fill and reducing emissions of microplastics during that time can be justified on a precautionary principle basis.

Ongoing research could usefully prioritise studying the impacts of microplastics as found in the environment – focussing on weathered particles, mixed assemblages of different shapes and polymers, and reflecting the size classes observed in the environment. This would look to improve understanding of impacts. In addition, it could be valuable to attempt longer term studies looking at the impacts of NMPs as well as looking to understand impacts at the ecosystem level. Finally, a better understanding of the impacts of microplastics on terrestrial ecosystems is required.

E.1.2 Quantification of the main sources and pathways of Microplastic in Scotland’s terrestrial, freshwater and marine environments

The scope of this study is both primary and secondary microplastics. In the case of secondary microplastics we focus only on those that are created through wear and tear during the normal life of a product – the generation of microplastics is therefore an inherent part of their function. This means that larger items that are littered and subsequently degrade into microplastics are not the focus; to tackle these sources of secondary microplastics through mismanagement of waste require different sets of interventions.

There are a great many sources of microplastics that have been identified over the past 5 -10 years as the topic has gained more attention. Many are relatively small and the result of niche products or applications. A long list was narrowed down based on existing knowledge of the magnitude of the sources and areas that are believed to be of particular relevance and interest to Scotland.

The sources prioritised for further investigation are:

- Artificial turf and equestrian surfaces
- Automotive tyre wear
- Synthetic clothing fibres
- Road markings
- Agricultural fertilisers and treated seeds
- Fishing/aquaculture gear (but not lost or discarded gear breaking down further)
E.1.2.1 Summary of Source Emissions

Figure 1 summarises the microplastics source emissions for each of the six priority products. Most have upper and lower estimation boundaries which are dependent on the assumptions for each of the sources. For artificial turf the key assumption is the proportion of infill that needs to be replaced every year as observed in the literature. For agricultural products the key assumption is based on a range estimate by the European Chemicals Agency (ECHA) on the proportion of water insoluble content of the finished product. The range shown for road markings is due to questions over how these particles are defined—where just the polymer content is considered, the lower boundary is appropriate; where the whole particle including various fillers such as aggregates and glass beads are considered, the high boundary is appropriate. The difference is a factor of ten in this instance. The ranges for fibres released from clothes washing reflects the uncertainty around release rates observed through the numerous studies on the subject. Finally, the range of fishing gear microplastic release during use is based on an indicative assumption from a previous study using a qualitative judgment —no empirical evidence is available for this, but the loss rates are unlikely to be higher (than the upper boundary of 10%) given that the ropes etc. would become unusable beyond this. Automotive tyres do not have a range for generation at sources as the data for vehicle km and wear per km driven is well understood and subject to less variation than other sources—the variation and uncertainty for this source rests with the nature of tyre particles as a diffuse source of microplastics once emitted from the vehicle.

Figure 1: Summary of Microplastic Source Emission Estimates for Scotland for Priority Products
E.1.3 Microplastics Pathways and Fates

The pathway model for Scotland is based upon the Eunomia model developed for an EU project which takes the estimates of microplastics emissions at source and estimates—through reasoned assumptions based on scientific observations—where these might end up.

From current data and understanding, several environmental accumulation zones have been identified. These are locations where a build-up of microplastics is expected, but may not necessarily be the final resting place due to the complex dynamics that are not fully understood at present.

- **Agricultural soil** – microplastics arrive at this point by two pathways for the products on study; direct application through use with regard to agricultural products and, mixed in with sewage sludge from wastewater treatment. There is evidence of accumulation of microplastics as a result of these practices. It is also suspected that these microplastics could leach into waterways via run-off and soil erosion and therefore this may not be the final destination. There is no data that allows quantification of this as the proximity of waterways will play a huge part in the likelihood of this taking place.

- **Non-Agricultural soil** – This sink results from emissions of microplastics at the roadside from tyres in predominantly rural areas and from artificial turf infill as it migrates to the areas surrounding the pitch. It is likely that a proportion of the microplastics from tyres ending up in rural soils, will also be agricultural land – particles are known to travel at least 50 metres from the roadside. This also means that if waterways are close to roads, these airborne particles could land there or easily be washed into them.

- **Marine Water** – This category is for direct emissions that will only enter the marine environment and only applies to fishing gear in this study.

- **Surface Water** – This is used as the general term for the water environment with the prospect of emissions either directly (e.g. through coastal WWT outfalls) or indirectly entering into the marine environment (through river transport).

- **Residual Waste** – This sink results from several activities which includes-
  - Sewage sludge containing microplastics sent to incineration and to a much lesser extent, landfill;
  - Roadside sedimentation devices such as gully pots and settling ponds being cleaned out; and,
  - Road cleaning activities.

- **Air** – This sink is unlikely to be the final resting place, but concerns the particulate (PM) emissions associated with tyre wear. The emissions contribute to air pollution.

There are two key assumptions that affect the proportion of microplastics that enter wastewater treatment and then subsequently enter the environment; the type of wastewater treatment (primary, secondary, tertiary) and the proportion of sludge that is applied to land.

For the former we adopt the same approach as the EU study by applying the best and worst microplastic capture rates observed in the literature to primary, secondary, tertiary treatment systems. This ranges from 17% capture in the worst case primary treatment and 99.7% in the best case tertiary treatment.
It is assumed that any microplastic that are captured, will be retained in sewage sludge. According to Scottish Water, 54% of sewage sludge is applied to agricultural land and a further 15% as ‘land reclamation’ and the remaining 31% is predominantly sent for incineration with 0.3% send to landfill.

Figure 2 shows the results (using midpoints) split by the accumulation zones. This demonstrates that the largest accumulation zone is expected to be soils, particularly agricultural—accounting for 63% of source emissions (between 57% - 69%). Surface waters (including direct marine emissions) are the third largest accumulation zone—accounting for 15% of source emissions (between 9% - 21%). Microplastics in residual waste account for 13% of source emissions (between 10 - 25%).

**Figure 2: Microplastic Accumulation Zones**
E.1.4  Problem Analysis and Measures for Reduction

Section 7.0 of the report details the problems and measures that were discussed during the meeting associated with this project.

E.1.4.1  Automotive Tyre Wear

Problems which relate to the tyre itself, including its design, manufacture and use, are;

1) insufficient incentive for manufacturers to prioritise reducing tyre abrasion,
2) lack of a standard test method for tyre abrasion;
3) insufficient information on the extent to which tyres from different manufacturers may be contributing; and
4) the prevalence of cars as the default choice for travel for many.

Problems which result in the subsequent loss of tyre-wear from the roads and into the environment include;

1) a lack of awareness of roads as pathways for microplastic emissions
2) insufficient financial or regulatory incentives to capture microplastics through above mentioned mechanisms.

Options for Measures

1) Reducing vehicle kilometres driven
2) Increased capture at roadside
3) Engaging in development of a standard test for tyre tread abrasion
4) A Tax on Tyres
5) Producer Responsibility
6) Awareness raising and encouraging driver behaviour change

E.1.4.2  Synthetic Textile Washing

Problem drivers relating to the nature of the clothes placed on the market are that;

1) there has been insufficient incentive for manufacturers to investigate the factors which influence the rate at which different fabrics and garments shed fibres
2) at present there is no standard test method for fibre loss which is agreed upon by industry and applied consistently

Problem drivers relating to washing machine design and use include;

1) a lack of consumer awareness as to the actions that can be taken to minimise the loss of synthetic fibres
2) a lack of incentive for some manufacturers to develop capture mechanisms and knowledge of relative efficacy of mechanisms.
Options for Measures

There is limited opportunity for Scottish Government to influence those problems which relate to either the design of clothing or washing machines. The measures below relate to funding for research that is needed to support efforts to mitigate releases.

1) Fund research to identify factors contributing to shedding and microfibre characterisation
2) Support the Setting of a Maximum Threshold for fibre shedding from fabrics
3) Support the development of labelling at a European level for microplastic emissions
4) Washing Machine Filter testing and development
5) Research into Shedding via abrasion during use
6) Research into Supply Chain losses

E.1.4.3 Agricultural Products

Problems which relate to controlled release fertilisers and Plant Protection Products (PPPs) are:

- a lack of equally-effective alternatives to synthetic polymers that will degrade slowly in soils over a period of up to 18 months to allow gradual release;
- a lack of incentive to develop alternatives to synthetic polymers for controlled release of fertilisers and PPPs.¹

A problem common to both fertiliser additives and seed coatings is that:

- Growers have poor visibility of the contents of their fertilisers and seed treatments outside of the concentration of the active ingredients. There is therefore low awareness of whether they are applying polymers to soils in using synthetic fertilisers and seed treatments.

Problems which relate to Fertiliser Additives are:

- Lack of awareness amongst some manufacturers of whether additive component ingredients contain synthetic polymers and of non-synthetic polymer alternatives; and
- Lack of incentive to adopt non-synthetic polymer containing additives over polymer-containing additives, despite the availability of such alternatives.

Problems which relate to seed coatings are:

- Farmers are buying coated seeds where growing, storing and planting may be advantageous;
- Lack of awareness amongst some manufacturers of whether seed coating ingredients contain synthetic polymers; and
- Lack of incentive for seed coating producers to develop alternatives to synthetic polymers for seed coatings.

¹ See detail in Appendix 1 about new fertiliser biodegradability requirements.
Options for measures

1) Undertake further problem definition and evaluation of the need for polymer use in Scottish agriculture in collaboration with industry
2) Align with new EU rules for CRFs taking faster action where feasible
3) Require labelling of biodegradability of CRF coatings
4) Legislate to implement biodegradability requirements for other agricultural products taking faster action than the EU where feasible
5) Implementing a more immediate restriction (less than 3 years) on Fertiliser Additives
6) Encourage less reliance on polymer-containing agricultural products

E.1.4.4 Artificial Turf

Problem drivers relating to artificial turf can be summarised as follows:

1) Insufficient incentive for pitch operators/specifiers to implement best practice measures or specify these in new procurement contracts
2) Insufficient incentive upon installers and/or manufactures of artificial sports pitches to design-in best practice measures.
3) Insufficient incentive for pitch operators to use alternative infill material
4) Lack of data on loss pathways and exact amounts lost from pitches annually

Options for Measures

As the football pitches in Scotland are designed and built in Scotland there is a great deal of scope to regulate this to mandate that all current and/or subsequent pitches are required to install infill loss mitigation measures.

1) Implementing Mandatory Infill Loss Mitigation
2) Provide Guidance for Public Procurement
3) Banning Synthetic Infill

E.1.4.5 Fishing Gear

Problem drivers relating to fishing gear can be summarised as follows:

- Absence of key data sources on the use of fishing gear and the microplastic loss rates
- Lack of alternatives or known best practice

Options for Measures

Although there has been a large focus on lost fishing gear and its contribution to both macro and microplastic pollution, there has been significantly less work on the microplastic generation during use. There are three key pieces of information that are necessary to quantify the problem and begin to understand whether there are effective measures that can be put in place;

1) Put monitoring in place for the use of fishing gear and replacement
2) Research funding for fishing gear wear testing to determine the quantity and nature of losses
3) Research and development funding for materials/designs that shed less
E.1.4.6 Road Markings

The problem drivers in respect of road markings can broadly be divided into problems that relate to the road markings itself, and those that relate to the drainage infrastructure and the nature and frequency of street cleansing. Problem drivers relating to road markings can be summarised as follows:

- Insufficient knowledge of the nature of road marking microplastics, where they are found, and in what quantities;
- Insufficient knowledge of the rate of wear of alternative marking types to inform purchasing decisions;
- Inconsistent specification of the functional life required of road markings in contracts for procurement and application;
- Poor programming of surfacing works such that markings are applied in colder and wetter months when they are less likely to adhere;
- The poor condition of the existing road surfaces which affects bonding of markings;
- Insufficient technical knowledge within buying authorities which prevents informed procurement decisions from being made;
- Financial constraints on road authorities such that price and quality are not always suitability balanced; and,
- Insufficient financial or regulatory incentives to capture microplastics through roadside capture given that the environmental science community’s recognition of roads as pathways/sources of microplastics is comparatively recent and as such there has been relatively little pressure on local authorities to mitigate against loss of microplastics from the road environment.

Options for Measures

The following options are proposed:

- Funding primary research into road marking wear processes, products and flows
- Funding primary research into relative durability of road marking products
- Encourage or mandate use of procurement and end-product performance requirements linked to payment schedules
- Increased capture at roadside and reducing vehicle kilometres driven
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1.0 Introduction

This research project sets out to understand the sources, pathways, fate and environmental impact of microplastics in Scotland in three environmental contexts and the interaction between these: the terrestrial environment, including arable land; the freshwater environment, and the marine environment.

Marine plastic pollution is a serious emerging environmental issue. It is estimated that more than 150 million tonnes have already accumulated in the world’s oceans and that more than 12 million tonnes are being added every year. It has been reported that the vast majority (approx. 80%) of this marine plastic pollution arises on land and is subsequently lost either directly to the marine environment or via the freshwater environment.

Plastic pollution has ecological, physical, aesthetic and economic impacts, but also potential biochemical effects. Polymer particles can adsorb organic contaminants already in the environment as well as providing a source of harmful additives that migrate from the polymer matrix itself, potentially releasing them when ingested or degraded. Marine plastic alone costs the Scottish economy at least £20m per annum ($8B globally).

Large plastic items can entangle marine life, as well as be ingested by larger marine animals. Microplastics are small (<5mm) fragments of plastic which are of additional concern because of their potential to accumulate organic contaminants in increasing quantities with decreasing size. When they enter aquatic systems, microplastics can be ingested by a range of organisms and accumulate through the food web, causing harm to health and the environment.

The Scottish Government has made tackling marine litter and plastics one of its key goals, and this featured strongly in the 2017/18 Programme for Government. Under the Scottish Marine Litter Strategy, a number of initiatives are underway in order to bring a strategic approach to tackling this growing anthropogenic threat to our seas, the life within them and to wider society.

Further evidence is required on the sources, pathways, fate and environmental impact of microplastic pollution in the Scottish context. This will be used to inform targeted action and further investigation.

The aims of this research project are to:

- Appraise the main environmental risks posed by microplastic pollution in Scotland’s terrestrial, freshwater and marine environment;
- Determine and quantify the main sources and pathways of microplastics in Scotland’s terrestrial, freshwater and marine environment;
- Determine further work that needs to be carried out to strengthen the evidence base and propose mitigation measures.
2.0 Methodology

This study is split into three research areas in order to fulfil the aims:

1) **Identification and appraisal of the main environmental risks posed from microplastic pollution in and around Scotland**

   As well as to understand the risk posed in general, a further rationale for understanding this is to know whether specific types of microplastic pose a greater risk than others. The evidence base for this is summarised by way of a comprehensive literature review into the current state of the science on the impacts of microplastics.

2) **Develop a tailored microplastic emissions model for Scotland**

   This is undertaken by:
   
   - Developing a long list of microplastic sources
   - Developing a prioritised list for investigating key sources in more depth
   - A review of the evidence and literature available on how microplastics end up in the Scottish terrestrial, freshwater, and marine environment (including via airborne transport) and identify principle gaps in the evidence
   - A review of the existing evidence of types and quantities of microplastics in the terrestrial, freshwater and marine environment and their fate and behaviour in the Scottish environment
   - A quantified review of the main types of plastic within the Scottish economy (that are or generate microplastics) and how they are used, handled or lost within the economy.

3) **Develop a list of policy options and monitoring recommendations**

   A number of policy options have already been proposed in various countries in Europe and at the EU level for some of the known key sources of microplastics. This informs the basis for discussion of options for Scotland.

   It is of particular interest to look for interventions that Scotland (including SEPA and the Scottish Government) has direct responsibility over. The availability of interventions that have previously been proposed also helps to guide the prioritisation under the previous research area.

   As part of this identification of the key knowledge gaps the monitoring of different sources of microplastics is also explored along with the challenges around doing so and how this could be used to demonstrate the effectiveness of interventions.
2.1 Scottish Government Workshop

On the 18th of September a workshop was held with SEPA and other relevant Scottish government organisations and agencies. The purpose of the workshop was:

- **for Scottish Government and attendees;** to create a group of Scottish Government and SEPA staff who are aware of the latest knowledge on microplastic emissions risks, flows and problem drivers in Scotland and who have collaborated on the development of possible mitigation options; and
- **for Eunomia;** to share findings of project to date, and get feedback to improve on the scoping of problem drivers of emissions and recommended mitigating solutions.

The workshop took the form of a combination of presentation sessions where Eunomia fed back on interim findings regarding emissions at source, pathways flows and environmental risks of microplastic pollution in and around Scotland. This was followed by interactive sessions where participants were asked to:

- review and expand upon problem drivers identified by Eunomia;
- identify strengths and weaknesses of the suite of mitigating solutions suggested by Eunomia;
- generate their own ideas for mitigating solutions which would address weaknesses in the solutions put forward by Eunomia;
- shortlist a solution bearing in mind its potential effectiveness in reducing emissions, cost-effectiveness and feasibility;
- develop the shortlisted solution, identifying what organisation would be best placed to take it forward, and what immediate next steps would be needed to implement it.

Insights generated by these interactive sessions have been incorporated throughout the following sections of this report. In particular, noted weaknesses have been used to refine the options for solutions presented, and some of the ideas generated for other solutions have also be incorporated.

Due to the specialisms of the attendees of the workshop it was decided that workshop sessions would be run for microplastic emissions from Automotive Tyre Wear, Synthetic Textile Washing, Agricultural Products and Fishing Gear only.
3.0 Review of the Environmental Risks

3.1 Background

This section looks to identify and appraise the main environmental risks of nano and microplastics (NMPs) in and around Scotland, covering (1) the marine environment, (2) the freshwater environment, and (3) the terrestrial environment. Further, it will identify key gaps in the research where understanding of the risks, or even presence of microplastics in the environment, is limited. Generally, microplastics are classified into two groups, primary microplastics and secondary microplastics. Primary NMPs are pieces of plastic purposefully manufactured to this size for specific applications, e.g. pellets for industrial production and cosmetic microbeads. Secondary NMPs are formed from larger plastic items via photo-oxidation, mechanical action and biodegradation, reducing the structural integrity of plastic debris, resulting in fragmentation.

For the purposes of this work, the definition for microplastics as used in the European Chemicals Agency (ECHA) restriction proposal has been adopted. Definitions for nanoplastics and macroplastics are as used in the SAPEA report on microplastics in nature and society. These definitions are as follows:

- **Microplastics**: a material consisting of solid polymer-containing particles, to which additives or other substances may have been added, and where ≥ 1% w/w of particles have (i) all dimensions 1nm ≤ x ≤ 5mm, or (ii), for fibres, a length of 3nm ≤ x ≤ 15mm and length to diameter ratio of >3. Polymers that occur in nature that have not been chemically modified (other than by hydrolysis) are excluded, as are polymers that are (bio) degradable.3
- **Nanoplastics**: those which fulfil the above definition but are below the smallest size boundary of the definition as covered (i.e. <1nm). At present, there is no agreed lower size limit for nanoplastics. It is also worth recognising that these are a further stage of the weathering process where the microplastic particle decreases in size.4,5

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• **Macroplastic**: those plastics larger than the upper size class as described for microplastics. However, it is worth noting that the 5mm cut-off is relatively arbitrary and has been developed as a convention in the plastic debris community. Hence it is likely that some particles larger than this may behave in a similar way.\(^6\)

The contamination of the environment with microplastics is increasingly being recognised as a widespread, and likely pervasive problem.\(^7^8\) However, there are significant knowledge gaps in our understanding of sources, fates, sinks, and associated risks. The knowledge gaps which are unresolved regarding marine NMPs are all the more pronounced when it comes to the freshwater and terrestrial environments. However, these are growing areas of research.\(^9^10\) Additionally, very little is known about how microplastics accumulate or are transported in the soil matrix – the organic matter and other components which make up the soil structure including minerals, air, and water.\(^11\)

Despite this, there is consensus that microplastics are being released to, and potentially accumulating in the Scottish environment. A 2017 research project looked to assess sea-surface microplastics in Scottish waters.\(^12\) The work sampled 27 sites around the Scottish coasts and islands, collecting 49 samples for analysis. Of these samples, 31 (63%) contained microplastics with chemicals also detected in the samples including those used as plastic additives such as phthalate esters, heavy metals, and flame retardants.\(^13\) Additional studies have looked at microplastic output from a Scottish wastewater treatment plant, in Loch Lomond and at the falls of Dochart (to be published), and the first study analysing microplastics in a Scottish river was

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\(^7\) Santillo, D., Oakes, G., Labunska, I., et al. Physical and chemical characterisation of sea-surface microplastics collected from coastal and inland waters of Scotland in the summer of 2017, p.63


\(^12\) Santillo, D., Oakes, G., Labunska, I., et al. Physical and chemical characterisation of sea-surface microplastics collected from coastal and inland waters of Scotland in the summer of 2017, p.63

\(^13\) The authors defined “containing microplastic” as presence of at least one piece of microplastic in the size range 0.5-5mm in diameter in two dimensions.
published in 2019. As such, it is worth understanding – to the extent allowed by existing research – the risk posed by microplastics to the Scottish environment. Recent developments in microplastic risk are discussed, and the literature is reviewed and discussed for certain Scottish species and environments. Due to technical limitations in detecting and identifying nanoplastics in the environment, much of the discussion focusses on research on microplastics.

### 3.1.1 Recent Developments in Microplastic Risk

With the research base continuing to expand, some recent work has focussed attention on the risk posed from microplastic. These sources take an initial approach to applying risk assessment methods to microplastics, with many highlighting certain gaps in understanding or research as preventative to a clear understanding of risk. By comparison, the recent European Chemicals Agency (ECHA) restriction proposal for intentionally added microplastics recognises these gaps but still recommends action to prevent release of microplastics based on their persistence in the environment. This is in line with the EU’s precautionary principle.

Three recent papers have looked to understand better the ecological risk posed from microplastics, and in some cases also the risk from macroplastics. The focus of these papers has been global, with one looking only at the marine environment, and two looking at both freshwater and marine contexts. They make use of existing data from the literature, and apply

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risk assessment methodologies to try and generate a more quantitative understanding of the ecological risk from microplastics. These are based on methods for assessing ecological risk, where the Predicted Environmental Concentration (PEC)/Predicted No Effect Concentration (PNEC) ratio is used as a risk score to quantify adverse effects that may occur at specific predicted environmental concentrations. At PEC to PNEC ratios higher than 1, unacceptable effects on organisms may occur with increasing ratios representing increased likelihood of adverse effects.\textsuperscript{23}

Predicted No Effect Concentrations can be derived to protect organisms from lethality (often called maximum acceptable concentrations) and from sub-lethal (eg on growth and reproduction) effects. Two methods are provided to derive the value of the PNEC in the EU Technical Guidance Document (EU-TGD).\textsuperscript{24} The first method uses assessment factors to establish the level of the PNEC from results of ecotoxicity tests with the most sensitive species. The second method uses a lower assessment factor on a percentile protective of a proportion of tested species (usually 95%, from the HC5 – concentration hazardous for 5% of species) from a Species Sensitivity Distribution (SSD) based on results of a database of ecotoxicity tests. The latter approach is only possible when a large dataset is available.

One major shortcoming with PNEC estimates for NMPs at the time of writing is that there is limited evidence demonstrating impacts on whole organisms that are relevant for population effects (like lethality, growth, reproduction). In the studies described below information on endpoints covered is included when known.

Everaert \textit{et al} estimated a maximum acceptable concentration for the marine environment and compared this with the estimated average concentration in the oceans using a Species Sensitivity Distribution.\textsuperscript{25} Based on this comparison, they anticipate that a risk is not expected with current environmental concentrations. However, with a prospective risk assessment the authors predict adverse effects of sedimented and beached microplastics around the year 2060 and wider implications from 2100, based on estimates of future emissions.\textsuperscript{26}

\begin{itemize}
\item \textsuperscript{23} van Westenenk, L. (2005) From PEC/PNEC ratio to quantitative risk level using Species Sensitivity Distributions; Methodology applied in the Environmental Impact Factor, p.73
\item \textsuperscript{26} Everaert, G., Van Cauwenberghe, L., De Rijcke, M., Koelmans, A.A., Mees, J., Vandegehuchte, M., and Janssen, C.R. (2018) Risk assessment of microplastics in the ocean: Modelling approach and first conclusions, \textit{Environmental Pollution}
\end{itemize}
Besseling et al looked at an estimate for HC5 for microplastics – that is the concentration which is hazardous for 5% of species (see above). They estimate this as $113 \times 10^3$ particles/m$^3$ and suggest that risk could exist in certain coastal waters where the particle concentrations are similar at present, with the highest reported measured environmental concentration being $102 \times 10^3$ particles/m$^3$. The authors note that the highest reported concentrations arise in rivers and coastal waters near heavily urbanised and industrialised areas. However, they also noted that the highest limit of reported ranges (HLRR) in freshwater are (as of 2016) three orders of magnitude lower than the estimated HC5, and those in open ocean surface water almost five orders of magnitude lower. In context, they note that quantities of microplastic may be underestimated by up to a factor of 30 during surface sampling, hence the difference between the current highest observed and predicted HC5 may be smaller than this.

However, the Besseling paper includes some interesting commentary on risks going forwards. In particular, the paper estimates an effects threshold for nanoplastics. An effects threshold is the concentration above which a (negative) effect occurs, and is often estimated for chemical contaminants to help understand the point at which there is a risk. For nanoplastics, this is ~7 orders of magnitude higher than for microplastic and cannot be compared to current environmental concentrations given lack of environmental measurement at present. The paper states that environmental concentrations of nanoplastics (by number of particles) may become 17 orders of magnitude higher than those of microplastic in the future, due to fragmentation of larger plastic particles. The paper goes on to state that this would mean environmental nanoplastics concentrations could exceed the estimated effect threshold within several hundred years. This threshold could be exceeded sooner in “hotspots” – areas which experience particularly high concentrations of microplastic. Equally, current underestimation of nanoplastics concentrations may also lead to effects thresholds being exceeded earlier than currently

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projected and it is worth recognising that there are no methods for large scale removal of microplastics once in the environment.\textsuperscript{31,32}

Burns and Boxall also reviewed risks of microplastics for the aquatic environment, combining data from freshwater and marine studies to compare measured environmental concentrations with effect thresholds.\textsuperscript{33} This work generated a Species Sensitivity Distribution based on studies in the literature reporting ecotoxicity endpoints related to growth, mortality and reproduction.\textsuperscript{34} The distribution plots the concentration of microplastics at which an effect was reported for algae, invertebrates and fish and compares the results against reported environmental concentrations. Similarly to the previous studies, they concluded that the current reported concentrations are orders of magnitude lower than those at which effects have been observed in laboratory studies. However, they recognise that at present there is potential for harm in highly polluted areas, and to particularly sensitive species.\textsuperscript{35}

Given the limitations of the data used to generate the above preliminary risk assessments, the recent SAPEA report concludes that the information, overall, is fragmentary and that a systematic risk assessment based on dose-response relationships for species across compartments is not yet possible.\textsuperscript{36} Further, no risk assessments have been undertaken for nanoplastics specifically, barring the Besseling work which looked to estimate an effect threshold.\textsuperscript{37,38}


\textsuperscript{34} Burns, E.E., and Boxall, A.B.A. (2018) Microplastics in the aquatic environment: Evidence for or against adverse impacts and major knowledge gaps: Microplastics in the environment, Environmental Toxicology and Chemistry, Vol.37, No.11, pp.2776–2796


By contrast, the recent ECHA restriction proposal takes a slightly different stance. The restriction dossier presents a risk assessment which was completed by ECHA for intentionally added microplastics. It states that concern relating to microplastics arises from the fact that microplastics are:

- “Small, making them readily available for ingestion, and potential transfer;
- Very resistant to environmental biodegradation which will lead to them being present in the environment for a long time after initial release;
- Known to biodegrade in the environment progressively via fragmentation into smaller and smaller particles, theoretically via nanoplastics; and,
- Practically impossible to remove from the environment after release.”

The report found that there is insufficient information to derive a robust PNEC for microplastics. A robust PNEC could be used to justify a conclusion that risks are adequately controlled, either based on current exposures in the environment or exposures that are forecast to occur in the future. As such, ECHA used a case by case approach to hazard and risk assessment of microplastics, based on what is referred to as their ‘extreme persistence in the environment’ and the potential for this to result in non-reversible pollution and associated environmental, or human health risks. The report comments that due to their extreme persistence in the environment, it is a case of when rather than if microplastics would reach a (as yet undefined) threshold of effect. As such, they recommend using release as a proxy for risk and restricting intentionally added microplastic. The proposal is due for stakeholder consultation before being reviewed and potentially implemented as a restriction under the EU REACH Regulation in 2020.

In summary, there is progress in the literature to look at assessing the ecological risk from microplastics. This is limited at present by the studies that the risk assessments are based on, with critique that research has not been targeted towards generating results which contribute to this. The estimates of risk which are generated suggest that environmental concentrations are generally below estimates for effect thresholds at present – however, there may be exceptions in the case of hotspots and understanding for nanoplastics is much more limited. The ECHA report recognises this information and its limitations and recommends release of microplastics to be used as a proxy for risk – based on their extreme persistence in the environment.

3.2  Focus on the Risks for Scotland

3.2.1  Approach

Whilst the field is still developing and there are still limitations on conducting a risk assessment for NMPs it has been possible to review the evidence for impacts of microplastics on certain Scottish species and environments – to the extent that they are understood at present. To determine a list of focal species for this targeted literature review, academics, environmental scientists at SEPA and at Scottish Government, were consulted. Given the limited extent of existing research, this list focussed on specific marine species of importance to Scotland. For freshwater and terrestrial compartments, a more general approach was taken, looking to summarise the risks as currently understood. Scotland specific data was prioritised and supplemented with information from further afield where necessary and appropriate.

3.2.2  Risk to Commercial Marine Species

There is concern over the impact of NMPs on commercial fish species, via impact on the health of the populations, as well as concern over potential transfer to humans. In 2017, Scottish vessels landed 466,000 tonnes of sea fish and shellfish, with a gross value of £560 million. Hence, commercial fisheries are an economically important sector for Scotland.

It is difficult to assess the impacts of NMP ingestion on the health of marine species in the field under real world conditions. This is due to the confounding natural and anthropogenic factors affecting the health of marine organisms. As such, laboratory studies have been used to determine impacts of microplastic ingestion on marine species whilst field studies have looked to understand the concentrations of microplastics to which these species may be exposed at present. Laboratory studies have demonstrated that at high exposure concentrations, microplastics can induce physical and chemical toxicity, leading to physical harm, inflammation, stress responses, or blockages of the gastrointestinal tract. Other ecotoxicity endpoints identified in laboratory studies include changes to reproduction, growth, and increased

42 Thanks to Natalie Welden (Glasgow University), Brian Quinn (University of the West of Scotland), Bill Turrell (Scottish Government), Daniel Merckel (SEPA), Robin Guthrie (SEPA), and Claudia Erber (SEPA)
45 E.g. Catarino, A.I., Macchia, V., Sanderson, W.G., Thompson, R.C., and Henry, T.B. (2018) Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal, Environmental Pollution, Vol.237, pp.675–684
This section looks to assess the evidence for impacts of microplastics on certain marine species which are commercially important for Scotland. In places, the evidence base is limited to studies looking to understand the exposure of these species to microplastics which have not investigated impacts, and a summary of these has been included.

### 3.2.2.1 Crustacea

*Nephrops norvegicus*, the Norway Lobster, is an important commercial species for Scotland. As a crustacean, the Norway Lobster has a significantly more complex gut structure than commercial fish species. Due to their gut morphology, they are thought to aggregate plastics more quickly and can retain these items for long periods.\(^{49}\) In laboratory studies, it was found that exposure to, and ingestion of microplastics (using polypropylene fibres) resulted in higher mortality and reduced body condition of the lobsters, with a 41.6% mortality rate over the 8 month feeding experiment.\(^{50}\) This compared to a 33.2% mortality rate in the control (fed) condition, and hence an 8.4% increase in mortality over the study period. The aggregations of microplastic in the individuals following the feeding experiment were reported as comparable to those observed in wild-caught individuals from the Clyde Sea in a second study looking at the Norway Lobster.\(^{51,52}\)

This study looked to understand the occurrence of microplastic in *N. norvegicus* from different areas around Scotland, sampling the Clyde Sea, the Minch and the North Sea.\(^{53}\) Analysis of 1,450 individuals found that 67% contained microplastics. These microplastics were predominantly microfibers – nylon, and polypropylene as well as smaller amounts of polyethylene and polyvinyl chloride. This work developed on findings from a previous study which found 50% (n=120) of individuals collected from the North Clyde Sea had a ‘ball’ of filaments in their stomach.\(^{54}\)

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\(^{49}\)Personal Communication with Natalie Welden.


As such, there is evidence to suggest that presence of microplastics in the Scottish environment is resulting in ingestion by *N. norvegicus* at levels with the potential to result in negative impacts on their health and survival as per the findings of the laboratory study. At present, the highest reported levels are for the Clyde Sea. However, increasing concentrations across the region would be expected going forwards. It is worth recognising that the Norway Lobster represents 42% of the value of shellfish landings, and 13% of the total value of Scottish landings making it the second most valuable stock overall. Hence, negative impacts on the health of the population, as a result of microplastics, could be concerning. Further, the studies on the Norway Lobster represent a case whereby the study species has been investigated with exposure to microplastics similar to those detected in individuals from environmental samples – hence making the case for similar impacts in the environment stronger.

One study has also looked at the occurrence of microplastics in Spider Crab *Maja squinado* in the Celtic Sea, finding microplastic in 42.5% of individuals sampled (n=54). As with the work described above, the microplastic ingested was dominated by fibres with the most commonly ingested plastics being polypropylene, polyester, and polyamide. Spider Crab are also commercially fished in Scotland.

### 3.2.2.2 Molluscs

Filter feeding species, alongside deposit feeders and planktonic suspension organisms, have been highlighted as a potential group where the impacts of NMPs could be significant due to their unselective feeding strategies. To understand the state of knowledge of impacts on commercial molluscs, as relevant to Scotland, the literature has been reviewed looking at Blue

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Mussels (*Mytilus edulis*), Pacific Oyster (*Crassostrea gigas*) in lieu of the Common Oyster, and King Scallops (*Pecten maximus*).

Blue mussels are well documented in the microplastics literature with 44% of studies in a recent Exeter University literature review looking at impacts of microplastics on commercial marine species working with blue mussels (*M. edulis*), and 62% at mussels more generally (*Mytilus sp*). These studies have looked at both occurrence of microplastics in mussels, and at the impacts of microplastics on them. Sub-cellular oxidative stress responses to polystyrene microbead (2–6 μm) ingestion have been reported in mussels exposed to 2,000 microplastic particles per ml seawater. Another study in mussels found that an inflammatory response, and lysosomal membrane destabilisation was associated with the translocation of <10 μm microplastics from the intestinal tract into the circulatory fluid. However, there is by no means consensus on the impacts of microplastic ingestion on mussels. Studies have also been published which demonstrate no effect, such as a 2015 study looking at the potential impact of microplastic ingestion on the energy budget of the mussel *Mytilus edulis* and the lugworm *Arenicola marina*. Organisms exposed to 110 particles per ml (11,000 particles per litre) showed no significant adverse effects on energy budget, despite the high concentrations used. Furthermore, work has been done which suggests that mussels are, to some extent, able to egest microplastics with a study finding that over 40% of ingested microplastics were egested and that ingestion of the particles by mussels was size dependent. Interestingly, the size class of microplastics used by von Moos *et al* which resulted in an inflammatory response is an order of magnitude smaller than the sizes of microplastic demonstrated to be taken up in the work by Zhao *et al* which looked at uptake and egestion or excretion of microplastics. The study of mussels may have value beyond understanding their exposure. One study suggests that by looking at mussels we may be able to understand the impacts on other organisms in the ecosystem and levels of microplastic experienced. This would use them as a ‘bioindicator’ with the paper suggesting that

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62 No literature was found looking at the Common Oyster, native to Scotland. The Pacific Oyster has been looked at instead due to similarity, and cultivation in Scotland.

63 Unpublished Literature Review into impacts of NMPs on commercial marine species, Exeter University for Eunomia Research and Consulting.


they are suitable due to their wide geographical range and high abundance.\textsuperscript{68} Oysters were also highlighted as important species in Scotland. Whilst the Common Oyster is Scotland’s native species, it has experienced significant decline and is now cultivated commercially at one active oyster fishery in Scotland.\textsuperscript{69} The Pacific oyster is also cultivated in Scotland and has been researched with respect to microplastics.\textsuperscript{70} Hence, studies on the Pacific oyster were reviewed. A key study on Pacific oysters (\textit{Crassostrea gigas})\textsuperscript{71}, found that an eight week exposure of adults to polystyrene microbeads across a reproductive cycle resulted in reduced sperm motility, reduced oocyte numbers (fecundity) and reduced oocyte size (energetic investment per oocyte). Following fertilisation, larval yield and growth were significantly reduced without any further microplastic exposure – suggesting the impact as a carryover from the effects on adult oysters.\textsuperscript{72} Again however, the outputs of the literature do not reach a consensus with respect to the impacts. A further study on Pacific oyster larvae, exposing them to polystyrene particles, found that exposure over eight days had no significant effect on feeding or growth at concentrations up to 100 microplastics per mL (10,000/L) – concentrations exceeding those reported in the Scottish environment.\textsuperscript{73}

For scallops, work has shown that NMPs can be taken up by the king scallop \textit{Pecten maximus} at environmentally relevant concentrations – using radiolabelled nanoplastystyrene.\textsuperscript{74} In this study, 250nm plastics accumulated in the scallop’s intestine, whilst 24nm plastics were dispersed throughout the body, potential indicating translocation across membranes. The study also found that retention of these plastics was transitory with no 24nm particles detectable after 14 days, and a decline in the number of 250nm particles.\textsuperscript{75} However, this work didn’t look at impacts of this ingestion of NMPs.

\begin{footnotesize}
\begin{itemize}
\item \textsuperscript{69} Native oyster, accessed 15 May 2019, \url{https://www.nature.scot/plants-animals-and-fungi/invertebrates/marine-invertebrates/native-oyster}
\item \textsuperscript{70} Sussarellu, R., Suquet, M., Thomas, Y., et al. (2016) Oyster reproduction is affected by exposure to polystyrene microplastics, \textit{Proceedings of the National Academy of Sciences}, p.201519019
\item \textsuperscript{71} Also referred to as the Japanese Oyster, or Miyagi Oyster
\item \textsuperscript{72} Sussarellu, R., Suquet, M., Thomas, Y., et al. (2016) Oyster reproduction is affected by exposure to polystyrene microplastics, \textit{Proceedings of the National Academy of Sciences}, p.201519019
\item \textsuperscript{75} ibid
\end{itemize}
\end{footnotesize}
3.2.2.3 Demersal Fish

Demersal fish species, those which feed on or near the bottom of the sea, are also commercially important to Scotland, and the literature was explored for papers looking into the impact of microplastic on dab (e.g. *Limanda limanda*) and flounder (e.g. *Platichthys flesus*). Three papers were found looking at demersal species, in Scottish (North East Atlantic) and UK waters (English Channel).\(^76,77,78\) These studies focus on the occurrence of microplastic in field-caught individuals. Between them, they sampled 1,477 individuals. However, their scope was not limited to only dab and flounder – also sampling other demersal and pelagic fish species including plaice, pollock, ling, halibut, magrim, blue whiting, greater argentine, gurnard, horse mackerel, black scabbard, and round nose grenadier.\(^76,79,80\) Within the 2017 *Murphy* et al study, 51% of flounder (n=47) and 47% of dab (n=19) contained plastic although the work looked at ingestion of both micro and macroplastics. The 2013 *Lusher* et al study found similar proportions of blue whiting and gurnard to contain plastics (>50%), but found the lowest level of ingestion in flat fish such as *M. variegatus* (22%) and *B. luteum* (28%), likely to be most similar to flounder and dab. However, overall *Lusher* et al found no difference between all pelagic and all demersal species.

In addition, *Murphy* et al (2017) found much lower prevalence of microplastics in individuals sampled from offshore sites with presence of microplastics identified in just 2.4% of fish sampled. This suggests that proximity to population centres may be a factor influencing the microplastic exposure of fish in Scottish waters. Difference in the uptake of plastic in fish found in urban rivers compared to rivers in areas with low anthropogenic activity has been observed previously in gudgeons in France.\(^81\)

Across these studies, it has not been possible to understand the potential impacts of ingestion on these species as the capacity of fish to retain plastic is unknown, as is their ability to egest plastic, and as such understanding of likely retention time is poor. In the 2016 *Lusher* et al work, it was not possible to determine retention time as the digestion rates of the mesopelagic fish

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\(^{81}\) Sanchez, W., Bender, C., and Porcher, J.-M. (2013) Wild gudgeons (*Gobio gobio*) from French rivers are contaminated by microplastics: Preliminary study and first evidence, *Environmental Research*
studied were unknown and the method dissolved digestive tracts whole. One study of pelagic fish in the North Sea looked to establish a relationship between the condition of caught fish and ingestion of plastic. However, no difference was found between fish which had ingested plastic and those which had not.\textsuperscript{82}

However, the studies all find that fibres are the most commonly ingested microplastics. Murphy \textit{et al} (2017) report 82.1\% of detected microplastics as fibres, whilst Lusher \textit{et al} (2016) report 93\% of detected microplastics as fibres. Finally, Lusher \textit{et al} (2013) reported that microplastics detected were predominantly fibres (68.3\%), followed by fragments at 16.1\% and beads 11.5\%.

As such, there is evidence that demersal fish species are ingesting microplastics in the marine regions around Scotland, and that this ingestion is dominated by fibres. It could be further suggested that fish populations closer to coasts, or regions of greater habitation may experience greater exposure to microplastics, and hence may be at greater risk from any associated impacts.\textsuperscript{83}

3.2.3 Risk to the Health of Marine Ecosystems

The research discussed in the previous sections focusses on organism level, or sub organism level impacts of microplastics. Linking these to potential impacts at the ecosystem level is challenging, however, it is the impact at this level which will be of ultimate concern. A handful of studies have identified ecosystem level processes that may be impacted by organisms ingesting or processing microplastics. For example, nutrient recycling in benthic sediment may be impacted by reduced activity in lugworms exposed to microplastics which in turn links to nitrogen cycling and primary productivity of the sediment.\textsuperscript{84} An outdoor mesocosm experiment found that exposure to microplastic altered the burrowing activity of lugworms. In this study, PVC microplastics were reported to have a stronger effect than HDPE or PLA.\textsuperscript{85} Work has also looked at the potential impacts of microplastics on benthic processes using mesocosms with sediment cores and bivalve molluscs.\textsuperscript{86} The study showed no effects on assemblages or ecosystem functioning in mussel dominated assemblages. However, in oyster dominated muddy sediments, the addition of microplastics resulted in a decrease in the flux of inorganic nutrients, a decrease in the biomass of primary producers in the sediment and a shift in community composition with a decrease in


\textsuperscript{83} Sanchez, W., Bender, C., and Porcher, J.-M. (2013) Wild gudgeons (Gobio gobio) from French rivers are contaminated by microplastics: Preliminary study and first evidence, \textit{Environmental Research}


\textsuperscript{85}ibid

polychaete worms, and increase in the presence of oligochaetes. Additionally, a study looking at addition of microplastics to a mesocosm of sandy sediment with European flat oysters found their presence to have a negative impact. Whilst minimal impacts were recorded on the oysters themselves, the researchers found that the total number of organisms was ~1.2 – 1.5 times greater in control mesocosms than in the treatments exposed to microplastics with the species assemblages also differing. Abundances of juvenile periwinkle *Littorina sp.* and isopod *Idotea baltica* were especially reduced. There is also emerging evidence for interplay of microplastic with carbon transport in the oceans. Faeces and ‘marine snows’ transport carbon to the ocean depths, via the biological pump. A 2016 study looked at incorporation of polystyrene microplastics in copepod faeces, finding that microplastics could be incorporated in copepod faeces and that the rate of sinking was much reduced when this happened. As such, there is emerging evidence for microplastic interference with biological processes – however, the extent of these impacts is at present unknown.

It may also be valuable to understand how microplastics interact with certain Scottish ecosystems. Coldwater corals are an important species to Scotland, and create unique ecosystems providing habitats for many other species. A small number of studies have looked at the interaction of species such as *Lophelia pertusa* with microplastics. One lab study exposed *L. pertusa* to LDPE microbreads and film pieces, finding that corals exposed to micro and macro plastics had significantly lower growth rates than those in the control conditions. However, the results weren’t entirely clear, demonstrating a reduced capture rate for corals exposed to microplastics at the early points of the study (7 days, and 20 days) and no significant difference after 47 days. A second study looking at a range of coral species suggested responses which could be energetically costly to the corals, and observed some health impacts such as necrosis. However, it is worth noting the concentrations in this work were high - in the range of 3800 particles per litre, compared to concentrations of 350 particles per litre in the study with *L. pertusa*. Further work has looked at the species assemblages on the reefs, however these so far have looked just at presence of microplastics. A study looking at cold water reef benthos

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87 ibid
88 ibid
93 ibid
from the East Mingulay protected area found 11% of organisms across a range of feeding strategies to have ingested microplastics from anthropogenic debris. 95

Finally, filter-feeding megafauna may be at risk from microplastic exposure such as the charismatic basking shark, *Cetorhinus maximus*. Research is limited on these species as gaining direct evidence through conventional approaches for studying diet is not possible. 96 Looking at stomach content or collecting egested material may be difficult or impossible. However, they are likely to be exposed to significant microplastic loads as they must filter hundreds to thousands of cubic metres of water each day. They can ingest microplastics directly from polluted water or indirectly through contaminated planktonic prey. Whilst there is a lack of evidence relating to such species, Gall and Thompson comment in a review of impacts of plastic debris that this does not necessarily imply a lack of effect. 97

### 3.2.4 Risk to Freshwater Ecosystems

Due to the limited research base, the approach taken for understanding the risk to Scotland’s freshwater and terrestrial environments has been to summarise the state of knowledge based on recent scientific reviews. Research gaps are identified and consideration is given to the potential risk to these ecosystems in the Scottish context. Whilst the previous sections have looked at the evidence for impacts on certain marine species and on the marine environment as a whole, the research for freshwater environments is much less extensive. 96 However, one study has looked at ingestion of microplastics by riverine macroinvertebrates in the UK. This work found microplastics in ~50% of the macroinvertebrates sampled across a range of sites and covering both detritivores (those feeding on dead organic material) and filter feeders. 99 As an occurrence study, the impacts on these freshwater species were not explored. Further work based in France has also provided evidence of synthetic fibres in the digestive systems of freshwater fish, indicating direct consumption or uptake via consumed prey. 100 Other freshwater

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species reported to uptake microplastics include annelids, crustaceans, ostracods and gastropods. As such, the evidence base for consumption of microplastics by freshwater species is growing. This reflects the findings for marine species which have been more thoroughly studied. Given that there is an understanding that microplastics are released to freshwater ecosystems, it is to be expected that freshwater species will also be consuming microplastics.

A very recent study has looked at the presence of microplastics in an urban river in the West of Scotland. This work sampled sediment from the river Kelvin in Glasgow, finding fibres to dominate the microplastics found, making up 88% of the total. The authors comment that their findings demonstrate diffuse microplastic pollution entering Scottish waterways.

In addition, there is potential for Scotland’s lochs to act as sinks for microplastics. Although, whether particles accumulate or flow through lochs (which have tributaries) will likely depend on their density relative to the water. Due to the lower density of fresh water, certain polymers may behave differently in freshwater as compared to saline water. The load of microplastics experienced by lochs may also be influenced by proximity to urban centres – something which has been shown for the great lakes in the North America. Similar microplastic concentrations to those in North America have been reported for Lake Hovsgol in Mongolia, despite low population density around the lake. The similar concentrations have been tentatively attributed to poor waste management around the lake, and a smaller water volume – hence higher concentration of microplastics. Research is yet to establish microplastic concentrations in Scotland’s lochs and loch sediments, however, based on findings from elsewhere the highest concentrations would be expected in smaller lochs and lochans close to urban areas.

Interestingly, a recent paper has also looked specifically at the impact of tyre wear particles (TWP) on a freshwater model organism Hyaella azteca. The work looked to establish an LC50 for TWPs and look at the impact of chronic exposure on growth, mortality and reproduction. The work found negative impacts on growth at concentrations between 500-2000 particles/mL and an LC50 of 3426 particles/mL (+/- 172). Such concentrations seem high, and relate to figures for particles per litre in the millions. However, the authors state that 0.29g represents 1 x 10^6 particles, and hence, in terms of mg/L these concentrations are actually within a range of what

has previously been reported in surface waters from other global regions – assuming particle size to be similar.\textsuperscript{106,107,108,109,110} Further work would be needed to establish whether such effects are observed in other freshwater organisms, and to verify that such environmental concentrations are experienced in the Scottish environment.

### 3.2.5 Risk to Terrestrial Ecosystems

Whilst there are significant knowledge gaps in understanding of the presence and impact of microplastics on marine ecosystems, these gaps are even greater when looking to the terrestrial realm.\textsuperscript{111} This is despite the understanding that many of the microplastics detected in the oceans have originated on land and hence their first encounters with biota may be those of the terrestrial realm.\textsuperscript{112} Many of the analytical methods used for detecting microplastics in water cannot be applied to samples of soil given the complex nature of the substrate and it containing many other small particles.\textsuperscript{113} The expectation is that exposure to microplastics is higher for soil ecosystems and that one major route for this is the application of sewage sludge from

\textsuperscript{106} Concentrations of 0.0037mg-3.6mg/L reported
\textsuperscript{108} (2018) Characterizing export of land-based microplastics to the estuary - Part I: Application of integrated geospatial microplastic transport models to assess tire and road wear particles in the Seine watershed, \textit{Science of The Total Environment}
wastewater treatment plants to land.\textsuperscript{114,115,116,117,118} There may also be a contribution from digestate from composting applied to land.\textsuperscript{119} The direct application of microplastic containing fertilisers and seeds has also been highlighted as a significant source of terrestrial microplastic emissions – this is discussed further as a source in Section 5.4. The potential impacts of increasing microplastic concentration on agricultural land may have important implications for soil biota and in association for production.\textsuperscript{120}

There are few experimental studies on soil biota. Those which do exist have investigated potential impacts on a limited set of species – with earthworms most investigated to date. Earthworms \textit{Lumbricus terrestris}, \textit{Eisenia andrei} and \textit{Eisenia foetida} have been studied, alongside the nematode worm (and model organism) \textit{Caenorhabditis elegans}.\textsuperscript{121,122,123,124} Earthworms are an important model species and are also environmentally important, maintaining soil structure and permeability which in turn influences nutrient cycling, soil fertility


\textsuperscript{119} Aspray TJ, Dimambro ME, and Steiner HJ (2017) Investigation into plastic in food waste derived digestate and soil, Report for Scottish Environment Protection Agency, 2017


and drainage. In addition to these studies, work has been done with soil isopods and microarthropods such as the common rough woodlouse Porcellio scaber, \(^{125}\)\(^{126}\)\(^{127}\)\(^{128}\)

Research from marine taxa such as on the marine lugworm Arenicola marina may also be relevant to understanding potential terrestrial impacts on the basis that the organisms are of similar feeding guilds and hence findings could be transferrable across environments.\(^{129}\)

Exposure of A. marina to uPVC particles has been studied, and was found to result in weight loss and reduced lipid reserves.\(^{130}\)

Huerta Lwanga et al studied the impacts of microplastic incorporation into surface soil litter on the earthworm L. terrestris.\(^{131}\) Concentration of microplastics was varied with samples at 0%, 7%, 28%, 45% and 60% dry weight. In the 60-day mortality study they found that mortality of the worms was higher at 28%, 45%, and 60% than at 7%. However, mortality at 45% concentration was lower than at 28% or 60% conflicting with the expected trend of increasing mortality at increasing concentrations. A lack of trend was also observed when looking at growth rate in a shorter petri-dish based experiment where the growth rate reported was lower at exposures of 7% and 60% compared to the 0%, 28% and 45% concentration treatments.

Comparison of the size of particles in the litter vs that in the worm casts suggested size selective ingestion and a maximum size of 50µm for worm uptake. Incorporation into casts led the authors to suggest that bioturbation of microplastics in burrows and casts could lead to transport of microplastics deeper into the soil and eventually to groundwater, which was then investigated in a later study. The number of tunnels produced by the worms varied with concentration but, in similarity to the mortality results, did not produce a clear trend with increasing concentration. The study reported no effect of microplastic concentration on reproduction. However, and likely of interest for land management the microplastic concentration affected which soil layer the worms occupied. At the highest concentration they moved to the bottom of the mesocosm whereas in the baseline condition worms occupied the surface and middle layers suggesting high

\(^{130}\) ibid
Microplastic concentrations may influence worm behaviour. However, it is worth noting that the concentrations used in these studies were very high.

Overall this research shows that there could be an effect of microplastics on growth and survival of *L. terrestris*. Whilst the reliability of this research is undermined by the lack of a meaningful dose-response relationship, following studies have produced findings to corroborate it. These studies demonstrated decreased growth rates and elevated mortality rates of earthworms with increasing microplastic concentrations. Following a 30-day exposure to a 2% w/w treatment of polystyrene microplastic, 40% mortality was observed. 132

Research has also been conducted on *Eisenia andrei*, an earthworm closely related to the tiger worm. 133 This study reported no significant effects on reproduction, survival and growth of adults after 28 days of exposure. However, histopathological analysis of samples from the worms provided evidence of damage and immune response to microplastics. Such damage was observed even at the lowest tested concentrations of microplastics but was most severe at high concentrations. This finding was supported by Cao *et al* who also showed evidence of immune damage, in *Eisenia fetida*. 134 Evidence of physiological effects of microplastics on a sediment engineer could be used to motivate further research with longer term studies and provides a potential mechanism for some of the effects observed on survival and growth in other research. However, a 2019 study which looked to understand potential impacts in environmentally relevant conditions suggested that microplastics should not cause significant toxic effects. The work studied *Eisenia fetida* with polystyrene and polyethylene microplastics, with detection of significant oxidative stress only in the highest (20% w/w) concentration treatment. 135

Further work on interactions between soil biota and microplastics has shown a high incorporation rate for small fraction microplastics into burrow walls of earthworms which could increase risk of leaching through preferential flow into groundwater bodies. This may have implications for the transport of plastic associated contaminants through soil. 136 A similar study looked at downwards transport of polyethylene microbeads and found that earthworms could be significant transport agents, increasing incorporation of microplastics in soils likely via cases, 136

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burrows, egestion or adherence to the earthworm exterior.\textsuperscript{137} Decomposition of organic material is slower deeper in the soil due to decreased microbial populations and lower temperatures so earthworm transport of microplastic to deeper soil layers could increase persistence further.

However, the body of research for the terrestrial environment is still limited. A major gap in understanding relates to concentrations in the soil environment which are difficult to study, and where methods are not standardised.\textsuperscript{138,139,140} As such, understanding of how laboratory demonstrated effects relate to concentrations experienced by these organisms in the environment is poor, especially given the high concentrations used in studies – ranging up to 60% by dry weight. Despite this, the studies demonstrating impacts are important given the potential for soils to act as a sink for microplastics, accumulating them over time.\textsuperscript{141,142,143} In addition, the taxa studied to date are limited, as is understanding of how microplastics may influence the terrestrial system at a higher level.

Hence, whilst primary and secondary microplastics are likely to be widely present in the terrestrial environment, current understanding of the risk is poor.\textsuperscript{144}

### 3.3 Research Gaps and Future Priorities

#### 3.3.1 Overarching Research Gaps

Significant research gaps exist in understanding the environmental risk from microplastics. Understanding of the impacts on terrestrial and freshwater ecosystems is still limited and requires additional effort. In particular efforts are needed to understand the impact of

microplastics on soil ecosystems given their importance for ecosystem services and their likely exposure to microplastics via application of sewage sludge to land.

Other gaps persist across all environments. In general, research has focussed on individual, or sub-individual, level impacts of microplastics whereas there is greater interest in understanding how these effects will scale to the ecosystem level. This is something which is highlighted by the recent SAPEA report. Examples of the levels of study, and types of endpoint which could be identified are shown in Figure 3-1.145

In addition, understanding of risk has been limited by a lack of studies establishing ‘no-effect’ thresholds (or considering toxicological endpoints relevant for setting such thresholds). This relies on testing with sufficient ranges of concentrations in order to establish the concentration at which biological effects become visible. This information is very valuable to understanding the environmental levels of microplastic which are a risk to species, and helps researchers to work towards quantitative risk assessments for microplastics.

Finally, a major gap exists with respect to understanding of nano-plastics. Few studies have looked at the impacts of nanoplastics on aquatic species, especially when compared to study with microplastics. This comes despite recognition that nanoplastics are of ecological importance as they may be able to surpass biological barriers due to small size and could hence enter cells and tissues. Indeed, transport across biological barriers has been demonstrated in laboratory studies with zebrafish.146

3.3.2 The Nature of Microplastics

Further gaps in understanding exist owing to the types of microplastic which have received research effort. One key issue complicating assessment of risk from microplastics is their diversity and complexity. Arising from a wide variety of sources and pathways, microplastics may be a wide range of sizes, shapes and polymer types. Whilst in the environment, released microplastics are likely to change size and shape due to weathering, may sorb other chemicals and may acquire biological films. These features will all affect the ways in which the particles interact with organisms and hence their potential impact.

This plethora of microplastic types and weathered particles is not reflected in the particle types used in lab studies to determine effects.\textsuperscript{148,149} The experimental literature is dominated by studies using primary, spherical microplastics which are often polystyrene and often exposing  


\textsuperscript{148} Phuong, N.N., Zalouk-Vergnoux, A., Poirier, L., Kamari, A., Châtel, A., Mouneyrac, C., and Lagarde, F. (2016) Is there any consistency between the microplastics found in the field and those used in laboratory experiments?, \textit{Environmental Pollution}, Vol.211, pp.111–123

organisms to only one or two polymer types. This is not reflective of microplastics in the environment, and also makes it difficult to understand whether the impacts of certain types of microplastic are greater than others. Some researchers are now looking to better reflect the environmental mixture in laboratory studies, for example, by generating microplastics from collected beach plastic or by weathering microplastics prior to study. In the recent Burns and Boxall paper, a review of 26 studies reporting concentration of microplastics in organisms collected from the environment found that 91% of microplastics identified from invertebrates were fibres, compared to 38% in fish and 74% from birds. By contrast, beads, which are the most studied in the literature, account for just 2% of the microplastics recovered from fish, 5.3% of those in invertebrates, and 0% of those from birds. This observed difference in composition could be reflective of higher retention of fibres by the organisms, being potentially more difficult to excrete than “harder” particles, or could reflect a genuine difference in composition of the microplastics in their environment.

An additional difference to note is that between the size classes of microplastics detected in the environment when compared with those used in laboratory studies. Due to challenges with detection methods, only microplastics down to a certain size class can be detected in the environment – with no present method for measuring environmental nanoplastic concentrations. Typically, mesh sizes sample particles between 50-3000µm, with 300µm mesh commonly used to avoid the rapid clogging of nets experienced with mesh sizes smaller than this. By comparison, size classes used in laboratory studies can be orders of magnitude smaller. In addition, concentrations of microplastics used in laboratory studies can be orders of

150 Phuong, N.N., Zalouk-Vergnoux, A., Poirier, L., Kamari, A., Châtel, A., Mouneyrac, C., and Lagarde, F. (2016) Is there any consistency between the microplastics found in the field and those used in laboratory experiments?, Environmental Pollution, Vol.211, pp.111–123
magnitude higher than those measured in the environment. Some researchers justify this as reflecting potential future concentrations of microplastic, however, it can make it difficult to relate study findings back to the environment. With regard to studies looking at exposure of microplastics in the environment, differences in sampling and analysis methodology can lead to widely different results since no standardised techniques are currently available. Finally, it is worth noting that detection of microplastics in soil samples presents even greater challenges than aquatic samples, and hence understanding of present exposure of soil organisms to microplastics is poor.

As such, owing to difficulties in detecting and studying microplastics there are significant disparities between the types and compositions of microplastic which have been studied with organisms in laboratory conditions, when compared to those detected in the environment.

Issues around researching microplastics may have also contributed to the current picture. Certain species have been researched considerably more than others, especially with reference to laboratory studies – generally owing to how conducive they are to laboratory culture. In addition, there may be some publication bias around reporting and publication of studies which show impacts and presence of microplastics in the environment. This may be due to publishers wanting to publish work which fits with previously accepted conclusions on the impacts of plastic debris on the environment.  

### 3.4 Conclusions

Whilst research in the field of microplastics has been developing rapidly over the past few years, there are still significant gaps to fill before it is possible to have a robust understanding of the risks posed by microplastics to the Scottish environment. In part, this arises from the difficulties in scaling potential impacts from the individual or sub individual level to anticipated impacts on the ecosystem. Equally, there are more major gaps when looking to understand the potential risk for freshwater environments and in particular for terrestrial environments. The sparse studies which have been done with mesocosms and small assemblages of species have produced some results which suggest impacts of microplastics at an ecosystem level not suggested by effects seen in individual species studies, and wider replication of such findings could generate cause for concern – suggesting that differential responses of species to microplastics as a stressor could result in changes to the ecosystem. It is also not clear from the literature whether certain types of microplastics present a greater risk than others, despite the dominance of fibres in field studies.

However, despite these unknowns there is evidence that marine species in Scotland are consuming microplastics and that this could be negatively impacting their health with field and

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laboratory evidence available for presence and negative impact of microplastics on the commercially valuable Norway lobster. There is further evidence in the literature for presence of microplastics in waters in and around Scotland, and for their consumption by commercial fish species. More widely, research reports a range of negative impacts of microplastics on fish, molluscs, and invertebrates.

Whilst the papers which have looked to use existing data to create a risk assessment for microplastics have generally concluded that harm is not expected at the environmental concentrations experienced at present, it is worth considering the persistent nature of microplastics. It is understood that microplastics are extremely persistent in the environment and will break down over time into nanoplastics. This persistence was the basis of the ECHA recommendation for a restriction on intentionally added microplastics – recognising that this was an area where microplastic use could be regulated and that removal from the environment once released is incredibly challenging. The wording in the REACH annex which the restriction refers to recognises that delaying regulation or not acting is a choice which allows continued release of the substance in the meantime.\textsuperscript{159} As such, whilst there are significant gaps in the research base and current understanding of risks from NMPs, these will take time to fill and continuing emission of intentionally added microplastics during that time can be prevented on a precautionary basis.

Ongoing research could prioritise studying the impacts of microplastics as found in the environment – focussing on weathered particles, mixed assemblages of different shapes and polymers, and reflecting the size classes observed in the environment. In tandem efforts to standardise sampling and analytical techniques would help to ensure comparisons between exposure studies are meaningful. This would look to improve understanding of impacts. In addition, it could be valuable to attempt longer term studies looking at the impacts of NMPs as well as looking to understand impacts at the ecosystem level. Finally, a better understanding of the impacts of microplastics on terrestrial ecosystems is required.

\textsuperscript{159} REACH Online REACH, 0.6., Steps of a chemical safety assessment :: ReachOnline, accessed 17 April 2019, https://reachonline.eu/reach/en/annex-i-0-0.6.html
4.0 Prioritisation of Microplastic Sources

The scope of this prioritisation exercise is both primary and secondary microplastics. In the case of secondary microplastics we focus only on those that are created through wear and tear during the normal life of a product – the generation of microplastics is therefore an inherent part of their function. This means that larger items that are littered and subsequently degrade into microplastics are not the focus; to tackle these sources of secondary microplastics (mismanagement of waste) require different sets of interventions. This also includes microplastics in compost spread on agricultural land as this is also considered to be an example of poor waste management of larger plastic items.

There are a great many sources of microplastics that have been identified over the past 5 -10 years as the topic has gained more attention. Many are relatively small and the result of niche products or applications. A full list can be found in Table A- 1 in the Appendix. The list was narrowed down based on existing knowledge of the magnitude of the sources and areas that are believed to be of particular relevance and interest to Scotland. This provided a short list of 14 sources (Table A- 2). These were narrowed down further for subsequent investigation using a set of weighted prioritisation criteria which are summarised in Table 1.

The sources prioritised for further investigation are:

- Artificial turf and equestrian surfaces
- Automotive tyre wear
- Synthetic clothing fibres
- Road markings
- Agricultural fertilisers and treated seeds
- Fishing/aquaculture gear (but not lost or discarded gear breaking down further)

Tyre wear, synthetic fibres and road markings have already been highlighted in many studies and are thought to be large contributors to microplastic pollution; this is expected to be the same in Scotland. Artificial turf is expected to contribute more to Scottish microplastic pollution compared with the rest of Europe as only Norway and the Netherlands have a higher number of artificial football pitches per capita. There are also opportunities for Scotland to act to mitigate this source. Agricultural products made from or containing microplastics have only recently been highlighted by the European Chemicals Agency (ECHA) as a significant source; this is considered worthy of investigation for Scotland as the quality of agricultural land has never been more important and there may be opportunities for Scotland to act. Equally, the fishing industry is important in Scotland and therefore identifying its contribution to the microplastic issue requires some attention. The notable exception missing from this short list are pre-production plastic pellets (the raw material for producing plastic products). Whilst these have previously been identified as a significant source of microplastics – and are often found on beaches – these are already being addressed directly by the Scottish Government in a trial running throughout 2019.
<table>
<thead>
<tr>
<th>Prioritisation Criteria</th>
<th>Wtg</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental impact</td>
<td>15%</td>
<td>This criterion concerns the extent to which the form of microplastic pollution has an adverse impact on the environment, and the level of emissions believed to be occurring. At this time there is no evidence to suggest any source is more damaging than another, therefore this analysis is primarily focused on the emissions to the environment by mass. Data is more readily available for the marine environment, and less for terrestrial and freshwater environments. Recent research, however, estimates terrestrial micro-plastic concentrations to be four to 23 times higher than marine micro-plastic, depending on the environment, and more than 80% of plastics found in marine environments originated on land. Micro-plastics are often applied to agricultural soil via sewage sludge being used as fertiliser, and there are concerns over diseases these particles may carry, and the effect they have on soil fauna such as earthworms.</td>
</tr>
<tr>
<td>Human Health Impact</td>
<td>15%</td>
<td>This criterion concerns the extent to which the form of microplastic pollution is believed to have an adverse impact on human health based on the current state of scientific understanding. It is worth noting that agreed-upon and reliable risk assessments of the risk to humans posed by ingestion or inhalation of microplastics are not yet available. Despite this, scientific studies have highlighted some forms of microplastic and the exposure pathways associated with them, and noted that some may pose greater risk.</td>
</tr>
<tr>
<td>Ability to influence stakeholders in Scotland</td>
<td>15%</td>
<td>This concerns how easy it would be for Scottish Government to influence stakeholders in Scotland with a view to reduce the prevalence of microplastic pollution. This is currently focused on the ability of Scottish Government to influence.</td>
</tr>
<tr>
<td>Public awareness of problem</td>
<td>5%</td>
<td>This criterion concerns how aware the general public are of pollution from a plastic item, and/or the negative impacts this item can have. A high level of public awareness is generally the result of media attention on an item, or a campaign led by NGOs. For example, on microbeads (e.g. ‘Beat the Microbead’). Public awareness can be a precursor to increase in public support for action.</td>
</tr>
<tr>
<td>Current level of public support for action</td>
<td>5%</td>
<td>This concerns how keen the general public are to see this item and the negative impacts it has on the environment and wildlife addressed. It is closely linked to public awareness.</td>
</tr>
<tr>
<td>Risk to Scottish Business</td>
<td>15%</td>
<td>This relates to the Transition (from regulatory changes and/or technological disruption), Reputational, Physical (arising from the presence of plastic pollution in the environment) and Liability risks posed by microplastics sources</td>
</tr>
<tr>
<td>Scope for additional national control</td>
<td>20%</td>
<td>This relates to the controls already in place to reduce plastic pollution. These might be voluntary controls (for examples, supermarkets committing to phase out plastic packaging) or regulatory (bans on plastics bags or microbeads).</td>
</tr>
<tr>
<td>Practicability of further reducing impacts</td>
<td>10%</td>
<td>This relates to the overall ease and feasibility of actions to reduce pollution. It generally depends on availability of alternatives, their costs, the support of government to implement bans and other regulations, and behavioural change. Sometimes action will require a product or packaging supply chain to dramatically change.</td>
</tr>
</tbody>
</table>
5.0  Microplastics Emissions at Source

The following section provides some indicative estimates of the emissions of microplastics at source for the key products identified in the prioritisation exercise.

The presented numbers are what is expected to be generated and emitted into the open environment. Section 6.0 details where these microplastics may go once they are emitted. These pathways differ for each source.

The methodology for the calculations is based upon a similar study carried out for all EU countries for the European Commission. This is referred to as the ‘EU study’ throughout and this should be consulted for full and complete methodological details. The following sections describe where assumptions and data are different for the Scottish situation or where new evidence has come to light.

5.1  Automotive Tyre Wear

Tyre wear particles are generated mechanically through shear forces acting on tyre tread when it interacts with the road surface and by a thermo-mechanical process called volatilisation. The resulting particles are typically long and cylindrical and are made up of a central core made largely of tyre tread material itself which is encrusted with particles including metals derived from brake wear, road wear, and minerals from soil or the road surface materials, and which can also incorporate air bubbles. The central rubber core is comprised of various natural and synthetic rubber compounds (rubber is a type of polymer that is believed to persist in the environment in the same way as other plastics) as well as various additives in blends that are proprietary for each tyre manufacturer.

There is also increasing concern around the finer particles that are generated (known as PM\textsubscript{10}) which become airborne. Such particulates contribute to air pollution which is linked to various

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respiratory illnesses.\textsuperscript{165} Though there is uncertainty due to the range of methods used to
generate, sample and measure particles, it is generally accepted that particles small enough to
enter the respiratory system which are smaller than 10 micrometres in diameter (known as
PM\textsubscript{10}),\textsuperscript{166} make up between 0.1\% and $\sim$10\% of total wear.\textsuperscript{167} Between 20\% and 50\% of this PM\textsubscript{10}
material is believed to be smaller than 2.5 micrometres in diameter (PM\textsubscript{2.5}).\textsuperscript{168,169} PM\textsubscript{2.5} is known
to have more serious health impacts associated with it than PM\textsubscript{10}. In addition, the resuspension
of material already deposited on the road surface by passing cars contributes further to the
material available for inhalation.\textsuperscript{170} Tyre wear will contribute to that material which is
resuspended.

It is very difficult to identify and track exactly where tyre-derived microplastics go as they can be
widely dispersed around roads and washed away during rain or blown around with the wind.
Their buoyancy in water varies and a large proportion of the particles are likely to settle into
river and estuary sediments where they may still interact with river wildlife. Nevertheless, the
sheer volume of these particles thought to be entering the environment is a cause for concern
and their occurrence and effects on the environment is a subject of ongoing research.\textsuperscript{171}

\textbf{5.1.1 Estimate of emissions in Scotland}

Tyre wear emissions at source are estimated by multiplying traffic activity data expressed as
vehicle kilometres (vkm) by a grams per-vkm rate of wear to calculate overall emissions of tyre
particles. To distinguish between wear deposited on urban, rural and highway roads, and to
facilitate a more powerful environmental pathways analysis for tyre-derived microplastics, the
wear rates presented in a 2016 guide from the Netherlands National Water Board (Water Unit)\textsuperscript{172}
are applied to the traffic data disaggregated by vehicle type and road type, taken from

\begin{itemize}
  \item Charron, A., Polo-Rehn, L., Besombes, J.-L., et al. (2019) Identification and quantification of particulate
    tracers of exhaust and non-exhaust vehicle emissions, \textit{Atmospheric Chemistry and Physics}, Vol.19, No.7,
    pp.5187–5207
  \item Grigoratos, T., Gustafsson, M., Eriksson, O., and Martini, G. (2018) Experimental investigation of tread
    wear and particle emission from tyres with different treadwear marking, \textit{Atmospheric Environment},
    Vol.182, pp.200–212
  \item Grigoratos, T., Gustafsson, M., Eriksson, O., and Martini, G. (2018) Experimental investigation of tread
    wear and particle emission from tyres with different treadwear marking, \textit{Atmospheric Environment},
    Vol.182, pp.200–212
  \item Amato, F., Favez, O., Pandolfi, M., et al. (2016) Traffic induced particle resuspension in Paris: Emission
    factors and source contributions, \textit{Atmospheric Environment}, Vol.129, pp.114–124
  \item https://www.plymouth.ac.uk/news/university-receives-government-funding-to-analyse-impact-of-tyres-
    and-textiles-on-the-marine-environment
  \item Deltares, and TNO Consulting (2016) \textit{Emissieschattingen Diffuse bronnen Emissieregistratie:}
\end{itemize}
the 2018 Scottish Transport Statistics.\textsuperscript{173} This provides an estimate of the total tonnage of particles formed on roads in Scotland each year. The most recent and thorough literature review suggests that tyres emit around 6.1 mg of PM\textsubscript{10} per kilometre driven. This represents around 6\% of total wear. It should be noted that publicly-available emissions factors for tyre wear are largely derived from primary studies conducted at least 15 years ago and in the intervening period changes in tyre materials and design, and vehicle design, will likely mean that current emission rates vary from those detailed in emissions inventories.\textsuperscript{174} However, in the absence of new direct measurements of emissions from modern vehicles and tyres, these data remain the most robust available.

\begin{boxedminipage}{\textwidth}
\textbf{In Brief}

Microplastics generated from the wear of automotive tyres in Scotland

\begin{itemize}
    \item 6,678 tonnes per year in total, of which
    \item 407 tonnes are particulate matter smaller than 10 micrometres in diameter
\end{itemize}
\end{boxedminipage}

5.2 Synthetic Textiles

The release of small synthetic plastic fibres, known as microfibres, due to abrasion during the laundering of synthetic clothing is now widely recognised as one of the major sources of microplastic pollution. Studies have also shown that fibres can be released during tumble drying, however the pathway to the environment from this is less clear as filter residues would normally be disposed of in the general waste bin; washing machines emit directly into the sewer network. Common synthetic fibres include acrylic, polyester/PET (e.g. Terylene\textsuperscript{TM}, Dacron\textsuperscript{TM}), polyamide (nylon), acetate, and PPT (poly-paraphenylene terephthalamide i.e. Kevlar\textsuperscript{TM}). Polyester dominates the synthetics market.

Regarding the nature of particles released, the size distribution of fibres is such that the vast majority of fibres lie between 50 and 1000 \(\mu\text{m}\) in length with a roughly even distribution throughout these sizes\textsuperscript{175} and with diameters around 15 ±5 \(\mu\text{m}\). Additive chemicals are

\begin{footnotesize}
\textsuperscript{173} Scottish Transport Statistics No 37 2018 Edition, p.324
\end{footnotesize}
frequently used in synthetic textiles for example to reduce flammability and impart different colours.

The existing scientific literature testing microfibre loss has highlighted the following factors as potentially influencing microfibre release rate:

- material composition of fabrics;
- polymer origin (e.g. virgin fossil, mechanically recycled, chemically recycled, bio-based);
- yarn size and length;
- extent of fibre twist;
- fabric construction type (e.g. whether knitted or woven, and the type of knit/weave);
- finishing treatments;
- choice of colouration methods including timing of dyeing;
- garment density;
- age of garment;
- temperature;
- spin speed;

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• use of detergent (chemical composition, liquid vs. powder);
• type of washing machine (top-load or front-load); and
• extent of UV degradation.

Upon abrasion from textiles, these fibres are discharged into washing machine effluent and, through wastewater, can make their way into the aquatic environment.

5.2.1 Fibres from Atmospheric Deposition

There is growing evidence that not only are fibres released into waterways by washing, but they abrade during wear and can end up in almost any environment via atmospheric deposition. Fibres have been found in the Arctic\textsuperscript{187} and on high Alpine mountains\textsuperscript{188} where fibres from washing would not end up. Two studies by Dris in France looked at the atmospheric fallout\textsuperscript{189} and the concentrations of fibres in indoor air.\textsuperscript{190} Between 2 and 355 fibres were found to land per square metre per day in urban areas with air concentrations of up to 1.5 fibres per metre cubed – this compares with up to 60 fibres per metre cubed indoors which raises questions around the number of fibres inhaled per day and the impact this may have on human health. A 2019 study by Plymouth University for Defra\textsuperscript{191} also detected a significant number of both textile fibres and tyre particles being deposited by atmospheric fallout within 50 metres of roadsides.

The prevalence and occurrence of fibres is difficult to quantify as the data and studies available are limited. Taking the results from Dris and applying them to Scotland can provide an indicator, however. If the same atmospheric deposition was observed throughout the entire 80,000 km\textsuperscript{2} of Scotland (not just the urban areas in Dris’s study) this would equate to a deposition of 120 to 250 tonnes per year\textsuperscript{192} – around 30% of these would be synthetic according to Dris. This is considerably less than one might expect given the perceived prevalence, and considering only a fraction of Scotland is urbanised these figures are likely to be even lower in reality. However, using mass can be problematic as one tonne of fibres would constitute around 13 trillion fibres; this demonstrates how little mass is required to create enough fibres to become relatively prevalent in the environment.

\textsuperscript{192} Between 53 and 110 fibres per M\textsuperscript{2} per day from Dris with a fibre mass assumed to be 0.00008mg.
It is too early to dismiss this pathway due to the lack of studies on the subject. With test methods for measuring atmospheric deposition developed by Plymouth University it would be possible to replicate such studies in Scotland for both urban and rural areas. In the meantime, the focus on clothing fibre release in washing should also be extended to abrasion during use and the ways to reduce both of these at the same time—it is likely that solutions will be complementary.

5.2.2 Estimate of emissions in Scotland

The range of studies which have attempted to quantify the release of microplastics from the washing of clothing can be broken into two main types; those that use laboratory machines, where the conditions of washing can be closely controlled and so the impact of such conditions on relative loss rates can be compared, and those that use domestic washing machines in an effort to quantify actual releases. As the goal of the current assessment is to estimate actual releases of microplastics to the Scottish environment, the latter category is more relevant.

In 2017, Eunomia undertook a comprehensive literature review of such studies to inform the estimation of emissions at a European level. To ensure the accuracy of emissions estimates for Scotland, a thorough review of papers published between 2017 and 2019 was conducted in support of this study. Eight relevant studies were identified and their methodologies scrutinised and compared with existing literature.

Up to 2017, there was considerable variation in the scientific literature in the range of methods used in washing, capture of released fibres and subsequent measurement, counting and weighing of samples. Although it appears that over the last two years there has been an effort made by some researchers to harmonise methodologies, such as washing at consistent temperatures and nearly always washing with detergent to reflect real-world conditions, there still remain significant inconsistencies related in particular to length of washing trials and filter sizes used.

As a result, we do not believe there is yet sufficient certainty within the scientific literature to justify altering the loss rates applied in Eunomia’s 2017 study. It should however be noted that one more recent study into polyester microfibre loss rates which applied washing conditions likely to reflect ‘real-world’ conditions found a slighter lower loss rate than that which has been reported previously, though they did not explain this lower result.193

We therefore apply a lower bound estimate based upon a journal article\textsuperscript{194} published by the EU-funded 2017 Mermaids project\textsuperscript{195} that summarises some of the project’s results. The journal article includes testing of polyester and polypropylene fabrics.

For the upper range estimate of fibre release the results of Hartline \textit{et al.} (2016)\textsuperscript{196} (average of fibres released from aged and new clothing from a front-loading machine) are used. These results are chosen as they arguably represent a close approximation to a real-life scenario, as the test involved washing an entire garment.

To scale up the loss rates reported in these papers to emissions for a standard domestic washing machine load, assumptions have been made about washing load composition. Data from a JRC report into the environmental improvement potential of textiles\textsuperscript{197} splits EU sales of textiles by clothing type, fabric type and fabric construction. For the purpose of the calculations it is assumed that this percentage split of fabric types consumed represents the makeup of an average washing machine load in Scotland, as it is unlikely that the mix of fabrics purchased will vary considerably.

Using this profile of washing load composition, and an assumption that an average Scottish washing machine capacity will be the same as that for the EU (5.4kg),\textsuperscript{198} a lower-bound and upper-bound mass of fibres emitted per typical domestic wash is constructed for viscose, polyamide, acrylics, polypropylene and polyester.

To scale up these profiles to a national level, the number of household laundry washes per year is calculated on the basis of the number of households in Scotland\textsuperscript{199} multiplied by a number of washes per year for the UK derived from a 2010 study into washing machine energy and water use.\textsuperscript{200}

The aforementioned 2017 Mermaids project also found that only 90\% of European households have a washing machine and therefore the mass releases per wash are scaled accordingly; it is


\textsuperscript{196}JRC (2014) \textit{Environmental Improvement Potential of Textiles (IMPRO-Textiles)}, Report for European Commission, January 2014

\textsuperscript{197}Mermaids (2017) \textit{Report on localization and estimation of laundry microplastics sources and on micro and nanoplastics present in washing wastewater effluents}. Deliverable A1., May 2017


assumed that the remaining 10% of households attend commercial laundrettes. This provides the total number of domestic washes carried out each year; a total of around 365 million.

Consideration was also given to how consumers fill their washing machines. AISE’s consumer survey\(^{201}\) stated that 84% of people surveyed in Europe wash with a full load. This figure has been assumed to be reflective of Scottish washing habits. Following this, the assumption has been made that the remaining 16% of consumers are washing with a half load. The inclusion of this factor along with the multiplication of the estimated fibre release per wash and the number of washes gives an upper estimated release of 505 tonnes per year and a lower estimate of 199 tonnes per year

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### In Brief

Total microplastics generated from the washing of synthetic textiles in Scotland:

Between 199 and 505 tonnes per year

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### 5.3 Artificial Turf and Equestrian Surfaces

#### 5.3.1 Summary – Turf

Artificial sports turf is becoming more and more popular in the UK with an estimate that 1,000 full sized pitches will be in use by 2020 – a figure which is expected to more than double by 2035. Artificial turf is primarily used for football, hockey and rugby pitches. Whilst previously consigned to training grounds and school type facilities, artificial pitches are now present at 15 of the 42 Scottish Professional Football League (SPFL) clubs.\(^{202,203,204}\)

All these sports require the turf to absorb impacts to help prevent injury and to mimic the feel of natural turf. This is usually achieved by the application of ‘infill’ material. This material is usually polymeric and in the form of small particles <5mm in size. It is distributed throughout the turf surface just below the artificial grass pile. Figure 4 shows a typical artificial turf composition of what is known as 3\(^{rd}\) Generation (3G) turf design. The stabilising infill is usually sand, to help the

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\(^{201}\) AISE (International Association for Soaps, Detergents and Maintenance Products) (2014) AISE Consumers Habits Survey Summary


piles to retain its shape. The performance infill is laid on top. Although the performance infill can be made from organic alternatives such as cork and coconut husk, the vast majority of the market uses rubber crumb from recycled tyres—often referred to simply as SBR (styrene-butadiene rubber). As well as SBR, there are also virgin elastomer alternatives such as EDPM and TPE—all of which are vastly more expensive and therefore SBR is often the default choice for most pitches.

**Figure 4 - Example 3G turf composition**

Artificial turf for domestic applications is unlikely to contain plastic infill material as it is both costly and unnecessary for this purpose. The pile fibres may wear or break and form microplastics, but this is expected to be substantially less when compared with sports turf which is subject to a great deal more abrasion. Non-contact sports such as hockey and tennis also have different requirements and cannot usually be played on 3G surfaces due to the need for much shorter pile. The use of 2nd Generation (2G) turf is more often used, which only includes the stabilising sand layer. Figure 5 shows an example of a typical artificial turf pitch which demonstrates how the infill can find its way outside of the pitch boundaries by attaching to players (particularly in wet weather) or as part of the migration to the outer edges of the pitch as it is played on. In this example, brushes have been installed to clean boots at the entrance/exit to the pitch, but no containment method is used.

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205 Kaminski, I. (2019) Turf it out: is it time to say goodbye to artificial grass?, *The Guardian*
5.3.2 Summary – Equestrian Surfaces

Equestrian surfaces are another sports facility which make use of end of life plastic products in surfacing. Rectangular ‘arenas’ are popular in private smallholdings and livery yards for exercising and training horses in all weathers, and gallop tracks (which may be miles long) are used for training of performance horses – racehorses and competition sports horses. Some private yard owners may also have such facilities. Finally, all weather bridleways may also make use of tyre derived rubber or carpet fibre based surfacing. Traditionally, these facilities would have been surfaced with woodchip, sand, or grass – each material having its own drawbacks.

Rubber and carpet fibre overcome some of the issues with natural materials, not splintering, not biodegrading and providing a cushioned surface to improve safety for both horse and rider. In addition, due to the limited markets for end of life tyres and carpets these materials are generally as cheap as their natural counterparts and available in large volumes. Generally, the rubber or carpet fibre is applied mixed with another material to alter the properties. Tyre chip is often combined with a layer of sand, and carpet fibre and tyre rubber may even be used in combination to provide additional surface properties.

Very little is known about the loss of material from equestrian facilities. It seems there is an absence of research on loss of carpet fibre or tyre rubber from these facilities or on the impacts this may be having on the surrounding environment. However, they are candidates for point sources of microplastic release. The surfaces are not generally bound in any way and are outdoors, exposed to weathering and UV radiation. Carpet is shredded prior to use and hence may result in release of microfibers, whereas tyre rubber is reduced to chip or crumb through a shredding process which removes embedded metals and other materials (although any chemical embedded in the tyre tread remain in rubber crumb). Furthermore, especially in the case of gallop tracks, facilities may be located on open than and horses will travel at high speed across them – increasing the potential for material to be ‘kicked up’ and to end up on surrounding land.

5.3.3 Other applications of post-consumer tyres

It is worth recognising that emissions of microplastics from post-consumer tyres likely goes beyond sports pitches and equestrian facilities. As previously mentioned they are also used in children’s play areas. However, in some instances they are also being used in gardens in lieu of wooden chip mulch to help suppress weeds in gardens and similar. It is therefore likely that this is not an exhaustive list of the applications of post-consumer tyre-rubber and it may be an area which warrants further investigation.

207 Time to renew the gallops, accessed 14 June 2019, http://www.mickeasterby.co.uk/featuresdetailsphoto.cfm?features_id=14
211 REBOUND Rubber chippings for play areas and gardens, accessed 14 June 2019, https://rebound.co.uk/
212 Rubber Crumb Chippings Scotland for equestrian arenas & sports arenas, trails and landscaping made onsite from tyre recycling in Forfar, Angus, accessed 13 June 2019, http://www.rubbercrumb.co.uk/
5.3.4 Estimate of emissions in Scotland

5.3.4.1 Artificial Turf

According to a survey by the European Synthetic Turf Organisation (ESTO) which contacted all European Football Associations, there were 296 full size 11-a-side artificial turf pitches in Scotland in 2012.\footnote{ESTO (2016) Market Report Vision 2020, 2016} ESTO believes that the market is growing at 8.5% per year – data from a Scottish survey of artificial turf pitches in 2006, which found there were 120 full sized pitches, suggests that the growth rate between 2006 and 2012 was around 16% annually.\footnote{Tim Cruttenden & Associates (2006) National Audit of Scotland’s Sports Facilities, Report for Sportscotland, 2006} More recent data provided my Sportscotland finds there were 288 pitches installed as of 2016 – slightly less than estimated in 2012. This data comes from Sportscotland’s survey of all known pitches which
they are confident is representative, but also that these figures represent the saturation point and do not expect to see noticeable growth since then. This only includes 11-a-side pitches and there is no available estimate on the number of smaller 5-a-side pitches. There are, for example, several venues in Edinburgh, each with around seven to eight 5-a-side pitches that are not on Sportscotland’s list—eight 5-a-side pitches are approximately the size of one 11-a-side pitch. In absence of any current Scottish data the ESTO report suggests that there were around 40,000 small pitches in 2012 across Europe – pro-rating this to Scotland means that there could be around 1,000.

The Sportscotland data also shows the size of the pitches with a total surface area of 1.75 million m². This is combined with a further 1 million m² estimated for small pitches. Using the infill density of 16.1 kg/m² the total infill estimated to be installed in Scotland is around 44,300 tonnes (see Table A-4 in the Appendix).

An infill loss rate of between 1.5 and 5 tonnes per year was used in the EU study and this **equates to between 1—4% of the total infill installed.** This correlates with the amount of infill top-up that is commonly reported by turf manufacturers—typically around 3% per year was stated. The result is an estimated 443 – 1,772 tonnes of infill loss in Scotland per year.

There is currently only one study which has attempted to create a mass balance for infill in artificial turf. The study, from the Netherlands, looked at three local pitches containing SBR infill and one containing TPE. The results of the study are inconclusive and may not be representative however, some indicative release figures can be used to determine where the infill goes. Transport by players was calculated at around 4% of losses and releases to surface water were also around this level (2—3%, with one notable exception at 75%). One this basis, an estimate of 5% is used for both. The remainder is split evenly between soils/grass and waste disposal. This is detailed in Table A-5 in the appendix and forms the basis for where the lost infill is expected to end up.

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**In Brief**

Total microplastics generated from artificial football turf in Scotland

443 – 1,772 tonnes per year

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215 [https://www.worldoffootball.com/](https://www.worldoffootball.com/), [https://www.powerleague.co.uk/football](https://www.powerleague.co.uk/football)

5.3.4.2 Equestrian Surfaces

The total number of facilities in England with an indoor or outdoor school (arena) stood at 1,197 according to a British Equestrian Federation report from 2012.\(^\text{217}\) This rises to 1,693 when competition venues for dressage, show jumping or eventing are included.\(^\text{218}\) Given there are no published estimates for the number of facilities with arenas in Scotland this number has been adjusted to reflect the equine population in Scotland relative to England and results in an estimate of 135 equestrian arenas in Scotland.\(^\text{219}\) Using a typical arena size of 20m x 40m and obtaining information on the typical quantities of carpet fibre and tyre rubber used in these facilities allowed an estimate of the total quantity of surface used to be obtained.\(^\text{220}\) Upper and lower estimates were obtained by using different figures from the industry on quantity of fill given that varying amounts of surface may be used to obtain different properties and depths.\(^\text{221}\) This recognised that carpet fibre may be used in small quantities in combination with sand and hence there is a wide range in the quantity of carpet fibre used in arenas.

An assumption was made about the proportion of arenas which use tyre rubber and carpet fibre respectively given no data was available on this. It was assumed that 15% of the arenas use natural surfaces (wood fibre, wood chip, sand etc.), that 20% use tyre rubber and 55% carpet fibre although these estimates are based on the opinions of equine surface providers in the absence of data.

Loss rates were estimated based on quantities of material used to ‘top up’ facilities from speaking with yard owners and surface providers.\(^\text{222,223,224,225}\) Similarly to artificial turf, some top up may be required due to compaction of material and shearing of infill into smaller pieces and hence the total top up may not represent the loss rate exactly. This is expected to be the case more for carpet fibre surfaces than tyre rubber. Given the absence of research into this topic, estimates used for artificial turf compaction were applied as an upper bound estimate of 50% loss due to compaction, and lower bound of 20% loss due to compaction given surface providers

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\(^{221}\) Personal communication with yard owners, September 2018

\(^{222}\) Personal communication with yard owners, September 2018

\(^{223}\) Personal communication with surface providers, September 2018

\(^{224}\) Carpet Gallop, accessed 14 June 2019, [https://forums.horseandhound.co.uk/threads/carpet-gallop.751987/](https://forums.horseandhound.co.uk/threads/carpet-gallop.751987/)

\(^{225}\) Personal communication with surface providers, June 2019
felt this was less the case for tyre rubber surfaces with tyre rubber experiencing greater loss as a result of removal from the arena.

To account for the contribution of gallop tracks, Scottish racehorse trainers were identified via Directory of the Turf. Of the 39 trainers listed, five had artificial gallop facilities listed on their websites and an estimate of the material used in these facilities, which included both carpet and rubber gallops, has been included.

For a number of reasons, our estimate of loss from equestrian facilities may be conservative. Firstly, assuming average arena size of 20x40m may be smaller than the average actual size used as many competition arenas are larger than this. Secondly, the number of gallop tracks may be greater than we have allowed for as this looked only at racehorse trainers, only at those trainers listed online and only those with websites describing facilities have been included. Additional facilities may be present at other equestrian holdings such as competition venues, and private livery yards. Finally, there is a significant unknown around the extent of compaction versus loss to the environment. Despite these assumptions, the estimate obtained gives a good indication of the magnitude of potential microplastic release in relation to other sources from equestrian facilities.

Based on these assumptions it was estimated that loss from equestrian facilities in Scotland stands between 11-102 tonnes per year.

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5.4 Agricultural Products

Plastics are used in a variety of agricultural and horticultural applications including;

- to protect seeds during germination,
- to control and delay the release of fertilisers and plant protection products; and
- as fertiliser additives such as anti-caking and aggregating agents.

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They are expected to remain in the soil to which they are applied, and therefore represent a direct pathway flow for microplastics to the terrestrial environment. A brief summary of each of these uses, the polymers applied and the estimated releases in Scotland is provided below. The study supporting the ECHA’s proposal for a restriction of intentionally added microplastics quantified the emission of microplastics from agricultural and horticultural at a European level for the first time based on extensive consultation with stakeholders.  

5.4.1 Controlled Release Fertilisers

Controlled release fertilisers (CRFs) take the form of granulated fertilisers coated with polymer material that slowly release fertilisers into the soil they are added to. This means of application provides a number of benefits over conventional methods including reduced nutrient loss to the environment, higher yields, and reduction in labour requirements. A variety of polymer types, ranging from cross-linked natural or thermosetting materials to thermoplastic materials, are used as the basis of coatings/capsules which are typically between 10 and 100μm thick resulting in granules with a diameter of between 1 and 5 mm and a final product polymer material concentration of between 1 and 12%.

In order to perform their function coatings must exhibit particular properties including a low degradation rate and insolubility in water and as a result it is believed that they will remain as inert dust particles in soil, with some biodegradation over time.

Estimate of emissions in Scotland

To estimate the total tonnage of fertilisers applied in Scotland, Overall Fertiliser Application Rates for Nitrogen, Phosphate and Potassium fertilisers were adjusted for their mineral content and multiplied by the total cultivated hectares of agricultural land in Scotland. The study supporting the ECHA’s proposal for a restriction on intentionally added microplastics reported that around 1% of agricultural fertilisers applied in Europe are CRFs and consultation with the Agricultural Industries Confederation (AIC) corroborated that this is also the case in the UK. CRFs have a polymer content of between 1% and 12%. These assumptions were applied

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232 Interview with Jane Salter – Agricultural Industries Confederation (20/08/2019)
here to arrive at an estimate that between 100 and 1,198 tonnes of microplastic are emitted to soils in Scotland from CRFs each year.

5.4.2 Fertiliser Additives

Another use of polymeric material in fertilisers is as additives which impart desirable properties such as:

- anti-caking agents;
- granulation and prilling\textsuperscript{235} aids;
- anti-dust agents;
- micronutrient binders;
- de-foaming aids; and
- colouring agents.

There is limited information publicly available on the extent of use of many of these additives, with most data available for anti-caking agents, which take the form of water-insoluble polyethylene pastes and waxes and water-soluble powders. Both of these types serve to improve the ease with which the fertilisers can flow through distribution and application systems which facilitates dosing and thereby results in improved efficiency of use. Water-insoluble anti-caking agents are inert and are not believed to biodegrade in soils and so will have a long residence time in the soil environment.

**Estimate of emissions in Scotland**

The total tonnage of fertilisers applied in Scotland was estimated as described in section 5.4.1. In the absence of publicly-available data and based on extensive stakeholder consultation the ECHA report estimated that two thirds of all fertilisers applied in Europe contain water-insoluble anti-caking agents.\textsuperscript{236} The Agricultural Industries Confederation which represents fertiliser producers in the UK was contacted to gather data on the rate of polymer use in fertiliser additives. The AIC explained that Fertiliser Manufacturers in the UK specify the performance characteristics they want in component ingredients from chemical manufacturers for their end-products, rather than the composition of those ingredients. It may not therefore be known whether the manufacturers are sourcing additives that contain polymers.

AIC asked its fertiliser producer members to determine whether their products contain polymers on behalf of the project team and reported that while some fertiliser producers are sure that they are not sourcing fertilisers containing microplastic materials, others were unsure. In the absence of sufficiently detailed Scotland—or UK—specific data on the extent of use of polymer-containing additives the European-level assumption applied by ECHA is used.

\textsuperscript{234} ibid

\textsuperscript{235} A form of pelletisation

\textsuperscript{236} ECHA (2019) *Annex to ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION*, March 2019, https://echa.europa.eu/documents/10162/1cae7c3c-4aa5-db3f-0a11-75ee2a8338e7
The concentration of such anti-caking agents in final fertiliser product is believed to be between 0.05% and 0.3%. These assumptions were applied to arrive at an estimate that between 333 and 1,997 tonnes of microplastic are emitted to soils in Scotland in the form of water-insoluble fertiliser additives each year.

5.4.3 Capsule Suspension Plant Protection Products (CSPs)

Capsule Suspension Plant Protection Products take the form of plastic capsules which are filled with pesticide products which they then release slowly over time once applied in the field. The benefits of CSPs relative to conventional means of pesticide application are similar to those for controlled release fertilisers, and include:  

- increased efficiency of use due to easier and thus more accurate dosing;
- reduced toxicity to the skin improving safety for those handling final product; and
- reduced unintended environmental harm by reducing the volatility of active ingredients.

A variety of polymers are used for capsules including polyurea, polyamide, and polyester amongst many others. Although the materials used are required by regulation to have low toxicity, they are not required to biodegrade. The nature of the capsules varies by product but capsules of diameters between 0.5 and 50μm with coatings 10 to 500nm thick and polymer concentrations of between 1 and 6% of the final product have been reported by industry.

Estimate of emissions in Scotland

In 2016, CSPs represented 2.8% of the global plant protection chemical market. Directly applying this figure to the total pesticide application in Scotland would assume that conventional and controlled-release pesticides sell for a similar price. However, while some CSPs do sell for a comparable price to conventional pesticides, other sell for far more, and so some conversion of revenues to mass of fertiliser applied is required. In the absence of pesticide-specific data, a maximum price premium of 41.3% for CRFs relative to conventional fertilisers is applied, as used in the ECHA report to estimate European-level emissions. A minimum price premium of 0% is assumed as some CSPs sell for comparable prices. In the absence of other data, it is assumed that the fraction of global pesticide sales that CSPs represent is applicable to Scotland.

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240 ibid
The total tonnage of plant production products applied in Scotland\textsuperscript{242} is multiplied by the market shares adjusted by price premium as outlined above to estimate total application of CSPs in Scotland. This is then multiplied by the polymer content of CSPs (1-6\%) to arrive at an estimate that \textbf{between 0.03 and 0.26 tonnes of microplastic are emitted to soils in Scotland in the form of CSPs each year.}

\section*{5.4.4 Seed Coatings}

Seed coatings typically take the form of a polymer-latex film around a seed which incorporates other synthetic particles including fertilisers, growth regulators and colouring. The coatings provide a number of functions including protecting seeds during germination, facilitating safe and efficient handling, and reducing the need for spraying of fertiliser and pesticide as these are incorporated within the coating.\textsuperscript{243}

There are three major types of seed coating treatment;

- \textbf{Type 1)} flowable suspensions with low polymer content applied to wheat and barley seeds;
- \textbf{Type 2)} film coatings which incorporate nutrients and pesticides applied to crops such as sunflower and corn; and
- \textbf{Type 3)} pelleting and encrusting which carries nutrients and pesticides applied to sugar beet and some vegetables.

\section*{Estimate of emissions in Scotland}

To first estimate the total volume of seeds sown in Scotland, hectares of cultivated agricultural land by crop\textsuperscript{244} were multiplied by sowing rates by crop reported by the European and Mediterranean Plant Protection Organization\textsuperscript{245} and gathered via stakeholder consultation.\textsuperscript{246} It should be noted that for the UK some of the reported sowing rates were maximums and so the release rates based on these sowing rates will be worst case scenarios. Additionally, sowing rates were available for 91\% of the area cultivated with crops in Scotland.

\textsuperscript{242} Reay, G., Monie, C., Wardlaw, J., and Hughes, J. \textit{Pesticide Usage in Scotland - Outdoor Vegetable Crops} 2017

\textsuperscript{243} ECHA (2019) \textit{Annex to ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION}, March 2019, https://echa.europa.eu/documents/10162/1cae7c3c-4aa5-db3f-0a11-75ee2a8338e7


\textsuperscript{246} Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
The full range of crops grown in Scotland were assigned to one of the three major types of seed treatment based on consultation with relevant stakeholders\textsuperscript{247} and the description of crops to which treatments are applied detailed in the ECHA call for evidence.

The mass of seeds sown was multiplied by the required dosing of treatment and polymer concentrations reported by industry in response to the ECHA call for evidence.\textsuperscript{248} An upper limit for the dosing rate of flowable suspension was provided by the AHDB.\textsuperscript{249}

These dosing rates and polymer concentrations are:

- **Type 1)** between 2 and 5 grams of treatment per kg of seeds with a max. 4% polymer concentration;
- **Type 2)** between 2 and 10 grams of treatment per kg of seed with a max. 35% polymer concentration; and
- **Type 3)** between 5 and 50 grams of treatment per kg of seed with a max. 35% polymer concentration.

Data published by the ECHA study suggested that seeds for the following categories of crop are treated:

- Wheat;
- Triticale;
- Winter barley;
- Spring barley;
- Rye;
- Oilseed rape;
- Linseed;
- Maize;
- Rape;
- Fodder beet; and
- Vegetables for human consumption.

AHDB were consulted\textsuperscript{250} on the use of seed coatings in Scottish agriculture which suggested that the following crops are also likely to have coatings applied to seeds;

- Oats;
- Protein Peas;
- Turnips and Swede; and
- Kale and Cabbage.

\textsuperscript{247} Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
\textsuperscript{249} Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
\textsuperscript{250} Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
AHDB noted that some farmers will grow and save their own seed and that these seeds are unlikely to be treated, unless tested for disease and shown to need treatment. The British Society of Plant Breeders (BSPB) were contacted for information on the proportion of seeds planted which are bought compared to farm saved seed. The BSPB disputed that these would not be treated and suggested that most seed farmers use the services of a mobile seed processor who may treat as well as clean the seeds. In the absence of certainty, it is assumed that whether seeds are bought or saved does not influence whether they are treated. This is however an uncertain point that Scottish Government may wish to explore further in consultation with relevant stakeholders.

The Agricultural Industries Confederation which represents seed producers in the UK was also contacted to gather data on the rate of polymer use in seed treatments. They reported that the structure of the market is that seed producers buy coatings from chemical producers who supply multiple industries (e.g. paints), and then apply these coatings to the seeds they sell. Because coating chemical composition is the intellectual property of chemical companies, detailed information on the content of coatings is not always available. AIC asked its seed producer members to check whether their products contain polymers on our behalf, but were unable to provide any data. They reported that in general the level of knowledge of coating composition is variable amongst their members. The impression of seed producers which AIC has contacted so far is that the vast majority of seed coatings applied in Scotland won’t contain polymers, but were unable to provide any evidence to support this assertion.

Based on the above assessment, it is estimated that between 10 and 53 tonnes of microplastic are emitted to soils in Scotland each year from treated seeds for the above-mentioned crops.

5.4.5 Estimate of Emissions in Scotland

In Brief

Microplastics emitted to soil each year from agricultural products include;

- between 100 and 1,198 tonnes from Controlled-Release Fertilisers;
- between 333 and 1,997 tonnes in the form of water-insoluble anti-caking fertiliser additives;
- between 0.03 and 0.26 tonnes in the form of Capsule Suspension Plant Protection Products; and
- between 10 and 53 tonnes in the form of treated seeds.

Total emissions between 443 and 3,249 tonnes

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251 Personal communication with the British Society of Plant Breeders, (24/10/2019)
5.5 Fishing Gear

Plastic products are common in the fishing and aquaculture sectors. In many ways, these industries are reliant on plastic material to provide affordable, lightweight and durable equipment. Plastics are widely used in fishing gear, with a report analysing the EuFir fishing gear collection scheme finding typical composition of gear (as collected for recycling) to be 76% Nylon, 13% Polypropylene, 9% HDPE, 2% lead and 1% steel.\textsuperscript{252} As the majority of business activities in the fishing and aquaculture sector are conducted in the marine environment these products are exposed to weathering conditions from sunlight (UV radiation), salt water, changes in temperature, and biofouling that can degrade the plastic and cause it to fragment over time.\textsuperscript{253} Some products degrade faster than others, particularly where they are also subject to abrasion from contact with the sea floor (i.e. bottom trawl nets), movement through the sea, or cleaning activities. In the case of rope, lines, and nets this may also occur from friction through interaction with other gear – for example being hauled back onto a vessel post use. These forces degrade the plastic products over time and have the potential to release microplastic particles directly into the marine or aquatic environment.

Research into microplastic formation from fishing gear during use is particularly sparse as attention is usually focused on preventing or recovering lost fishing gear.\textsuperscript{254,255,256} Some research suggests that the quantity of microplastic released may not be that significant, at least in certain regions, as the products are replaced before they are too badly degraded.\textsuperscript{257} This assumes that the material degrades in a non-linear fashion, that in the initial period very little microplastic is released and that the plastic products are replaced before they reach the point at which the rate of microplastic emissions increases significantly. Recent research from Plymouth University provides some evidence to suggest this may be the case, or at least that older gear is likely to


\textsuperscript{254} Macfadyen, G., Huntington, T., and Cappell, R.(2009) \textit{Abandoned, lost or otherwise discarded fishing gear}, Rome: United Nations Environment Programme : Food and Agriculture Organization of the United Nations

\textsuperscript{255} NoFir \textit{Collecting discarded equipment from fishing and fish farming around Europe}, \url{https://nofir.no/wp-content/uploads/2016/02/laymans_raport_eco_innovation.pdf}


\textsuperscript{257} Magnusson et al. (2016) Swedish sources and pathways for microplastics to the marine environment; after Sundt et al. (2014).
release greater quantities of microplastics. However, the study found that new fishing gear also released microplastic, albeit to a lesser degree. Further, the study loaded the gear with significantly lower weight (~2.5kg loading) than would be expected during fishing, hence the release quantities reported during use may be much lower than in practice. The release quantities reported from the Plymouth work have not been taken forward for use in modelling as they are unlikely to be representative for fishing gear usage as a whole.

A 2017 study investigated degradation of polymer ropes at 10m depth in Scottish coastal waters. A rate of mass loss of 0.4—1% per month was observed. The rate varied depending upon the polymer. The study indicates that polyethylene and polypropylene do not wear as much as nylon over a 12 month period. However, the study emphasises that the degradation of marine plastics is highly dependent on the context in which they are found and so it would be unwise to assume that the results are representative of degradation of fishing and aquaculture gear in use. Further research is required in this area in order to inform estimates of microplastic emissions from these sources. Indeed, similar techniques could be applied to measure the rate of plastic degradation and emission of microplastic particles from fishing and aquaculture gear in use and establish the correlation with the principal degradation factors.

There is also a lack of data on the on fishing nets sold, used, discarded and lost. This is compounded by spurious statistics such as a 2009 FAO report repeatedly being quoted as 640,000 tonnes of fishing gear being lost every year, when this refers to what is currently residing on the sea floor. However, and whilst it is not the focus of this modelling, it is worth recognising that beyond issues with ghost fishing and entrapment, lost or abandoned gear is also likely to degrade and release microplastics with a 2019 study looking at this in Italy. The work collected abandoned fishing gear from the Venetian Lagoon and examined the release of microplastics from it under washing conditions which looked to simulate what might be experienced in the ocean. Figure 4 shows a scanning electron microscope image from the study of a weathered polyethylene net, showing formation of filament microplastics.

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258 To be published: University of Plymouth, Newcastle University, King’s College London, and Eunomia Research & Consulting (2019) Investigating the sources and pathways of synthetic fibre and vehicle tyre wear contamination into the marine environment, 2019

259 To be published: University of Plymouth, Newcastle University, King’s College London, and Eunomia Research & Consulting (2019) Investigating the sources and pathways of synthetic fibre and vehicle tyre wear contamination into the marine environment, 2019

260 Welden and Cowie (2017), Degradation of common polymer ropes in a sublittoral marine environment

261 UNEP, and FAO (2009) Abandoned, Lost or Otherwise Discarded Fishing Gear, 2009

As such, the total quantity of microplastic released by products used in the fishing and aquaculture industries in Scotland is dependent upon:

- The relative weight of plastic product in use or storage in the marine environment;
- The disposal / replacement rate;
- Where the product is used and stored, as this will affect the exposure to:
  - UV\(^{264}\),
  - Other weathering factors discussed above, and
  - Abrasion; as well as
- Susceptibility to degradation factors to which it is exposed.

On this basis, nets pose an elevated risk of degradation due to their size, exposure to weathering from the sea and air, and abrasion in use. Gear used to protect bottom trawl nets, such as dolly ropes and rock hoppers (see Figure 8), are also high risk due to the strong friction forces they are subject to as they are dragged over the sea floor. However, it is not clear what portion of the material lost would be classified as microplastics – abrasion in particular could cause larger fragments to be lost. There are also some fishery types which will not contribute, or may contribute little, to microplastic pollution as they are less reliant on plastic-based gear. Scallop


dredging equipment can be made entirely from metal and hence these activities will not contribute where non-plastic gear is used.\textsuperscript{265,266}

**Figure 8 - (Right) End of life Rock Hoppers, derived from tyres (Left) Dolly ropes from end of life gear**

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig8.png}
\caption{End of life Rock Hoppers, derived from tyres (Left) Dolly ropes from end of life gear}
\end{figure}

\textit{Source: Eunomia}

As such, we would expect there to be some differences in rate of microplastic loss between different fishing gear applications. However, there is no research to demonstrate how different the rates of loss will be, and to which types of fishing gear they would apply. Loss rate is therefore averaged across all gear, but it should be noted that this is a knowledge gap which research could look to resolve in future.

### 5.5.1 Estimate of emissions in Scotland

Data on production from Scottish fisheries and aquaculture was obtained from reports produced by Scottish Government for 2017.\textsuperscript{267,268,269}

\textsuperscript{265} Queen Scallop Dredge, accessed 5 July 2019, \url{https://seafish.org/gear/gear/profile/queen-scallop-dredge}

\textsuperscript{266} Scallop Dredge, accessed 5 July 2019, \url{https://seafish.org/gear/full-search}


Swedish estimates for fishing net use stand at 464 tonnes. Scaling the Scottish production data by catch with the gear usage figures from Sweden suggests ~1000 tonnes of fishing and aquaculture gear is used. This has been used as an upper bound estimate for gear usage. Personal communication with the Icelandic Recycling Fund (IRF) who manage the collection and recycling of fishing gear in Iceland suggests a lower weight of gear is used per tonne of production, at ~1kg per tonne. This generates a lower bound estimate for gear use in Scotland of ~480 tonnes. There is a lack of scientific data on the generation of microplastics from fishing gear in use. However, a loss rate of 1-10% has been estimated in Sweden based on the reduced weight of fishing gear items at the point of being recycled.

Using the estimated loss rate from Sweden of 1—10 %, and lower and upper bounds as described above, a total loss of 5—110 tonnes (per year) direct to the ocean is therefore estimated. This estimate is highly speculative, as both the loss rate and the fishing gear data are very uncertain at this stage.

**In brief**

Total microplastics generated from fishing net wear and emitted directly into oceans:

5 – 110 tonnes per year

### 5.6 Road Markings

A road marking is a material used on road surfaces to communicate information, providing guidance to pedestrians, motorists or other road users. They are products such as paint or structural plastics which can provide frictional and reflective properties, and are generally composed of a pigmented marking material and glass beads. There are four types of road marking, two of which are more common. The two most common road markings in Europe are solvent based markings and thermoplastic markings. In solvent markings the pigment and binder are suspended in an organic solvent, whereas thermoplastic markings are applied when heated.

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270 Personal Communication with Gudlaugur Sverrisson, Operational Manager, Icelandic Recycling Fund (2019)
271 Kerstin Magnusson, and et al. (2016) *Swedish sources and pathways for microplastics to the marine environment*, Report for Swedish Environmental Research Institute, March 2016
272 Kerstin Magnusson, and et al. (2016) *Swedish sources and pathways for microplastics to the marine environment*, Report for Swedish Environmental Research Institute, March 2016
273 Road Marking | City Road Markings, accessed 31 May 2019, [https://www.cityroadmarkings.co.uk/services/road-marking](https://www.cityroadmarkings.co.uk/services/road-marking)
274 Anglo 4 Methods of road marking in the UK | Anglo Liners, accessed 13 June 2019, [https://www.angloliners.co.uk/4-methods-of-road-marking-in-the-uk/](https://www.angloliners.co.uk/4-methods-of-road-marking-in-the-uk/)
which allows the marking to be flexible and to set when cooled. Thermoplastic road markings do not need to be removed before they are refreshed and are one of the cheaper methods for installing markings—this reportedly represents 95% of the UK market. Water borne paints and cold plastic road markings are also used to a lesser extent. Cold plastic markings are incredibly durable and hence may be used in areas of high traffic flow such as at roundabouts and box junctions.

**Figure 9 - Photographs comparing particles collected directly from coloured road surfaces/road marking**

Arrows highlight incorporated glass beads, present both in particles taken from road marking paints and in environmental samples.

As well as polymer binders, a large proportion of the coatings often comprises fillers that provide wear resistance (aggregates) and increase tyre grip and reflectiveness (glass beads)—a breakdown of a thermoplastic road marking composition can be found in Table A-6 in the Appendix. Road markings are worn away largely due to traffic movements and abrasion. Evidence of where these particles go is sparse. However, a 2016 study looking at the river Thames and its tributaries identified microplastics found in the river as deriving from road paints. Key identifying features used included the colour of the particle, many being red and yellow, and the incorporation of glass beads. In addition, site location was commonly downstream of a

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storm drain input. To confirm the origin of the particles, those identified from samples were compared with particles collected directly from upstream road markings and were found to have comparable properties. As such, there is evidence that in the UK wear of road markings is resulting in microplastics in river sediments. Figure 9 contains images showing the particles collected from samples and those directly from the road surface.

5.6.1 Estimate of emissions in Scotland

Road paint sales data was not available for Scotland. However, data was provided by CEPE for European sales of different types of road paint in tonnes, and their respective solids content. This data was apportioned to Scotland by using the vehicle km reported for Europe from Eurostat and from Scotland (see Section 5.1) to obtain an estimate of the quantity of road markings applied per year. CEPE also state that 80% of road markings are applied for maintenance purposes with the remaining used for new road.

Loss rates were estimated based on further data provided by CEPE on the polymer content (16%) of thermoplastic road markings and their expected degradation rates to provide the lower estimate of emissions. The upper estimate uses the assumption that the entire particle should be classed as microplastic (which includes the fillers such as aggregates and glass beads)—this is likely to be the very upper end that is possible as there are several European countries such as Germany and the Nordics (accounting for 23% of the total vehicle km driven in Europe) that have particularly high standards for road paint use where they are typically using 50% more paint than other countries. This means that apportioning the European paint use by vehicle km may be overestimating its use in Scotland.

This was combined with understanding of the nature of the road network in Scotland and split between motorway, urban roads and rural roads due to likely differences in the wear level of road marking prior to replenishment. However, it may be possible to refine this estimate in future, as other factors such as the traffic load of roads may impact wear rate. Whilst motorways and trunk roads account for only 6% of Scotland’s road network they are estimated to bear 37% of all traffic.

The amount worn away before repainting can be estimated by using guidelines for the renewal of road markings. In the UK, the guidelines appear to vary depending upon the responsible

ibid
CEPE (2017) Micro-plastics emitted from ‘wear and tear’ of dried paints. The view of the paint industry., September 2017
Personal communication with SAR, a European manufacturer of road marking products
Department for Transport statistics (2018) Road lengths (miles) by road type and region and country in Great Britain, 2018
Strategic roads which are the responsibility of Transport Scotland rather than the local authorities.
authority. National guidance\textsuperscript{284} for highways suggests that a visual wear limit of 70\% is achieved before renewal. Several cities\textsuperscript{285,286} specify that only 30\% wear should be evident before renewal—reflecting the increased requirement for highly visible road markings in cities. There are obvious issues with this, as a subjective approach. To overcome this issue, the UK highways guidance has since been updated to use a visual scoring assessment to compare with example pictures. Nevertheless, these figures are useful indicators as to the likely wear that will occur before repainting and may even underestimate the wear with some reports suggesting the condition of road markings in Scotland to be unsatisfactory, with many in need of imminent replacement.\textsuperscript{287,288} This suggests that in Scotland, standards for road marking replacement may not have been met (the report being from 2014) and therefore more may be worn off before replacement.

The emissions of microplastics from road paints \textit{at source} are derived using the previously stated data and assumptions. This leads to an estimated emission of 99 - 911 \textbf{tonnes per year} from road paints.

<table>
<thead>
<tr>
<th><strong>In Brief</strong></th>
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<tbody>
<tr>
<td>Total microplastics generated from road markings in Scotland</td>
</tr>
<tr>
<td><strong>99 - 911 tonnes per year</strong></td>
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### 5.7 Summary of Source Emissions

Figure 10 summarises the microplastics source emissions for each of the six priority products. Most have upper and lower estimation boundaries which are dependent on the assumptions for each of the sources. For artificial turf the key assumption is the proportion of infill that needs to be replaced every year as observed in the literature. For agricultural products the key assumption is based on a range estimate by ECHA on the proportion of water insoluble content of the finished product. The range shown for road markings is due to questions over how these particles are defined—where just the polymer content is considered, the lower boundary is appropriate; where the whole particle including various filler such as aggregates and glass beads

\textsuperscript{284} The Highways Agency (2007) \textit{Inspection and Maintenance of Road Markings and Road Studs on Motorways and All-Purpose Trunk Roads}, 2007


\textsuperscript{286} London Borough of Hackney (2012) Highways Maintenance Policy

\textsuperscript{287} (2012) Road markings in Scotland are among the worst in the UK, according to a survey.

\textsuperscript{288} (2014) \textit{Highways Magazine} - \textit{Almost half of road markings in Scotland need replacing}, accessed 31 May 2019, \url{https://www.highwaysmagazine.co.uk/Almost-half-of-road-markings-in-Scotland-need-replacing/1307}
are considered, the high boundary is appropriate. The difference is a factor of ten in this instance. The ranges for fibres released from clothes washing reflects the uncertainly around release rates observed through the numerous studies on the subject. Finally, the range of fishing gear microplastic release during use is based on an indicative assumption from a previous study using a qualitative judgment — no empirical evidence is available for this, but the loss rates are unlikely to be higher (than the upper boundary of 10%) given that the ropes etc. would become unusable beyond this.

Automotive tyres do not have a range as the data for vehicle km and wear per km driven is well understood and subject to less variation—the variation and uncertainty for this source rests with the problematic nature of tyre particles as a diffuse source of microplastics once emitted from the vehicle.

Figure 10: Summary of Microplastic Source Emission Estimates for Scotland for Priority Products
6.0 Microplastics Pathways and Fates

The pathway model for Scotland is based upon the model developed for the EU report mentioned in the previous section which takes the estimates of microplastics emissions at source and estimates —through reasoned assumptions based on scientific observations— where these might end up. The full methodology is available in the EU report and the following details where the information and assumptions differ for the Scottish situation. It should be noted, that the EU study was focused on the marine environment, but there is now growing concern for the prevalence of microplastics in other environments. There are two key assumptions that affect the proportion of microplastics that enter wastewater treatment and then subsequently enter the environment; the type of wastewater treatment (primary, secondary, tertiary) and the proportion of sludge that is applied to land.

For the former we adopt the same approach as the EU study by applying the best and worst microplastic capture rates observed in the literature to primary, secondary, tertiary treatment systems. This ranges from 17% capture in the worst case primary treatment and 99.7% in the best case tertiary treatment. Using extrapolated data from 2011 suggests that 7% of treatment is tertiary, 41% is secondary and the remainder is primary or lower. Combining this with the best and worst capture ranges suggests a capture range for Scotland of 24-80% - a lower range than the one calculated for the whole of the EU (50-98%).

It is assumed that any microplastic that are captured, will be retained in sewage sludge. According to Scottish Water, 54% of sewage sludge is applied to agricultural land and a further 15% as ‘land reclamation’ —this is a broad term used for applications involving the restoration of derelict land for use as public amenity areas, forestry and agriculture. It is therefore reasonable to assume that this total (69%) will end up in or around agricultural soils of some description. The remaining 31% is predominantly sent for incineration with 0.3% sent to landfill. This differs from the UK as a whole which applies 78% of its sewage sludge to land.

From current data and understanding, several environmental accumulation zones have been identified. These are locations where a build-up of microplastics is expected, but may not

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289 Primary treatment is a physical and/or chemical process involving settlement of suspended solids. Secondary treatment is a process generally involving biological treatment designed to reduce the suspended solids and oxygen demand. It also reduces the bacterial content of sewage. Tertiary treatment is the final stage of the process and can include filtration, removal of nutrients such as phosphorous and nitrogen, and disinfection, for example by UV light. None of these processes is specifically designed to capture microplastics.


291 Scottish Water Sustainability report 2018
necessarily be the final resting place due to the complex dynamics that are not fully understood at present.

- **Agricultural soil** – microplastics arrive at this point by two pathways for the products on study; direct application through use with regard to agricultural products and, mixed in with sewage sludge from wastewater treatment. There is evidence of accumulation of microplastics as a result of these practices. It is also suspected that these microplastics could leach into waterways via run-off and soil erosion and therefore this may not be the final destination. There is no data that allows quantification of this as the proximity of waterways will play a huge part in the likelihood of this taking place.

- **Non-Agricultural soil** – This sink results from emissions of microplastics at the roadside from tyres in predominantly rural areas and from artificial turf infill as it migrates to the areas surrounding the pitch. It is likely that a proportion of the microplastics from tyres ending up in rural soils, will also be agricultural land – particles are known to travel at least 50 metres from the roadside. This also means that if waterways are close to roads, these airborne particles could land there or easily be washed into them.

- **Marine Water** – This category is for direct emissions that will only enter the marine environment and only applies to fishing gear in this study.

- **Surface Water** – This is used as the general term for the water environment with the prospect of emissions either directly (e.g. through coastal WWT outfalls) or indirectly entering into the marine environment (through river transport).

- **Residual Waste** – This sink results from several activities which includes-
  o Sewage sludge containing microplastics sent to incineration and to a much lesser extent, landfill;
  o Roadside sedimentation devices such as gully pots and settling ponds being cleaned out; and,
  o Road cleaning activities.

- **Air** – This sink is unlikely to be the final resting place, but concerns the particulate (PM) emissions associated with tyre wear. The emissions contribute to air pollution.

Figure 11 graphically shows the full pathways that were modelled for this project for all of the emission sources. In order to show all the microplastic emission sources and their accumulation zones in Figure 12, the midpoint is used between the upper and lower boundary for all results. Other sources are shown separately to tyre wear emissions and the total tyre wear emissions is so much greater than other emissions that the granularity is lost. Figure 13 shows the same results (using midpoints), but split by the accumulation zones. This demonstrates that the largest accumulation zone is expected to be soils, particularly agricultural—accounting for 63% of source emissions (between 57% - 69%). Surface waters (including direct marine emissions) are the third largest accumulation zone—accounting for 15% of source emissions (between 9% - 21%). Microplastics in residual waste account for 13% of source emissions (between 10 -25%).
Figure 11: Microplastic Pathways Modelled
7.0 Problem Analysis and Measures for Reduction

The following section identifies the key factors that relate to why the source of microplastics is a problem. This also highlights where there is a lack of knowledge or data that prevents action.

A series of options for improvement or mitigation of the problem is proposed in response to the problem analysis. This is focused on particular actions that the Scottish Government may be able to undertake either unilaterally or collaboratively with others to tackle wider systemic issues. For a full discussion of the measures proposed in brief here, see Appendix A.1.0.

Proposed options are also assessed under the following criteria to provide an initial indication of the viability of each option. These are based on expert judgement and would require a more detailed assessment to fully determine the relative costs and benefits. Each criterion is also assumed to be weighted equally and the measures are given a score of 1-5 against each criterion.

- **Effectiveness of a measure in emission reduction (1=not effective)**
  For each potential measure, the emission reduction is qualitatively assessed. For measures that do not result in a direct reduction, but are a prerequisite for further measures, the score is based on how necessary the measure is.

- **Cost-effectiveness (1=not cost effective)**
  The costs of the measures by public and private organisations as well as individuals are considered. This includes costs to business for any alternatives.

- **Feasibility (1=not feasible)**
  Technical and regulatory feasibility are considered under this criterion. If new regulation needs to be developed or if there are technical challenges yet to be overcome, a measure will have a low score on this criterion.

7.1 Automotive Tyre Wear

7.1.1 Problem Analysis

Wear from vehicle tyre treads is an inevitable effect of their use, however the degree to which tyres abrade in real-world conditions is influenced by a number of factors. These include the design of the tyres itself (including the range of compounds used in the tread), vehicle characteristics, the nature of the road surface, driving behaviour and weather. A different set of

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factors then influence the degree to which tyre wear particles become lost from roads and into the environment.

Problems which relate to the tyre itself, including its design, manufacture and use, are;

1) insufficient incentive, be it financial, regulatory, or reputational, for manufacturers to prioritise reducing tyre abrasion amongst other key performance characteristics valued by consumers such as grip in wet conditions and fuel efficiency;
2) lack of a standard test method for tyre abrasion such that tyres cannot be compared objectively, preventing informed customer choice and targeted action by regulators;
3) insufficient awareness of and information on the extent to which tyres from different manufacturers may be contributing and of what mitigating behaviours can be adopted, without which behaviour change is unlikely to occur; and
4) the prevalence of cars as the default choice for travel for many.

Problems which result in the subsequent loss of tyre-wear from the roads and into the environment include;

1) a lack of awareness of roads as pathways for microplastic emissions and knowledge of best practice for mitigation, despite the promise of various means of capture, including porous asphalt, Sustainable Urban Drainage Systems (SUDS) and optimised street cleansing regimes; and
2) insufficient financial or regulatory incentives to capture microplastics through above mentioned mechanisms:

7.1.2 Options for Measures

3) Reducing vehicle kilometres driven
   Encourage modal shift away from cars towards active travel, greater use of public transport, lift-sharing and car clubs and improvements to efficiency in freight logistics. In light of the additional co-benefit provided by such activities of reducing microplastics emissions, Scottish Government might consider increasing support and funding to such schemes, or simply incorporating the reduction of microplastic emissions within communications encouraging their uptake.

4) Increased capture at roadside
   SEPA might consider implementing a programme of trial and efficacy monitoring for a range of conventional drainage and SUDS techniques to help close the knowledge gap regarding what best practice for road drainage management would look like, with regards to microplastics emissions from tyres.

5) Engaging in development of a standard test for tyre tread abrasion
   As a devolved administration with responsibility for environment and transport, the Scottish Government may be interested in contributing its expertise to the ongoing development by the European Union and key stakeholders of a standard test for tyre tread abrasion which it is hoped will help to inform legislative control of tyre wear emissions. This may involve directing funding through its Rural Affairs, Food and the
Environment Research portfolio to address specific questions which are delaying the development of a test and approaching government authorities with responsibility for environment and transport across Europe to foster collaboration.

6) A Tax on Tyres
To cover the costs of researching and then potentially implementing the capture of microplastics through roadside drainage and street cleaning, and also to internalise some of the air quality damage costs associated with airborne tyre particles, Scottish Government could explore the introduction of a tax on tyres, potentially working with other nations to develop the case for a uniform tax to be applied at a UK level which would be preferable to unilateral implementation.

7) Producer Responsibility
There is arguably an insufficient incentive for tyre manufacturers to produce tyres that abrade at a lower rate. To counter this, Scottish Government might in future consider a form of Extended Producer Responsibility (EPR) for vehicle tyres, to make producers responsible for the post-consumer stage of their product’s life cycle including costs of end-of-life collection, sorting, treatment and eventual recycling or disposal. The fees that producers are charged can then be varied, or “modulated” based on product characteristics which are seen as desirable. In future, once a standard test for tread abrasion rate has been developed, it might be possible to use tread abrasion rate to modulate fees and, in so doing, create an incentive for tyre manufacturers to produce more durable tyres.

8) Awareness raising and encouraging driver behaviour change
Driving behaviour including the frequency and extent of acceleration, braking and cornering, are known to influence the rate of wear of tyres with most material lost during these activities. It is believed that eco-driving techniques which encourage “smooth” driving with limited braking and acceleration and reducing the weight of vehicles where possible for the sake of fuel efficiency, will also contribute to reductions in tyre wear.

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*indicates that although the measure will not itself reduce emissions of microplastics to the environment it is a prerequisite step to implementing further measures which will mitigate against emissions.

7.1.3 Monitoring and Knowledge Gaps

Tyre particles are generally more difficult to capture and positively identify than textile fibres, for example. The latest work by Plymouth University on behalf of DEFRA has developed methods for doing this in storm water effluent, WWT effluent and from airborne deposition adjacent to roadsides. These sort of sampling techniques will be important in the process of identifying key ‘hot spots’ for tyre wear deposition. These are likely to be in higher-speed urban areas – near ring-road roundabouts for example. Identifying such areas will be important in prioritising where improved roadside capture should be installed or more regularly maintained. The same sampling sites can be used to verify effectiveness after implementation.

Other key assumptions in the pathways model suggest that road sweeping and existing roadside capture (such as gully pots) already have a certain level of effectiveness at removing particles. These assumptions have not been empirically tested with regard to microplastics and therefore it may be beneficial to determine whether these mechanisms are effective, to what extent, and whether small changes could increase this – more road sweeping in certain areas or an increase in gully pot emptying for example.

7.2 Synthetic Textile Washing

7.2.1 Problem Analysis

Problem drivers relating to the nature of the clothes placed on the market are that;

1) there has been insufficient incentive, be it financial, regulatory, or reputational, for manufacturers to investigate the factors which influence the rate at which different fabrics and garments shed fibres, ultimately with a view to designing clothing and selecting fabrics in a way that reduces likelihood of loss; and
2) at present there is no standard test for method for fibre loss which is agreed upon by industry and applied consistently, which could be used to accurately identify those factors with the greatest influence and measures which would be most effective for mitigating against losses and which workshop participants suggested might also inform the development of a sustainability labelling requirement for clothing.

Problem drivers relating to washing machine design and use include;

1) a lack of consumer awareness as to the actions that can be taken to minimise the loss of synthetic fibres when washing clothing which might include choice of detergent and use of in-drum capture mechanisms. Workshop participants suggested that this is in part contributed to by a lack of awareness amongst consumer that clothing is made of plastics.

2) a lack of incentive for some manufacturers to develop capture mechanisms and knowledge of relative efficacy of mechanisms. However, the Turkish company Arçelik has recently become the first washing machine manufacturer to announce that it will be releasing a microfibre filtration system for integration into a new line of its washing machines.

7.2.2 Options for Measures

There is limited opportunity for Scottish Government to influence those problems which relate to either the design of clothing or washing machines, given that there is insufficient information available to identify those design features or mitigation measures which would be most effective in reducing microfibre loss rates and capturing fibres once released. The measures below relate to funding for research that is needed to support efforts to mitigate releases. It should be noted that UK Research and Innovation is currently exploring funding priorities for addressing microfibre emissions from the washing of clothing and so Scottish Government should coordinate with UKRI to avoid duplication of effort.

1) **Fund research to identify factors contributing to shedding and microfibre characterisation**

Once a standard test is developed, a large body of work will be needed to accurately identify those key factors related to textile construction and condition (e.g. extent of previous use) which are driving microfibre losses across fabric structures. Scottish Government might consider offering funding through its Rural Affairs, Food and the

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Environment Research portfolio for research into said factors contingent on the use of
the standardised test method.

2) **Support the Setting of a Maximum Threshold for fibre shedding from fabrics**
In the 2018 EU ‘Plastics Strategy’ the European Commission committed to examining
possible minimum requirements related to fibre shedding during the washing of textiles.
This might involve determining a fibre release range for various fabrics and create a
threshold that removes the worst performing products from sale. It is unknown whether
any such minimum requirements will be taken forward, but Scottish Government could
consider engaging with industry and policy makers at a European level to support
development of such a measure.

3) **Support the development of labelling at a European level for microplastic emissions**
In the 2018 ‘Plastics Strategy,’ the European Commission committed to examining
minimum requirements for information requirement, such as labelling if appropriate.
Such a label might take the form of a sewn-in label containing washing and user
guidance. Alternatively, it might take the form of a removable label providing a
microfibre emissions rating to influence buying decisions. Workshop participants
suggested that any future labelling requirement for clothing could require inclusion of a
broader range of environmental and social sustainability information, such as carbon
impacts, water use and social impacts. It is unclear whether any such labelling
requirement will be taken forward, but Scottish Government could consider engaging
with industry and policy makers at a European level to support development of a
labelling requirements.

4) **Washing Machine Filter testing and development**
Once a standard test for absolute fibre losses from domestic washing is available, fund
independent research to confirm the efficacy of washing machine filters to understand
how these could contribute to eliminating emissions to the environment of fibres across
all size classes.

5) **Research into Shedding via abrasion during use**
Fund collaborative research to begin the design of a standard test for the emission of
microfibres from the abrasion of textiles e.g. fibres being emitted during normal use of
clothes. This research might extend to carpets and other indoor soft furnishings.

6) **Research into Supply Chain losses**
Fund research focused at quantifying loss rates of microfibres from key points along the
textile production supply chain, so as to identify hotspots where mitigative action could
be focused. In future, funding could then be targets to develop solutions to microfibre
emissions along the supply chain.
Figure 15: Assessment of Options for Synthetic Textiles

*indicates that although the measure will not itself reduce emissions of microplastics to the environment it is a prerequisite step to implementing further measures which will mitigate against emissions.

7.2.3 Monitoring and Knowledge Gaps

As fibres are ubiquitous in the environment, it is likely that it may take several years or even decades before any mitigation measures are seen to be effective by monitoring environmental concentrations. In the case of washing textiles, the logical choice for determining whether reduction measures have been successful is in the influent of a waste water treatment plant. Monitoring influent and effluent and sludge is also key to understanding the effectiveness of WWT at capturing microplastics and therefore whether there should be further measures to protect agricultural land from the microplastics in sludge. Monitoring of agricultural land microplastic concentrations may also be worthwhile – this is discussed further in relation to agricultural products in Section 7.3.3.

The ubiquitous nature of fibres also suggests that WWT is not the only pathway to the environment. Atmospheric deposition of fibres is an emerging area of study and the exact mechanisms and pathways are yet to be understood. Whether this is a greater source (by mass) is unclear, but there does appear to be greater potential for wider dispersal. The concentration of fibres in the air may be concerning from a health point of view (via inhalation, particularly in buildings) but evidence for this is limited at present.
7.3 Agricultural Products

7.3.1 Problem Analysis

Problems which relate to Controlled Release Fertilisers and Plant Protection Products (PPPs) are:

1) a lack of equally-effective alternatives to synthetic polymers that will degrade slowly in soils over a period of up to 18 months to allow gradual release;
2) a lack of incentive to develop alternatives to synthetic polymers for Controlled Release of fertilisers and PPPs.299

A problem common to both Fertiliser Additives and Seed Coatings is that:

3) Growers have poor visibility of the contents of their fertilisers and seed treatments outside of the concentration of the active ingredients. There is therefore low awareness of whether they are applying polymers to soils in using synthetic fertilisers and seed treatments.

Problems which relate to Fertiliser Additives are:

4) Lack of awareness of whether additives contain synthetic polymers and of non-synthetic polymer alternatives; and
5) Lack of incentive to adopt non-synthetic polymer containing additives over polymer-containing additives, despite the availability of such alternatives.

Problems which relate to seed coatings are:

6) Farmers are buying coated seeds where growing, storing and planting may be advantageous;
7) Lack of awareness of whether seed coatings contain synthetic polymers; and
8) Lack of incentive for seed coating producers to develop alternatives to synthetic polymers for seed coatings.

7.3.2 Options for measures

1) Undertake further problem definition and evaluation of the need for polymer use in Scottish agriculture in collaboration with industry

As was explained in Section 5.4, there are some uncertainties surrounding the use of polymers in Scottish agriculture, with both manufacturers and growers unaware of whether the products they are marketing and applying contain synthetic polymers. Additionally, some stakeholders consulted as part of this study suggested that polymers are being used unnecessarily in some instances. Further investigation in collaboration with all relevant stakeholders (e.g. growers, agri-product distributors, manufacturers,

299 See detail in Appendix 1 about new fertiliser biodegradability requirements.
polymer ingredient manufacturers) to develop a clearer picture of the extent of use and necessity of polymers in agricultural applications would be valuable in designing responses. Remaining knowledge gaps should not, however, necessarily be seen as a reason not to adopt mitigating solutions such as those outlined below.

2) **Align with new EU rules for CRFs taking faster action where feasible**

Following Brexit, Scottish Government could align its regulation of fertilisers with the amended rules for those placing fertilisers on the EU market which the European Council recently adopted which will, amongst other provisions, require that by seven years after the date of entry into force polymers used for the coatings of CRFs meet biodegradability criteria. Additionally, Scottish Government may wish to go further than the requirements of the European Regulation and evaluate whether specific applications or types of Controlled Release Fertilisers can feasibly and cost-effectively be switched to biodegradable alternatives sooner than 2026.

3) **Require labelling of biodegradability of CRF coatings**

As was explained in Sections 5.4 and 7.3.1, due to the nature of the supply chains of fertilisers, both manufacturers and growers can be unaware of exactly the composition of products they are marketing and applying. In advance of 2026 when it is expected that all CRFs will have to have transitioned to biodegradable polymers, Scottish Government could consider requiring that all CRF products are labelled with whether they are using biodegradable or non-biodegradable polymers for their coatings. Such labelling would therefore provide growers with the product information required to motivate an earlier switch to biodegradable CRFs. This might also motivate faster efforts by manufacturers to transition to biodegradable coatings.

4) **Legislate to implement biodegradability requirements for other agricultural products taking faster action than the EU where feasible**

This measure would be complementary to Option 2. The European Chemical Agency’s (ECHA) proposed restriction of intentionally-added microplastics in Controlled Release PPPs, treated seeds and fertiliser additive products is based upon harmonisation of new requirements for biodegradability of controlled-release fertiliser coatings such that it covers all fertilising product, PPS and treated seeds placed on the internal market. Scottish Government could monitor the development of ECHA’s proposal as it goes through public consultation and review by the European Commission, with the intention

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of implementing legislation that would apply biodegradability criteria to CRPPPs and treated seeds. If adopted, Scottish Government might also wish to go further than the requirements of the European Regulation and evaluate whether specific applications or types of CRPPPs, treated seeds and fertiliser additive products can be switched to biodegradable alternatives sooner than 5 years after the entry into force of ECHA’s proposed REACH Restriction.

5) Implementing a more immediate restriction (less than 3 years) on Fertiliser Additives

There is a lack of awareness of, and incentive to adopt, non-synthetic polymer alternatives to fertiliser despite their commercial availability. The ECHA does not provide detail based on its call for evidence to industry of what length of transitional period, if any, would be required for the development of alternatives which would not reply on non-degradable polymers, given that multiple companies appear to be marketing alternative precipitated silica-based non-synthetic polymer anti-caking agents. As such, in consultation with the industry, Scottish Government might decide to bring forward a restriction of synthetic polymer-containing anti-caking agents. Scottish Government would likely need to consult industry in greater detail before making any decision to bring forward a restriction of synthetic polymer-containing anti-caking agents, undertaking a more in-depth case-by-case investigation of the feasibility and associated costs for each specific application. This is in the context of stakeholders reporting that polymer and non-polymer agents are not entirely comparable due to their having different modes of action which makes each preferable in certain circumstances.

6) Encourage less reliance on polymer-containing agricultural products

The above measures have focused on promoting changes to the formulation of inorganic fertilisers, PPPs and treated seeds. A complimentary set of measures could encourage less reliance on synthetic polymer-containing agricultural products through reducing use of inorganic pesticides and fertilisers.

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*indicates that although the measure will not itself reduce emissions of microplastics to the environment it is a prerequisite step to implementing further measures which will mitigate against emissions.

### 7.3.3 Monitoring and Knowledge Gaps

As the majority of proposed options focus on the move towards alternative approaches, monitoring of environmental concentrations of microplastics from this source would not be required. There are two exceptions to this: firstly, before implementation of any options it may be appropriate to conduct sampling of agricultural soil to determine the concentrations of microplastics in the soil that are derived from this source. In this case, identifying suitable sites that use such products, but are not subject to any other sources of microplastic will be important here – examples include sewage sludge or industrial compost/digestate which are both known to contain plastic fragments. As part of the research, sites should also be identified which only apply sewage sludge or industrial compost/digestate. Measuring the concentrations of microplastics over time from these three sources would be helpful in identifying where action is most required.

It should be noted that the current modelling suggests that around 160 tonnes of microplastic is applied to agricultural land in sludge. This is compared with between 334 and 2,316 tonnes from agricultural products. Determining whether the concentrations in soil reflect these estimates would be a useful exercise.

Microplastics in compost/digestate is out of scope of this project and is an ongoing issue for composters and worthy of further investigation in its own right.
7.4 Artificial Turf and Equestrian Surfaces

7.4.1 Artificial Turf

7.4.1.1 Problem Analysis

Problem drivers relating to artificial turf can be summarised as follows:

1) Insufficient incentive for pitch operators/specifiers to implement best practice measures or specify these in new procurement contracts
2) Insufficient incentive upon installers and/or manufacturers of artificial sports to design-in best practice measures: This is driven by the lack of pull from pitch specifiers.
3) Insufficient incentive for pitch operators to use alternative infill material
4) Lack of data on loss pathways and exact amounts lost from pitches annually

7.4.1.2 Options for Measures

As the football pitches in Scotland are designed and built in Scotland there is a great deal of scope to regulate this to mandate that all current and/or subsequent pitches are required to install infill loss mitigation measures.

- **Implementing Mandatory Infill Loss Mitigation**
  This option mirrors the legislation currently being enacted in Norway. This will have greater impact if the implementation period for existing installations is shorter.

- **Provide Guidance for Public Procurement**
  As the majority of pitches are procured by Local Authorities, there is potential to provide specific guidance to procurement teams on minimum requirements for specifications on mitigation measures.

- **Banning Synthetic Infill**
  This currently has two barriers; cost and performance. Natural alternatives can be problematic in colder or wetter climates – suitable alternatives are being developed, but the low cost of SBR means there is a lack of market demand. Infill is also an important recycling route for tyres at present which would require an alternative use to be developed. Landfilling is not an option and incineration is generally only performed in cement kilns.
7.4.1.3 Monitoring and Knowledge Gaps

As identified in the problem analysis, no mass balance has been undertaken which determines exactly how much infill is lost annually and where it goes. It is debatable whether this is required in order to justify action as the migration of infill to the surrounding areas of a pitch is self-evident and well documented. Determining the effectiveness of measures would potentially be a valid exercise. This would mean developing a test procedure for collecting infill that has migrated away from the pitch via the various mechanisms already identified. This could be employed at several pitches before and after measures have been put in place. A further benefit of this could be to determine whether captured infill could be reapplied to the pitch. This, combined with the infill that is prevented from migrating off the pitch may go some way to mitigating the lifetime costs of improvements.

7.4.2 Equestrian Surfaces

7.4.2.1 Problem Analysis

The potential for synthetic surfaces from equestrian facilities to contribute to the problem of microplastics has only been recently identified. Factors which contribute to this issue are outlined below:

1) There is an absence of data/information on loss of the material;
2) There is an absence of data on the number and size of facilities in Scotland;
3) Artificial surfaces are considered superior to natural surfaces by equestrian surface owners;
4) Artificial surfaces are low cost compared to alternatives’ and
5) There are no legal restrictions on use of waste carpets and tyres as surfaces.

7.4.2.2 Options for Measures

There is some capacity for Scottish Government to influence both the state of knowledge around loss from equestrian surfaces, and loss itself.
• **Developing the State of Knowledge**
  There are a significant number of unknowns at present regarding release of microplastics from equestrian surfaces. Developing the state of knowledge could look to address these gaps and could potentially be achieved through collaboration with other countries who have significant equestrian industries,

• **Awareness Raising Measures**
  At present, there is low awareness around the issue of release of microplastics from equestrian facilities. Awareness raising measures could be used to initiate engagement with the industry around the issue and to make facility owners aware of the potential problems.

• **Developing and Implementing Best Practice Guidelines**
  In the context of artificial turf, some facilities have implemented measures to minimise loss of rubber chip, whilst maintaining the functionality of the surface. Given the similarities between the two issues, some of these recommendations may be transferable to equestrian facilities.

• **Restricting the Use of Tyre Derived Rubber and Carpet**
  Whilst the state of knowledge is lacking at present, this could be considered in future. The tyre recycling industry is also much less reliant on this option and therefore it would be easier to implement.

**Figure 18: Assessment of Options for Equestrian Surfaces**

*indicates that although the measure will not itself reduce emissions of microplastics to the environment it is a prerequisite step to implementing further measures which will mitigate against emissions.

**7.4.2.3 Monitoring and Knowledge Gaps**

The same procedures for monitoring artificial turf are likely to apply to equestrian surfaces. Currently, there has been no work to determine loss rates or pathways, therefore this is the first step towards monitoring the situation.
7.5 Fishing Gear

7.5.1 Problem Analysis

Problem drivers relating to fishing gear can be summarised as follows:

1) **Absence of key data sources on the use of fishing gear and the microplastic loss rates:** The assumptions in this study are based on very limited data on both the usage of fishing gear in Scotland and the amount of microplastics that are generated and lost during use.

2) **Lack of alternatives or known best practice:** There is a lack of understanding around whether there are any better alternative materials or types of polymer than are less likely to produce microplastics. This leads on to the problem that there is therefore no recommended best practice for mitigation.

7.5.2 Options for Measures

Although there has been a large focus on lost fishing gear and its contribution to both macro and microplastic pollution, there has been significantly less work on the microplastic generation during use. There are three key pieces of information that are necessary to quantify the problem and begin to understand whether there are effective measures that can be put in place;

- **Put monitoring in place for the use of fishing gear and replacement**
  The issue of use data has been an ongoing problem for some time; with the best data on fishing gear usage usually coming from a well-managed EPR scheme (such as the one in Iceland). However, this is due to be improved in future as Marine Scotland will be publishing a study on the subject in 2020.

- **Research funding for fishing gear wear testing to determine the quantity and nature of losses**
  Whilst large pieces of fishing gear are known to break off during use, the nature of smaller microplastic wear and tear is not well understood. Field research would need to be carried out to determine how much is lost through wear with the experiments designed to isolate this from macro-sized losses - this would also help with the understanding of which materials/constructions are more or less prone to wear.

- **Research and development funding for materials/designs that shed less**
  Whether different materials/constructions used in fishing activities are more prone to wear.

7.5.3 Monitoring and Knowledge Gaps

Monitoring of microplastics sources that end up directly in the marine environment is practically impossible. If there are developments in fishing gear materials that release fewer microplastics over their lifetime, the best way to monitor this is to determine the loss rates of the current gear in comparison. A certification scheme could be implemented to make sure that the gear of the highest standard is always used. At present this is not something that can be implemented.
7.6 Road Markings

7.6.1 Problem Analysis

The problem drivers in respect of road markings can broadly be divided into problems that relate to the road markings itself, and those that relate to the drainage infrastructure and the nature and frequency of street cleansing. Problem drivers relating to road markings can be summarised as follows:

1) Insufficient knowledge of the nature of road marking microplastics, where they are found, and in what quantities;
2) Insufficient knowledge of the rate of wear of alternative marking types to inform purchasing decisions;
3) Inconsistent specification of the functional life required of road markings in contracts for procurement and application;
4) Poor programming of surfacing works such that markings are applied in colder and wetter months when they are less likely to adhere;
5) The poor condition of the existing road surfaces which affected bonding of markings;
6) Insufficient technical knowledge within buying authorities which prevents informed procurement decisions from being made;
7) Financial constraints on road authorities such that price and quality are not always suitability balanced; and,
8) Insufficient financial or regulatory incentives to capture microplastics through roadside capture given that the environmental science community’s recognition of roads as pathways/sources of microplastics is comparatively recent and as such there has been relatively little pressure on local authorities to mitigate against loss of microplastics from the road environment.

7.6.2 Options for Measures

The following options are proposed;

1) Funding primary research into road marking wear processes, products and flows

Given that estimates for emissions of particles through the wear of road markings are largely theoretical, and the resulting particles have rarely been sampled and identified in the environment, primary research to define the nature of road marking particles is needed. This research could also define the dominant mode of wear (e.g. weathering vs. abrasion) and begin to establish the pathways that particles take from the road environment.

2) Funding primary research into relative durability of road marking products

One key area which requires further investigation is the performance from a wear perspective of the variety of road marking products available on the market. The RSMA reported that while contractors are aware of the relative performance of different broad categories of marking, the lack of a road trial site in the UK where different markings could be comparably tested means that well-informed purchasing decisions cannot
easily be made by non-experts such as buying authorities. If comparable performance
data were collected on road marking products then the RSMA suggested this could feed
into a contractor-facing database, or alternatively a rating system.

3) **Encourage or mandate use of procurement and end-product performance
requirements linked to payment schedules**

The Irish National Roads Authority uses a performance-based specification whereby they
set challenging requirements for reflectivity, adhesion/durability, skid resistance,
luminance and quality of colour, as well as specifying certain conditions under which
application must occur, such as favourable weather/climatic conditions. The payment
schedule for works completed is then linked to achieving these performance outcomes
such that contractors only receive full payment after it is demonstrated that key
performance characteristics are maintained after 3 years. They report that this
procurement framework results in contractors placing greater emphasis on the quality of
application procedures, with subsequent improved durability of markings. The
effectiveness of this measure would likely be improved in combined with contractors
having access to comparable performance information for road markings products which
would be produced through the above measure. The Road Safety Markings Association is
supportive of this procurement approach, subject to some considerations detailed in
Appendix A.1.6.2.

4) **Increased capture at roadside and reducing vehicle kilometres driven**

Options 4 and 5 for reducing tyre wear emissions are also applicable to road paint (see
Section 7.1.2). They have similar pathways through storm water and a reduction in
driving will also mean that the paint will wear away more slowly. Transport Scotland and
SEPA could collaborate to co-locate a road test trial site for road markings with tests of
different drainage infrastructure for capturing road environment microplastics to make
better use of resources, and to share knowledge.
**7.6.3 Monitoring and Knowledge Gaps**

Literature review and consultation with the RSMA highlighted a number of knowledge gaps related to road marking adhesion/durability, including:

- A lack of understanding as to the relative importance of the following factors in influencing the bonding performance of TRMs:
  - road marking thickness, with a view to potentially defining a minimum thickness,
  - surface characteristics, e.g. positive and negative textures, road surface material; and
  - moisture and temperature conditions at the time of application including understanding what the critical temperature ranges are outside of which subsequent performance will suffer.

- A lack of understanding of the influence of manual versus mechanical application on performance in terms of the bonding strength of TRMs.

- The potential to increase understanding regarding how different types of road marking material and application method (solvent, thermoplastic or cold plastic etc.) are likely to perform better from a wear perspective; and
a lack of understanding as to whether areas exposed to heavy snowfall and salt operations could potentially be exposed to more aggressive abrasive action, and how this would influence road marking abrasion.

Further detail is provided in Appendix A.1.6.3.
A.1.0 Appendix 1 – Detail on Problem Analysis and Measures

A.1.1 Automotive Tyre Wear

A.1.1.1 Problem Analysis

Wear from vehicle tyre treads is an inevitable effect of their use, however the degree to which tyres abrade in real-world conditions is influenced by a number of factors. These include the design of the tyres itself (including the range of compounds used in the tread), vehicle characteristics, the nature of the road surface, driving behaviour and weather. A different set of factors then influence the degree to which tyre wear particles become lost from roads and into the environment.

Problems which relate to the tyre itself, including its design and use, are;

1) **Insufficient incentive to produce tyres with lower abrasion rates**: There is an insufficient incentive, be it financial, regulatory, or reputational, for manufacturers to prioritise reducing tyre abrasion amongst other key performance characteristics valued by consumers such as grip in wet conditions and fuel efficiency.

2) **Lack of a standard test method for tyre abrasion**: There is currently no standard test method for tyre abrasion such that tyres cannot be compared objectively to provide customers with robust information to make a decision based upon. Additionally, this means that regulators cannot accurately identify the worst performing tyres from a wear perspective. The lack of a standard test is underlaid in part by the complexity of the tyre wear phenomenon, including the range of factors which influence it.

3) **Insufficient information to encourage behavioural change**: There is a lack of awareness among consumers of the problem of tyre-wear derived microplastic pollution, of the extent to which tyres from different manufacturers may be contributing and of what mitigative behaviours can be adopted. Behaviour change is unlikely to occur without clear and accurate information.

4) **The prevalence of cars as the default choice for travel**

   It was highlighted by participants in the workshop that driving remains the default means of travel for many, and this is in part a result of the dispersed nature of urban areas especially in more rural areas of Scotland such that personal car use is essential in some areas. Participants also highlighted the lack of other options/alternative travel

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infrastructure as motivating the decision to drive. Despite the contribution of a suite of vision documents, strategies and policies supporting active travel, public transport, lift-sharing and car clubs in Scotland, these all acknowledge the existing further scope for improvement in shifting people out of cars and towards public transport and active travel.

Problems which result in the subsequent loss of tyre-wear from the roads and into the environment include;

1) A lack of awareness of roads as pathways for microplastic emissions and knowledge of best practice for mitigation: Despite the promise of various means of capture, including porous asphalt, Sustainable Urban Drainage Systems (SUDS) and optimised street cleansing regimes, there is a lack of awareness of them, their relative effectiveness in capturing microplastics, and of what combination of techniques ‘best practice’ would look like.

2) Insufficient financial or regulatory incentives to capture microplastics through above mentioned mechanisms: The environmental science community’s recognition of roads as pathways/sources of microplastics is comparatively recent and as such there has been relatively little pressure on local authorities to mitigate against loss of microplastics from the road environment. Awareness is however growing, as environmental NGOs bring attention to the issue, and the UK government funds research into the factors underlying emissions from the road environment. There remains however, no financial or regulatory incentive to target the capture of microplastics through the abovementioned mechanisms.

### A.1.1.2 Options for Measures

Overall, there is only limited opportunity for Scottish Government to influence those problems which relate to the tyre itself given that there is insufficient information available to effectively legislate against the most-polluting tyres or to demonstrate best practice through public sector green procurement, due to the lack of a standard test for abrasion. Given this, those problems relating to the use of the tyre, and those resulting in the loss of tyre-wear from the roads and into the environment, are more amenable to being influenced by Scottish Government.

Areas where Scottish Government could focus its attention to minimise the release of tyre-derived microplastics and the harm they subsequently cause are;

- awareness raising and driving behaviour change;
- engaging in development of a standard test for tyre tread abrasion;
- Extended Producer Responsibility for tyres;
- capture at roadside; and
- reducing vehicle kilometres driven.
Option 1: Reducing vehicle kilometres driven

Alongside changes to the tyre itself, the conditions it operates under as a result of driver behaviour and the capture of emissions subsequent to release, simply reducing the vehicle kilometres driven will reduce emissions of microplastics from tyres. A complimentary set of measures could encourage modal shift away from cars towards active travel, greater use of public transport, lift-sharing and car clubs and improvements to efficiency in freight logistics.

We are aware that Scottish Government already has a suite of policies targeting such outcomes including:

- for active travel, the 2030 Vision\textsuperscript{305}, National Walking Strategy,\textsuperscript{306} and 2017-2020 Cycling Action Plan for Scotland\textsuperscript{307},
- for Public Transport, a range of grant funding for bus fleet and driver training administered by Transport Scotland;
- for lift sharing/car clubs, the Travel Know How Scotland website which signposts citizens to relevant groups via the Regional Transport Partnerships,\textsuperscript{308} and
- for freight optimisation, a range of grants incentivising a switch from road freight to waterborne and rail, and the Freight and Logistics Advisory Group which engages with relevant industry to increase efficiency.\textsuperscript{309}

Despite this, there is likely scope for improvement across all these areas and so Scottish Government might consider, in light of the additional co-benefit provided by such activities of reducing microplastics emissions, increasing support and funding to such schemes, or simply incorporating the reduction of microplastic emissions within communications encouraging the uptake of modal shift, use of public transport and car clubs and involvement of relevant industry in freight efficiency schemes.

Option 2: Increased capture at roadside

Microplastics emissions from tyres occur across a range of road types covering motorways and the trunk network, managed by Transport Scotland, and the local road network, managed by councils, and within a range of environments including urban, industrial and rural areas with a variety of drainage management regimes exercised across these road types. The effectiveness of

\textsuperscript{305} Transport Scotland (2030) A long-term vision for active travel in Scotland 2030, p.16
\textsuperscript{306} Let’s Get Scotland Walking: The National Walking Strategy, p.26
\textsuperscript{308} Travel Know How / Regional Transport Partnerships, accessed 9 July 2019, https://www.travelknowhowscotland.co.uk/pages/view/regional-transport-partnerships
the capture of suspended particles of various methods of run-off treatment applied across these road types is a key consideration.

Swales, infiltration basins, wetlands, sedimentation ponds are all common methods used near roads to manage run-off and reduce pollutants entering water courses as part of sustainable drainage systems (SuDS). This also includes microplastics (under the guise of ‘suspended solids’), although this is rarely their specific intended purpose. Data on their effectiveness is sparse, particularly so for microplastic particles.

We note that as part of its Tyre Sector Plan, SEPA has committed to work with other public bodies to investigate and promote source, site and regional SUDS that remove microplastics from runoff. 310

Alongside this SEPA might consider implementing a programme of trial and efficacy monitoring for a range of conventional drainage, road cleaning and SUDS techniques to help close the knowledge gap regarding what best practice for road drainage management would look like, with regards to microplastics emissions from tyres.

Workshop participants noted that possible unintended consequences of increased microplastic emissions from abrasion of the road surface or brushes through use of road sweepers as a capture mechanism would be need to be avoided.

Option 3: Engaging in development of a standard test for tyre tread abrasion

As a devolved administration with responsibility for environment and transport, the Scottish Government may be interested in contributing its expertise to the ongoing development by the European Union and key stakeholders of a standard test for tyre tread abrasion which it is hoped will help to inform legislative control of tyre wear emissions. As announced in the EU Plastics Strategy, this might involve minimum requirements for tyre design and/or labelling (i.e. through the European Tyre Labelling Regulations). The European Tyre and Rim Technical Organisation (ETRTO) which, in dialogue with the European Commission, is exploring the feasibility of developing an accurate, reliable and reproducible standard test method for measuring tyre abrasion rate. It is our understanding that the ETRTO is due to report to the Commission on its feasibility assessment in the coming months, and that for the moment this exploratory work is focused on passenger car tyres with the intention to address other tyre types at a later date.

It is debatable whether a consortium of large manufacturers will be able to independently come to a consensus on a standard approach to measurement of abrasion given that different approaches to measurement will favour each. As such, Scottish Government / SEPA may wish to contribute its resources to help expedite the development of a standard test. This may involve directing funding through its Rural Affairs, Food and the Environment Research portfolio to address specific questions which are delaying the development of a test and approaching government authorities with responsibility for environment and transport across Europe to

foster collaboration. It should be noted that once the ETRTO have published their feasibility study into standard test development there will be greater clarity as to exactly what technical barriers research can be directed at to help expediate the development of a standard test.

Although this measure will not lead in itself to a reduction in emissions, development of a standard test is a prerequisite to numerous other potential policy options as well as assessing the potential efficacy of new material science technologies.

**Option 4: A Tax on Tyres**

The testing and monitoring of means of capturing microplastics generated on roads outlined in Option 4 will likely require some significant investment and ongoing costs. To cover these costs, and also to internalise some of the air quality damage costs associated with airborne tyre particles, Scottish Government could explore the introduction of a tax on tyres, potentially working with other nations to develop the case for a uniform tax to be applied at a UK level. If implemented unilaterally by Scotland, then a concern might be that consumers would travel to England to buy tyres on which a tax is not imposed. If the rate of tax were set at a relatively low level to start with in order to avoid this risk, then Scottish Government could steadily raise the rate of tax and monitor receipts over time to gauge whether consumers are travelling to England to purchase tyres there as the tax increases. However, it would be preferable to have a UK-wide tax.

**Option 5: Producer Responsibility**

As mentioned in the problem analysis, there is insufficient incentive for tyre manufacturers to produce tyres that abrade at a lower rate. To counter this, Scottish Government might consider a form of Extended Producer Responsibility (EPR) for vehicle tyres. EPR makes producers responsible for the post-consumer stage of their product’s life cycle including costs of end-of-life collection, sorting, treatment and eventual recycling or disposal. The fees that producers are charged can then be varied, or “modulated” based product characteristics which are seen as desirable. In future, once a standard test for tread abrasion rate has been developed, it might be possible to use tread abrasion rate to modulate fees and, in so doing, create an incentive for tyre manufacturers to produce more durable tyres.

Such a measure, might however prove redundant if the European Commission choses to adopt a rating for tread abrasion for inclusion in the Tyre Label, and remove tyres that abrade at the highest rates from the market under the Type Approval Regulations for Tyres.

We are aware that SEPA and Zero Waste Scotland are supporting Scottish Government’s review of Scotland’s approach to producer responsibility for tyres.\(^{311}\)

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\(^{311}\) *Tyre sector plan* | Scottish Environment Protection Agency (SEPA), accessed 8 July 2019, [https://sectors.sepa.org.uk/tyre-sector-plan/](https://sectors.sepa.org.uk/tyre-sector-plan/)
Option 6: Awareness raising and encouraging driver behaviour change

Driving behaviour including the frequency and extent of acceleration, braking and cornering, are known to influence the rate of wear of tyres with most material lost during these activities.\(^{312}\) It is believed that eco-driving techniques which encourage “smooth” driving with limited braking and acceleration and reducing the weight of vehicles where possible for the sake of fuel efficiency, will also contribute to reductions in tyre wear.\(^{313}\)

We are aware that Scotland’s third report on the proposals and policies of its 2018-2032 Climate Change Plan contains a policy to support fuel efficient driving, referencing government support to the Energy Saving Trust in training drivers in eco-driving techniques and states that behaviour change will be a major driver of success in achieving emissions reductions targets.\(^{314}\) Scottish Government might consider, in light of the additional benefit of reducing microplastics emissions, increasing support given for eco-driving schemes, or simply incorporating the reducing of microplastic emissions within communication materials encouraging the uptake of eco-driving techniques.

Additionally, another area in which effort is being made is in improving consumer stewardship of tyres after purchase which delivers benefits in terms of fuel efficiency with co-benefits for reduced tyre wear.

Alongside ongoing efforts of those seeking to reduce the number of tyre-related traffic incidents which result from poorly-maintained tyres such as the industry-funded tyre safety charity, Tyre Safe, some companies have developed innovative infrastructure targeting HGVs with underinflated tyres. WheelRight produces drive-over tyre pressure monitoring systems which uses ground-level sensors that transmit data directly to drivers via SMS or on-site touch-screen kiosk, or the maintenance staff of transport-operators at depots. Highways England and Welcome Break have collaborated on a year-long trial of this system in Keele Services on the southbound M6 motorway in 2016, and are now conducting further year-long trials with a number of commercial HGV fleet operators. Transport Scotland could conduct similar trials with fleet operators in Scotland.

A.1.1.3 Monitoring and Knowledge Gaps

Tyre particles are generally more difficult to capture and positively identify than textile fibres, for example. The latest work by Plymouth University on behalf of DEFRA has perfected methods for doing this in storm water effluent, WWT effluent and from airborne deposition adjacent to roadsides. These sort of sampling techniques will be important in the process of identifying key ‘hot spots’ for tyre wear deposition. These are likely to be in higher-speed urban areas – near

\(^{312}\) Boulter, P. (2005) A review of emission factors and models for road vehicle non-exhaust particulate matter

\(^{313}\) European Tyre and Rubber Manufacturers Association *Tyre and Road Wear*, accessed 9 July 2019, https://www.tyreandroadwear.com/

ring-road roundabouts for example. Identifying such areas will be important in prioritising where improved roadside capture should be installed or more regularly maintained. The same sampling sites can be used to verify effectiveness after implementation.

Other key assumptions in the pathways model suggest that road sweeping and existing roadside capture (such as gully pots) already have a certain level of effectiveness at removing particles. These assumptions have not been empirically tested with regard to microplastics and therefore it may be beneficial to determine whether these mechanisms are effective, to what extent, and whether small changes could increase this – more road sweeping in certain areas or an increase in gully pot emptying for example.

A.1.2 Synthetic Textile Washing

A.1.2.1 Problem Analysis

Problem drivers relating to the nature of the clothes placed on the market are;

1) **Lack of incentive to produce and sell clothing which sheds fewer fibres and relative contribution of different factors:** There is insufficient incentive, be it financial, regulatory, or reputational, for manufacturers to investigate the factors which influence the rate at which different fabrics and garments shed fibres, ultimately with a view to designing clothing and selecting fabrics in a way that reduces likelihood of loss.

2) **Lack of a standard test for fibre loss:** At present there is no test method for rates of fibre loss which is agreed upon by industry and applied consistently, which could be used to accurately identify those factors with the greatest influence. This makes targeting problematic materials and construction types impossible. Knowledge of such factors would produce consensus on what material types or construction methods should be the targets of regulatory, financial or reputational pressure. Additionally, the lack of standard test inhibits identification of the most effective measures for mitigating against losses (covered below). Despite this, work is underway to develop a standard testing after, in January 2018, five European textiles industry associations signed an agreement to collaboratively tackle the issue of synthetic microfibre emissions throughout the lifecycle of textiles, including through the development of common measurement methods. Consultation with participating partners in the CIA standard test development process suggested that it might take between 8 and 12 months for the remaining parameters to be agreed upon given that work is already ongoing to address

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315 The European Textile and Apparel Confederation (EURATEX), the International Association for Soaps, Detergents and Maintenance Products (A.I.S.E.), the European Outdoor Group (EOG), the European Man Made Fibres Association (CIRFS) and the Federation of European Sporting Goods Industry (FESI).

them. Additionally, the Microfibre Consortium, an industry membership organisation, is currently in the process of facilitating the development of a standard industry test method in collaboration with the University of Leeds, the only UK-based research institution participating in the CIA. Representatives from the School of Design having attended technical meetings since the group’s inception and contributed to the development of the standard test.

Problem drivers relating to washing machine design and use can be summarised as follows:

1) **Lack of awareness of mitigative practices**: The link between the washing of synthetic clothing and the shedding of fibres into domestic drains was only made in 2011, and though public attention given to synthetic fibre losses has grown significantly since then there remains a lack of consumer awareness as to the actions that can be taken to minimise the loss of synthetic fibres when washing clothing. Such mitigative measures include choice of detergent and use of in-drum capture mechanisms.

2) **Lack of incentive for some manufacturers to develop capture mechanisms and knowledge of relative efficacy of mechanisms**: Another problem driver for synthetic fibre release is the lack of sufficient financial, regulatory or reputational incentive for washing machine manufacturers to develop methods to capture synthetic fibres. However, the Turkish company Arçelik has recently become the first washing machine manufacturer to announce that it will be releasing a microfibre filtration system for integration into a new line of its washing machines. Alternatively, filters can be external with their own power supply. Greater exploration of the use of filters to trap microfibre release in household washing machines by the manufactures themselves would likely hasten wider use of such technologies.

**A.1.2.2 Options for Measures**

There is limited opportunity for Scottish Government to influence those problems which relate to either the design of clothing or washing machines, given that there is insufficient information...
available to identify those design features or mitigation measures which would be most effective in reducing microfibre loss rates and capturing fibres once released. Once a standard test is developed, there will be greater scope to take action such as discouraging problematic materials, washing products or fabric construction types, or encourage incorporation of abatement technologies by washing machine manufacturers.

**Option 1: Identification of contributing factors and microfibre characterisation**

As mentioned in Section 7.2.1, those involved in the development of a standard test for fibre loss rates at a European level believe that it will be finalised by between March and July 2020. As such, it is unlikely that Scottish Government can do much to speed the development of this test. Once a standard test is developed however, a large body of work will be needed to accurately identify those key factors related to textile construction and condition (e.g. extent of previous use) which are driving microfibre losses across fabric structures. It is hoped that this will lead to manufacturers being able to select materials and fabric construction types, or develop new fabrics, which minimise losses. Scottish Government might consider offering funding through its Rural Affairs, Food and the Environment Research portfolio for research into said factors contingent on the use, once finalised, of the standardised test method. It should be noted that UK Research and Innovation is currently also exploring funding priorities for addressing microfibre emissions from the washing of clothing and so Scottish Government should coordinate with UKRI to avoid duplication of effort.

**Option 2: Support the Setting a Maximum Threshold for fibre shedding from fabrics**

In the 2018 ‘Plastics Strategy,’ the European Commission included a commitment to examine policy options for reducing unintentional release of microplastics from textiles including possible minimum requirements related to fibre shedding during the washing of textiles. The UK has indicated that the Circular Economy Package will apply to the UK following Brexit, however, it is currently unclear how closely the UK will align with any future regulatory actions resulting from the Plastics Strategy.  

This might involve determining a fibre release range for various fabrics and create a threshold that removes the worst performing products from sale. This threshold could either be adopted as a new Regulation (as it is important that this is harmonised across Europe, and would also apply to all items placed on the market, including imports) or as part of a voluntary agreement.

It is unknown whether any such minimum requirements will be taken forward, but Scottish Government could consider engaging with industry and policy makers at a European level to support development of such a measure if the development of a standard test and subsequent comparison of release rates suggests that factors related to textile construction and condition significantly influence release rates.

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Option 3: Support the development of labelling at a European level for microplastic emissions

In the 2018 ‘Plastics Strategy,’ the European Commission included a commitment to examine policy options for reducing unintentional release of microplastics from textiles including minimum requirements for information requirement, such as labelling if appropriate. The UK has indicated that the Circular Economy Package will apply to the UK following Brexit, however, it is currently unclear how closely the UK will align with any future regulatory actions resulting from the Plastics Strategy.

Once a standard test for fibre losses has been established, and the factors which have the strongest bearing on release rates are identified, then there are two ways that labelling could be used to achieve different outcomes;

- **A Sewn in label**—containing washing and user guidance which can be referred to on an ongoing basis; and
- **A Removable Label**—containing information that is designed to provide environmental information and influence buying decisions, for example featuring an A-G rating based upon the expected level of fibre release.

There may be scope to include one or both of these labels

It is unclear whether any such labelling requirement will be taken forward, but Scottish Government could consider engaging with industry and policy makers at a European level to support development of a labelling requirements. Workshop participants suggested that any future labelling requirement for clothing could require inclusion of a broader range of environmental and social sustainability information, such as carbon impacts, water use and social impacts such as whether the material used in production are certified Fairtrade.

Option 4: Washing Machine Filter testing

Once a standard test for absolute fibre losses from domestic washing is available, fund independent research to confirm the efficacy of washing machine filters to understand with confidence how these could contribute to eliminating emissions to the environment of fibres across all size classes.

Option 5: Washing Machine Filter Development

Once a standard test for absolute fibre losses from domestic washing is available, fund independent research to confirm the efficacy of washing machine filters to understand how these could contribute to eliminating emissions to the environment of fibres across all size classes.

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Option 6: Shedding via abrasion during use

Fund collaborative research to begin the design of a standard test for the emission of microfibres from the abrasion of textiles e.g. fibres being emitted during normal use of clothes. This research might extend to carpets and other indoor soft furnishings.

Option 7: Supply Chain losses

Fund research focused at quantifying loss rates of microfibres from key points along the textile production supply chain, so as to identify hotspots where mitigative action could be focused. In future, funding could then be targets to develop solutions to microfibre emissions along the supply chain.

A.1.2.3 Monitoring and Knowledge Gaps

As fibres are ubiquitous in the environment, it is likely that it may take several years or even decades before any mitigation measures are seen to be effective by monitoring environmental concentrations. In the case of washing textiles, the logical choice for determining whether reduction measures have been successful is in the influent of a waste water treatment plant. Monitoring influent and effluent and sludge is also key to understanding the effectiveness of WWT at capturing microplastics and therefore whether there should be further measures to protect agricultural land from the microplastics in sludge. Monitoring of agricultural land microplastic concentrations may also be worthwhile – this is discussed further in relation to agricultural products in Section 7.3.3.

The ubiquitous nature of fibres also suggests that WWT is not the only pathway to the environment. Atmospheric deposition of fibres is an emerging area of study and the exact mechanisms and pathways are yet to be understood. Whether this is a greater source (by mass) is unclear, but there does appear to be greater potential for wider dispersal. The concentration of fibres in the air may be concerning from a health point of view (via inhalation, particularly in buildings) but evidence for this is limited at present.

A.1.3 Agricultural Products

A.1.3.1 Problem Analysis

The Agricultural Industries Confederation and Crop Protection Association (CPA) were contacted to gather insights on the problem drivers behind emissions of polymers from fertilisers/seeds and plant protection products (PPPs) respectively. No response was received from the CPA.

Problems which relate to Controlled Release Fertilisers and PPPs are;

1) **A lack of equally-effective alternatives to synthetic polymers**: A key characteristic of microencapsulation for controlled or targeted release of both fertilisers and PPPs is that they degrade slowly in soils over a period of up to 18 months to allow gradual release. Due to their low rate of degradation synthetic polymeric materials perform this function.
very well. Although alternative materials such as natural waxes and polymers derived from bacteria, algae, plants and shellfish have been put forward as alternative materials, supposedly these do not yet provide a sufficiently-long period for release due to faster degradation rates than synthetic polymers.

2) **Lack of incentive to develop alternatives to synthetic polymers for Controlled Release:** Until recently there was insufficient incentive, be it financial, regulatory, or reputational, for manufactures of agricultural products to develop alternatives to the synthetic polymers used for microencapsulation which facilitates controlled release in the field of fertilisers and PPPs. In May 2019, the European Council adopted a regulation laying down rules for those placing fertilisers on the EU market bearing the CE mark which included a requirement that, by seven years after the date of entry into force, polymers used for the coatings of CRFs would need to meet biodegradability criteria.\(^{325}\) Although this will now create incentive for fertiliser manufacturers to focus R+D activity on developing alternative materials for CRFs, it will not apply to fertiliser additives, treated seeds or to CRPPPs. In its March 2019 Restriction Proposal for intentionally-added microplastics, the ECHA recommended that the biodegradability requirements being proposed for CRFs be extended to cover all fertiliser products and also be applied to CRPPPs via Regulation (EC) No 1107/2009 for placing PPPs onto the market within the EU.\(^{326}\) The intention is that 7 years would be allowed for the reformulation of CRFs to contain biodegradable polymers (as per the recently adopted new rules), and 5 years would be allowed for CRPPPs.

At the time of writing, the proposed restriction is out for public consultation until September 2019, with final recommendations to the Commission expected in spring 2020, beyond which point the Commission may propose amendments to the REACH regulation to implement a restriction.\(^{327}\) Until such time, and pending treated seeds and CRPPPs having a biodegradability requirement applied to them, there remains insufficient incentive, be it financial, regulatory, or reputational, for manufacturers of these products to develop alternatives to synthetic polymers or to address their long residence time in the environment.

A problem common to both fertiliser additives and seed treatments is that:

- **Growers have poor visibility of the contents of their fertilisers and seed treatments:**

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Outside of the concentration of the active ingredients, the AHDB reported that growers have poor visibility of the contents of their fertilisers and seed treatments, and that even when some growers ask for details of, for example, heavy metals content of fertilisers, suppliers are unable to provide relevant information.\footnote{Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)} There is therefore low awareness of whether they are applying polymers to soils in using synthetic fertilisers and seed treatments. Without this awareness, growers will not have reason to choose to use alternative products which do not contain polymers.

Problems which relate to Fertiliser Additives are;

- **Lack of awareness of whether additives contain synthetic polymers and of non-synthetic polymer alternatives:**
  As was explained in Section 5.4.2, fertiliser manufacturers in the UK specify the performance characteristics desired of component ingredients from chemical manufacturers for use in fertiliser end-products, rather than the composition of those ingredients. As a result, manufacturers do not always know whether the additives they are sourcing contain polymers or not. Without this knowledge manufacturers will not have reason to choose to use alternative additives which do not contain polymers.

- **Lack of incentive to adopt non-synthetic polymer containing additives over polymer-containing additives, despite the availability of such alternatives**
  Even in instances where manufacturers do know that the additives they are using contain polymers, there is insufficient incentive, be it financial, regulatory, or reputational to select non-synthetic polymer-containing additives over polymer-containing additives, despite the availability of such alternatives. During the ECHA’s call of evidence on intentionally-added microplastics some members of Fertilisers Europe indicated that no alternatives exist for non-degradable polymers for anti-caking agents,\footnote{ECHA (2019) Annex to ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION, March 2019, https://echa.europa.eu/documents/10162/1cae7c3c-4aa5-db3f-0a11-75ee2a8338e7} despite the commercial availability of hydrophobic silica-based alternatives which can be applied to a range of fertiliser types.\footnote{SIPERNAT® precipitated silica for agriculture - SIPERNAT® specialty silica, accessed 3 July 2019, https://www.sipernat.com/product/sipernat/en/industries/agriculture/} However, the two product types are not entirely comparable due to their having different modes of action. Non-polymer silica anti-caking agents form a hydrophobic layer around fertiliser particles which has distance-holding effect between particles which avoids solid bridges forming between particles. This greatly improves free-flow characteristics and slows but does not eliminate moisture uptake in the way that polymer-coatings might. Polymer anti-caking agents, on the other hand, create a more comprehensive coating of fertiliser particles and so might be chosen over silica anti-caking agents where the imperative is to avoid moisture ingress. However, in instances where there is no technical/performance reason...
to choose one over the other, manufactures are likely to choose polymer additives because they are cheaper per tonne. Therefore, given the current suite of anti-caking agents available, there will not be a one-for-one switch of polymer for non-polymer products, but it appears that there is scope to further incentivise uptake of non-polymer options.

Problems which relate to seed coatings are;

- **Farmers are buying coated seeds where growing, storing and planting may be advantageous:**
  The AHDB reported that some farmers are being encouraged to buy new seeds by seed retailers and agronomists rather than ‘home growing,’ storing and planting untreated seeds despite this being appropriate.  

- **Lack of awareness of whether seed coatings contain synthetic polymers:**
  As was explained in Section 5.4.4, the structure of the market for treated seeds is that seed producers buy coatings from chemical producers who supply multiple industries (e.g. paints), and then apply these coatings to the seeds they sell. Because the chemical composition of coatings is the intellectual property of chemical companies, detailed information on the content of coatings is not always available. As a result, manufacturers do not always know whether the treatments they are sourcing contain polymers or not. Without this knowledge manufacturers will not have reason to choose to use alternative additives which do not contain polymers.

- **Lack of incentive for seed coating producers to develop alternatives to synthetic polymers for seed coatings:** The function that synthetic polymer material provides as a seed coating is inherently similar to that provided to CRF products. As such, the development of biodegradable alternatives to standard polymer CRF coatings which the new Fertiliser Product Regulations is intended to incentivise may be transferable to coated seeds. There is however, insufficient incentive, be it financial, regulatory, or reputational for manufactures to develop non-synthetic polymer seed coatings. However, as with PPPs, ECHA has recommended that the biodegradability requirements being proposed for CRFs also be applied to treated seeds. It remains to be seen whether the European Commission will adopt the ECHA’s proposals.

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332 Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
A.1.3.2 Discussion of measures

Option 1: Undertake further problem definition and evaluation of the need for polymer use in Scottish agriculture in collaboration with industry

As was explained in Section 5.4, there are some uncertainties surrounding the use of polymers in Scottish agriculture, with both manufacturers and growers unaware of whether the products they are marketing and applying contain synthetic polymers. Additionally, some stakeholders consulted as part of this study suggested that polymers are being used unnecessarily in some instances.

Scottish Government representatives who attended the workshop suggested that a useful next step would be to undertake a more detailed investigation involving greater collaboration with all relevant stakeholders (e.g. growers, agri-product distributors, manufacturers, polymer ingredient manufactures) evaluating the use of plastics in seeds, fertilisers and plant protection products which might seek to establish;

- a clearer picture of the extent of use of polymers in Scottish agriculture in the above-mentioned applications;
- what function the polymer is providing in these applications;
- whether the need for the function provided by the polymer can be reduced e.g. planting more seed to compensate for losses which might occur through not using protective polymer coatings;
- whether there are alternative materials to non-biodegradable polymers for these functions; and
- where the use of polymers is essential, whether harm be mitigated through other means.

The lack of certainty regarding the extent of use of polymers in Scottish agriculture should not necessarily be seen as a reason not to adopt mitigative solutions such as those outlined below.

Option 2: If necessary, align with new EU rules for CRFs taking faster action where feasible

criteria which will be defined by 16 July 2024. While fertilisers is a devolved matter in Scotland, only part of this new regulation will become retained EU law at the time of the UK’s exit from the EU, however we understand that Scottish Government’s Agriculture and Rural Economy Directorate is considering primary legislation that may be needed to reflect the new EU regulation in UK law. Scottish Government might consider trying to keep pace with this EU regulation in order to reduce microplastic accumulation in soils as a result of their use in CRFs.

Additionally, Scottish Government may wish to go further than the requirements of the European regulation and evaluate whether specific applications or types of Controlled Release Fertilisers can be switched to biodegradable alternatives sooner than 2026. Feasibility and associated costs would likely have to be assessed on a case by case basis.

**Option 3: Require labelling of biodegradability of CRF coatings**

This measure would be complementary to Option 2.

As was explained in Sections 5.4 and 7.3.1, due the nature of the supply chains of fertilisers, both manufacturers and growers can be unaware of exactly the composition of products they are marketing and applying.

In advance of 2026 when CRFs will have to have transitioned to biodegradable polymers, Scottish Government could consider requiring that all CRF products are labelled with whether they are using biodegradable or non-biodegradable polymers for their coatings. Without such labelling between now and 2026 it is unlikely that growers will be aware of whether the products they purchase contain biodegradable polymers or not due to the poor visibility of agriproduct contents outside of the active ingredients. Such labelling would therefore provide growers with the product information required to motivate an earlier switch to biodegradable CRFs. This might also motivate faster efforts by manufactures to transition to biodegradable coatings.

The requirement might be placed on any entity distributing fertiliser products in Scotland.

**Option 4: Legislate to implement biodegradability requirements for other agricultural products taking faster action than the EU where feasible**

This measure would be complementary to Option 2.

As mentioned in Section 7.3.1 above, the ECHA’s proposed restriction of intentionally-added microplastics in CRPPPs, treated seeds and fertiliser additive products is based upon harmonisation of the aforementioned new requirements for biodegradability of controlled-release fertiliser coatings such that it covers all fertilising product, PPS and treated seeds placed on the internal market.

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337 Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
Scottish Government could monitor the development of ECHA’s proposal as it goes through public consultation and review by the European Commission, with the intention of implementing legislation that would apply biodegradability criteria to CRFs through an amendment to the EC Fertilisers (Scotland) Regulations 2006, or inclusion of relevant clauses in any such legislation which replaces it following Brexit. In order to have such criteria apply to CRPPPs and treated seeds as well, such a requirement would have to be built into the Scottish Governments ongoing work with the Health and Safety Executive on changes to pesticide approval regulations following Brexit.

According to the Agricultural Industries Confederation which represents both fertiliser and treated seed manufacturers in the UK, fertiliser manufacturers are already in the process of undertaking research and development activity to formulate biodegradable alternatives to the polymer material coatings currently used on granulated fertilisers to bring about a controlled release over a growing season, in order to meet the biodegradability requirement deadline of the new EU Fertiliser Regulations. They are also apparently looking into developing biodegradable alternatives for additives as they see it as likely that the ECHA restriction proposal will be adopted. Regarding seeds, at present, the seed industry is reliant on chemical companies from whom they procure coating ingredients to produce non-polymer or biodegradable alternative ingredients. Replacements for polymers from sources such as starch and chitin are being investigated, but they are not yet available, as there are concerns regarding their stability and suitability.

For both seed coatings and fertiliser additives, pressure is being applied to manufactures of the end products to exclude polymers. This pressure has to be passed up the supply chain to chemical companies supplying the polymer ingredients. As such, innovation will rely on action being taken by these actors rather than by fertilisers manufacturers. Despite this, the times frames put forward by ECHA are generally seen as challenging but achievable.

If adopted, Scottish Government might also wish to go further than the requirements of any implementing European regulation and evaluate whether specific applications or types of CRPPPs, treated seeds and fertiliser additive products can be switched to biodegradable alternatives sooner than 5 years after the entry into force of ECHA’s proposed REACH Restriction. Feasibility and associated costs would likely have to be assessed on a case by case basis.

**Option 3: Implementing a more immediate restriction (less than 3 years) on Fertiliser Additives**

As mentioned in Section 7.3.1, there is a lack of awareness of, and incentive to adopt, non-synthetic polymer alternatives to fertiliser despite their commercial availability. Scottish Government could monitor the development of ECHA’s proposal as it goes through public consultation and review by the European Commission, with the intention of implementing legislation that would apply biodegradability criteria to Fertilisers Additives through an amendment to the EC Fertilisers (Scotland) Regulations 2006.

The ECHA does not provide detail based on its call for evidence to industry of what length of transitional period, if any, would be required for the development of alternatives which would
not reply on non-degradable polymers, given that multiple companies appear to be marketing alternative precipitated silica-based non-synthetic polymer anti-caking agents.\textsuperscript{338,339,340} However, consultation with industry has highlighted a number of barriers to faster implementation:\textsuperscript{341}

- Firstly, as mentioned in Appendix A.1.3.1, the two product types are not entirely comparable due to their having different modes of action which makes each preferable in certain circumstances. Silica anti-caking agents are preferable where the imperative is to maximise free-flow characteristics, whereas polymer anti-caking agents are preferable where imperative is to avoid moisture ingress. As a result, despite the potential for greater uptake of non-polymer anti-caking agents, there could not be a one-for-one switch without some negative outcomes. Reformulation and testing of polymer-containing additives to achieve the functions that currently aren’t being achieved by non-polymer additives might therefore be necessary.

- Secondly, because the means of incorporating polymer anti-caking agents within fertilisers is different to non-polymer silica anti-caking agents changes to infrastructure/equipment and processes used by fertiliser manufacturers might be necessary if there was a switch to non-polymer additives. For example, the process might switch from mixing equipment for incorporating waxes or liquids to equipment for powder mixing. Staff training might also be necessary alongside changes to processes and infrastructure.

Scottish Government would likely need to consult industry in greater detail before making any decision to bring forward a restriction of synthetic polymer-containing anti-caking agents, undertaking a more in-depth case-by-case investigation of the feasibility and associated costs for each specific application.

**Option 5: Encourage less reliance on polymer-containing agricultural products**

The above measures have focused on promoting changes to the formulation of inorganic fertilisers, PPPs and treated seeds. A complimentary set of measures could encourage less reliance on synthetic polymer-containing agricultural products through reducing use of inorganic pesticides and fertilisers.


\textsuperscript{341} Personal Correspondence with Evonik Industries (27/09/2019)
The Plant Protection Products (Sustainable Use) Regulations\textsuperscript{342} which implement the Sustainable Use Directive\textsuperscript{343} require that the Scottish Ministers demonstrate that Scottish growers are using Integrated Pest Management (IPM) practices. IPM involves the use of a broad range of methods including good crop husbandry, physical, plant-breeding or biological controls, which are supported by rigorous pest, weed or disease monitoring to reduce the need for the use of chemical pesticides.

This requirement to demonstrate consideration of IPM ahead of using pesticides is met through the voluntary completion of Integrated Pest Management Plans by Scottish Growers.\textsuperscript{344} Despite the existence of such mechanisms for encouraging consideration of IPM methods, it has been acknowledged by environmental NGOs and the UK Government that there is further potential for uptake, and a gap in policy encouraging sustainable crop protection with minimum use of pesticides.\textsuperscript{345, 346} The UK Government committed it its 25 Year Plan to improve the Environment that it will develop and implement policies to encourage and support uptake of IPM, though did not make clear through which mechanisms this will be achieved and thus whether the policy will be applicable to Scottish Growers or would need to be independently adopted by Scottish Government remains to be seen. We are aware that Scottish Government is involved in discussions with the HSE regarding pesticide registration regulations post-Brexit, and so assume that it is also involved in discussions regarding the pending review of the UK Pesticide National Action Plan, which could be used as an opportunity to develop policy supporting uptake of IPM.

Regarding fertilisers, further conversion to organic and low-input inorganic farming (such as that certified by the LEAF Marque\textsuperscript{347}) would result in a decrease in direct emissions of microplastics to soils from agricultural products. Consultation with the Agricultural and Horticultural Development Board suggested that there remains potential to reduce the use of synthetic fertilisers in Scottish Agriculture without suffering a reduction in yield.\textsuperscript{348} Scottish Government’s existing policy of supporting organic farming as laid out in the 2016 – 2020 Organic Ambitions

\textsuperscript{342} (2012) The Plant Protection Products (Sustainable Use) Regulations 2012
\textsuperscript{343} Directive 2009/128/EC
\textsuperscript{348} Interview with Chris Leslie - Knowledge Exchange Manager (Scotland) - AHDB – (03/09/2019)
Action Plan is noted, as is the related provision of support for conversion to, and maintenance of, organic farming practices under the Agri-Environment Climate Scheme.

We understand that Scottish Government has begun the process of defining, but has not yet confirmed, how it intends to structure financial support for agricultural enterprises following Brexit, but that it intends to retain direct payments alongside support for agri-environmental schemes. We are also aware that Scottish Government has had a briefing produced on the benefits and challenges of basing whatever agricultural support scheme does replace the EU CAP on a concept of “Public Money for Public Goods” (PMfPG) as DEFRA is currently trialling for application in England and Wales, whereby there is an explicit link between funding and the environmental outcomes which farmers provide on their land.

An option which Scottish Government might adopt would be to continue but decrease the level of basic income support following Brexit, as was recommended by the Scottish Government’s Agriculture Champions in their May 2018 Future Strategy for Scottish Agriculture Report, and increase the level of support available for, amongst other outcomes, the adoption and maintenance of organic and low inorganic input farming.

This would reduce microplastics emissions to Scottish soils, and recognise the broad range of other public and public-private goods that organic farming provides in encouraging biodiversity, reducing greenhouse gas emissions, improving soils and the quality of air and water. The improvement of environmental outcomes and wildlife issues were topics reported as frequently raised in response to the Scottish Government consultation on proposals for rural funding following Brexit.

A.1.3.3 Monitoring and Knowledge Gaps

As the majority of proposed options focus on the move towards alternative approaches, monitoring of environmental concentrations of microplastics from this source would not be required. There are two exceptions to this: firstly, before implementation of any options it may be necessary to conduct further monitoring to determine baseline concentrations of microplastics in soil, air and water. Secondly, it may be necessary to monitor the impact of any proposed options on microplastic concentrations in soil, air and water.

be appropriate to conduct sampling of agricultural soil to determine the concentrations of microplastics in the soil that are derived from this source. In this case, identifying suitable sites that use such products, but do not apply any other sources of microplastic will be important here – examples include sewage sludge or industrial compost/digestate which are both known to contain plastic fragments. As part of the research, sites should also be identified which only apply sewage sludge or industrial compost/digestate. Measuring the concentrations of microplastics over time from these three sources would be helpful in identifying where action is most required.

It should be noted that the current modelling suggests that around 160 tonnes of microplastic is applied to agricultural land in sludge. This is compared with between 334 and 2,316 tonnes from agricultural products. Determining whether the concentrations in soil reflect these estimates would be a useful exercise.

Microplastics in compost/digestate is out of scope of this project and is an ongoing issue for composters and worthy of further investigation in its own right.

**A.1.4 Artificial Turf and Equestrian Surfaces**

**A.1.4.1 Artificial Turf**

**Problem Analysis**

Problem drivers relating to artificial turf can be summarised as follows:

1) **Insufficient incentive for pitch operators/specifiers to implement best practice measures:** There is a lack of awareness to date amongst pitch operators that loss of infill can contribute to marine microplastics. There are also no financial, regulatory or reputational risks for pitch operators that do not implement best practice measures in specifying the facility and managing its use. Pitches procured by local authorities are often also subject to strict cost criteria, but with no corresponding criteria around infill management during use (and often no criteria for end-of-life).

2) **Insufficient incentive upon installers and/or manufactures of artificial sports to design-in best practice measures:** This is driven by the lack of pull from pitch specifiers. Designing in added cost during tendering for a pitch construction project would be uncompetitive without such measures being added to the specification.

3) **Insufficient incentive for pitch operators to use alternative infill material:** As SBR in particular is relatively cheap compared to other costs associated with the construction and maintenance of artificial sports pitches, there is an insufficient financial incentive to switch to natural infill alternatives such as cork or coconut husks—there are also potentially perform issues using organic material in wetter climates. Alternative virgin plastic infills are often prohibitively expensive and will also not solve the microplastic problem.

4) **Lack of data on loss pathways:** No mass balance has been undertaken which determines exactly how much infill is lost annually and where is goes. This may provide a barrier to justifying specific site interventions unless their effectiveness can be verified.
Options for Measures

As the football pitches in Scotland are designed and built in Scotland there is a great deal of scope to regulate this to mandate that all current and/or subsequent pitches are required to install infill loss mitigation measures. This is currently the process that is being considered in Norway—another country that has heavily embraced the use of artificial turf due to the climate. The Norwegian Government is consulting on making the following pitch specifications mandatory:355

1) a physical barrier around the playing field which prevents infill from spreading outside of the pitch.
2) solutions for handling drainage water and surface water which captures the infill
3) measures to prevent infill spreading outside of the pitch by the users (e.g. on clothing, boots etc.)

As part of this, the feasibility of adding these mitigation measures into existing pitches has been trialled at several installations in Norway. Around 20 pitches have been assessed in with the average cost being around £14,000356 – the highest was around £30,000 and the lowest around £4,000. The cost estimates for each measure are shown in Table A- 7 in the Appendix—it estimates that for a ‘normal’ installation costs will be around £14,000 raising up to £61,000 for more complex installations. The most expensive element is expected to be the physical barrier around the pitch. The costs of this will vary massively depending upon the material used. The assumption of the ‘normal’ costs is the clubs select inexpensive materials for the physical barrier (wood) and the work is performed by volunteers. The cost saving of capturing and reapplying the infill has not been considered by the Norwegian calculations – at around £500/tonne357 of SBR infill, £500 to £2,000 could be saved per year for each pitch. If all of the otherwise lost infill could be recovered, there is potential for the initial capital cost to be recouped over the (~10 year) life of the pitch.

It is estimated that in Norway an additional 231,000 NOK (£21,000) is required to provide an area for snow clearance to prevent the infill from being washed away as it melts. This is assumed not to apply for Scotland for, although there may be some cases where this is necessary due to regular winter snow fall.

Part of the consultation also look sat the implementation period which provides two options for existing installations:

- **Implementation 1:** a period of time (2 -3 years) is agreed before the requirement for a physical barrier and drainage systems are upgraded as these are the most expensive improvements. Low cost requirements such as improved cleaning procedures and shoe

356 Prices converted from Norwegian Krone
brush at pitch entrances requirements could apply from the entry into force of any regulation.

- **Implementation 2:** All requirements in the regulation take place when the pitch is refurbished, i.e. ever ~10 years when the turf is replaced or if a major upgrade is planned.

**Option 1: Implementing Mandatory Infill Loss Mitigation**

This option mirrors the Norwegian approach and it is therefore recommended that this is mirrored, but without the specific requirements related to snow management unless the pitch is expected to have snow cover for a significant proportion of the Winter. This will have greater impact if the implementation period for existing installations is shorter, but this will increase the cost.

**Option 2: Provide Guidance for Public Procurement**

As the majority of pitches are procured by Local Authorities, there is potential to provide specific guidance to procurement teams on minimum requirements for specifications on mitigation measures.

**Option 3: Banning Synthetic Infill**

This is the only other alternative is to ban the use of synthetic infills (including virgin polymers). This currently has two barriers; cost and performance. The cost of cork, for example, is around three times greater per tonne (~£1,500/t\(^{358}\)), however, it is around six times less dense and therefore to fill the same volume, may actually be less expensive. From a wider environmental perspective, the use of cork is also the most preferential option in greenhouse gas emissions terms, particularly if a reusable shock pad is installed.\(^{359}\) However, there are significant barriers to its more widespread use as it is affected by climatic conditions more so than rubber crumb—particularly in freezing environments cork can absorb water and freeze which can lead to the particles fragmenting. It is also prone to being transported easily by water which is why it is often used more in drier climates. It also generally needs topping up at more regular intervals as it decomposes.\(^{360}\)


\(^{360}\) Norwegian Environmental Agency (2017) *Environmentally friendly substitute products for rubber granulates as infill for artificial turf fields*, November 2017
Infill is also an important recycling route for tyres at present which would require an alternative use to be developed.

The following uses for the rubber from tyres are also being used to a lesser extent:361

- Playground flooring
- Carpet underlay
- Rubberised asphalt for road surfaces
- Speed bumps
- Running tracks
- Mud guards for vehicles

All of these see the rubber bound into one solid item rather than used as a crumb. This is much more preferable from a microplastic emission point of view, but care should also be taken to make sure that new or increased use of applications do not also contribute to the problem; speed bumps, for example are likely to wear away during use, so may be a less attractive option in this regard.

The rubber in tyres is also increasing being used as an alternative fuel in cement kilns (replacing coal). This reduces the GHG emissions from cement kilns, but it is unclear whether this is the best alternative fuel in this regard.

**Monitoring and Knowledge Gaps**

As identified in the problem analysis, no mass balance has been undertaken which determines exactly how much infill is lost annually and where it goes. It is debatable whether this is required in order to justify action as the migration of infill to the surrounding areas of a pitch is self-evident and well documented. Determining the effectiveness of measures would potentially be a valid exercise. This would mean developing a test procedure for collecting infill that has migrated away from the pitch via the various mechanisms already identified. This could be employed at several pitches before and after measures have been put in place. A further benefit of this could be to determine whether captured infill could be reapplied to the pitch. This, combined with the infill that is prevented from migrating off the pitch may go some way to mitigating the lifetime costs of improvements.

It is also helpful to determine the dispersion of pitches which might aid any targeting of measures. As can be seen in Figure 20 the locations of the 3G surfaces are broadly distributed in line with the major population centres of Scotland. Glasgow City and its surrounding Local Authorities (North Lanarkshire, West and East Dunbartonshire and Renfrewshire) contain over one third of the total pitches in Scotland whilst accounting for around 1% of Scotland’s land area.

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361 [https://www.asm-recycling.co.uk/blog/guide-to-tyre-recycling-uk/](https://www.asm-recycling.co.uk/blog/guide-to-tyre-recycling-uk/)
Figure 20: Locations of Scotland’s 3G Sports Pitches
A.1.4.2 Equestrian Surfaces

Problem Analysis

The potential for synthetic surfaces from equestrian facilities to contribute to the problem of marine microplastics has only been recently identified. It has not been widely discussed, and literature focusing on such surfaces generally looks at horse and rider safety from a perspective of injury and falls. It may be possible to take best practice measures to reduce the loss from individual facilities, and alternative surface materials (such as woodchip, wood fibre and sand) are available. However, at present there is a lack of financial, regulatory, or other incentives for facility owners to implement best practice measures to contain the surface, or switch to alternative surfaces instead.

Despite a significant lack of research, our modelling suggests that there is loss of microplastics from equestrian facilities (Section 5.3.2). Factors which contribute to this issue are outlined below:

1) Absence of information on loss: Despite some focus on artificial turf pitches in work on microplastics, equestrian facilities have been largely been overlooked. This contributes to the problem as without background research it is difficult to quantify the issue and hence make robust proposals for management. If microplastic pollution is an issue that gains more research attention, this gap is likely to be highlighted and addressed in future. However, at present it is limiting.

2) Absence of data on facilities: There is no record of all equestrian facilities in Scotland. To obtain a more robust estimate of potential losses, it would be important to obtain information on the total number of facilities, their size, and the surface type and quantity used. Additionally, this could be mapped to identify facilities which have a high risk of losing microplastics which could include those close to watercourses.

3) Beneficial properties of artificial surfaces: One of the drivers for uptake of artificial surfaces is that their properties are considered superior to natural surfaces. For example, tyre rubber and carpet fibre are less prone to freezing than natural surfaces (such as woodchip), provide benefits to equine and rider safety, and are less likely to become slippery when wet. As such, these surfaces may allow owners and trainers to exercise their horses year round, in conditions which may otherwise be prohibitive. This is a significant advantage for commercial trainers, such as racehorse trainers but is also likely

364 It is worth recognising that loss from indoor arenas is likely to be significantly lower, as these tend to have relatively high, solid boundaries and are not exposed to the elements in the same way as outdoor facilities.
to be preferable for the recreational horse owner. In addition, the surfaces are more durable and will not biodegrade in the same way as woodchip.

4) **Cost of artificial surfaces:** The carpets and tyres used for equestrian surfaces are those which would otherwise require disposal. As such, they can be provided to the equestrian industry at low cost, with the bulk of the cost to facility owners coming from the haulage of materials, rather than the materials themselves. Therefore, the inferior properties of natural surfaces combined with the relatively low cost of artificial ones creates a market which may favour the artificial option.  

5) **Legality of artificial surfaces:** It is theoretically possible for tyre derived materials to meet end of waste criteria and so be used legally with no waste controls in place. However, no specific criteria for this material current exist at an EU level nor in Scotland, and the current legal position is that this material is indeed regarded as waste. This means that, for legal application of tyre derived materials to artificial surfaces, a waste permit or exemption is required.

### Options for Measures

There is some capacity for Scottish Government to influence both the state of knowledge around loss from equestrian surfaces, and loss itself. Four areas of potential focus are:

- Developing the state of knowledge;
- Awareness raising measures;
- Implementing best practice guidelines for surface management;
- Research and development into alternatives; and,
- Restricting the use of tyre derived rubber and carpet.

### Option 1: Developing the State of Knowledge

As highlighted in the section above, there are a significant number of unknowns at present regarding release of microplastics from equestrian surfaces. Developing the state of knowledge could look to address these gaps and could potentially be achieved through collaboration with other countries who have significant equestrian industries, and climates which make the use of artificial surfaces especially beneficial. Examples would include Sweden, the rest of the UK, and Denmark and Norway who have already conducted research around loss of microplastics from artificial turf. Understanding needs to be developed around the rate of loss, and pathways of loss from these facilities, as well as around their quantities in Scotland. This information would

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be valuable both in better quantifying the issue, and also in being able to better target interventions to prevent loss to the environment.

**Option 2: Awareness Raising Measures**

At present, there is low awareness around the issue of release of microplastics from equestrian facilities. Awareness raising measures could be used to initiate engagement with the industry around the issue and to make facility owners aware of the potential problems. Stakeholder engagement may also be worthwhile to begin to initiate a dialogue, with academics and with providers of these surfaces to start to understand the supply chain better, and the potential barriers to preventing loss. Awareness raising is likely to have little impact on the actual release of microplastics from facilities, but will be a valuable tool in generating interest in the issue and developing networks to tackle the problem.

**Option 3: Implementing Best Practice Guidelines**

In the context of artificial turf, some facilities have implemented measures to minimise loss of rubber chip, whilst maintaining the functionality of the surface. Given the similarities between the two issues, some of these recommendations may be transferable to equestrian facilities. Guidance which prevents the loss of material from facilities will benefit both facility owners, reducing the need to top up the facility, and benefit the environment. Such guidance would recommend the installation of boards around the edge of arenas, and along the sides of gallop tracks which prevent material directly escaping (See Figure 6 for example of an unbound gallop track). In addition, picking of horses’ feet prior to leaving the arena to prevent transport out in this way could also be recommended, as well as ensuring that droppings removed from the arena or track are clear of surface material. However, there are likely to be other pathways which would not be captured by these recommendations. For example – small tyre wear particles may become trapped in horses’ fur, especially in wet conditions, and lightweight carpet fibre may be blown from the track in windy conditions, and with horses kicking up the material during exercise. Thus, whilst initial recommendations can be made, thorough and robust guidance would benefit from an increased understanding of the loss pathways from facilities.

**Option 4: Research and Development of Alternatives**

As recognised in the problem analysis, synthetic surfaces have gained popularity within the equestrian community due to their superior properties when compared to natural surfaces which were previously widely used. Offering better resistance to freezing and better rider and horse safety are key benefits which these surfaces provide. As such, there is a gap for an equestrian surface which delivers similar properties to tyre derived rubber and carpet fibre, but which won’t release microplastics to the environment.

At present, such an alternative does not seem available. However, given low levels of awareness of the potential for equestrian facilities to release microplastics and the beneficial properties of synthetic surfaces there has been little in the way of a driver to develop such an alternative. As such, research and development to look in to potential alternatives could be of value.
Option 5: Restricting the Use of Tyre Derived Rubber and Carpet

A final option would be to restrict the use of these materials altogether, with a ban on construction of new artificially surfaced facilities. Whilst the state of knowledge is lacking at present, this could be considered in future. With reference to the End of Waste criteria, it would seem that application of tyre rubber and carpet fibre in this way may fail to meet the criteria if they are releasing microplastics which cause environmental harm. As such, it may be sufficient to recognise that equestrian facilities are not an end of waste solution for these materials, which would also prevent them from being used in new facilities. Equally, requirements could be placed around the construction of new facilities, implemented through the planning application process. Such requirements could be a way of implementing the best practice measures recommended under Option 3, or could look to encourage a shift from synthetic materials to natural surface materials, or new alternative materials as discussed under Option 4.

However, there are barriers to doing this. It is firstly worth recognising that both tyres and carpets are difficult materials to dispose of at end of life, with equestrian surfaces currently seen as an ‘eco-friendly’ recycling option for these items. It is worth recognising that this does not represent closed-loop recycling and will likely only result in one additional use cycle before being sent to landfill or incineration.

Still, a measure to restrict their use in this way would be likely to generate resistance and would seem a leap from the current knowledge base. In addition, these materials do have beneficial properties which, if restricted, could put the Scottish equestrian industry at a relative disadvantage. For example, racehorse trainers need year round access to exercise facilities for horses in training. Surfaces not freezing, not biodegrading, and being safer for horses are a significant advantage. Enacting a restriction in the present context where the issue is little considered, there are vast unknowns, and where restrictions are not in place in any other countries is likely unfeasible. As such, there is a place for pursuing Options 1-4 with a view to considering Option 5 in the light of more information, research and the development of comparable alternatives.

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Monitoring and Knowledge Gaps

The same procedures for monitoring artificial turf are likely to apply to equestrian surfaces. Currently, there has been no work to determine loss rates or pathways, therefore this is the first step towards monitoring the situation.

A.1.5 Fishing Gear

A.1.5.1 Problem Analysis

Problem drivers relating to fishing gear can be summarised as follows:

1) **Absence of key data sources on the use of fishing gear and the microplastic loss rates:** The assumptions in this study are based on very limited data on both the usage of fishing gear in Scotland and the amount of microplastics that are lost during use. Workshop participants highlighted two particular gaps in knowledge regarding loss rates;
   a. a lack of understanding as to whether different fishing methods/strategies that use different tow speeds or ground gear might influence loss rates; and
   b. a lack of understanding as to the nature of particles lost from fishing gear e.g. clumps or fibres and what degree of secondary decay occurs.

2) **Lack of alternatives or known best practice:** There is a lack of understanding around whether there are any better alternative materials or types of polymer than are less likely to produce microplastics. This leads on to problem that there is therefore no recommended best practice for mitigation.

A.1.5.2 Options for Measures

Although there has been a large focus on lost fishing gear and its contribution to both macro and microplastic pollution there has been significantly less work on the microplastic generation during use. There are three key pieces of information that are necessary to quantify the problem and begin to understand whether there are effective measures that can be put in place;

1) The amount of fishing gear used and how often it is used and replaced;
2) The amount that is worn off during use and the nature of the wear; and
3) Whether different materials/constructions used in fishing activities are more prone to wear.

The first issue of use data has been an ongoing problem for some time; with the best data on fishing gear usage usually coming from a well-managed EPR scheme (such as the one in Iceland). However, this may be improved in future in Scotland. There is a study ongoing with Marine Scotland which is looking to generate an understanding of both the fishing gear in use in Scotland at present, and that which is in storage. This would provide information on both the
types and the tonnages of fishing gear within Scotland. It is expected that the results of this work will be published in 2020.

With respect to (2), whilst large pieces of fishing gear are known to break off during use, the nature of smaller microplastic wear and tear is not well understood. Fishing gear is also a broad term for a large number of products ranging from the fibres in ropes and nets to particles chipped off of buoys or similar. The small amount of research in this area to date has focused on nets, but losses are very much theoretical. Field research would need to be carried out to determine how much is lost through wear with the experiments designed to isolate this from macro-sized losses—this may be very difficult to achieve when nets have been significantly bio-fouled during use. Such experiments may bring forth recommendations for materials or constructions that are less prone to wear. Early indications suggest this may be the case and various mechanisms could be employed to incentivise the use of materials less prone to degradation.

A.1.5.3 Monitoring and Knowledge Gaps

Monitoring of microplastics sources that end up directly in the marine environment is practically impossible. If there are developments in fishing gear materials that release fewer microplastics over their lifetime, the best way to monitor this is to determine the loss rates of the current gear in comparison. A certification scheme could be implemented to make sure that the gear of the highest standard is always used. At present this is not something that can be implemented.

A.1.6 Road Markings

A.1.6.1 Problem Analysis

Problem drivers for road markings were identified on the basis of Eunomia’s previous consultation of stakeholders at a European level during work on road marking-derived microplastics for the European Commission and a 2016 study commissioned by the Scottish Road Research Board into the durability of thermoplastic road markings, which focused on factors affecting the bonding performance. The Road Safety Markings Association was consulted to determine which of these problem drivers are still relevant.

371 Personal Communication with Marine Scotland, August 2019
374 Personal communication with the Road Safety Markings Association (02/10/2019)
The problem drivers in respect of road markings can broadly be divided into problems that relate to the road markings itself and its application, and those that relate to the road environment. Problem drivers relating to road markings can be summarised as follows:

1) **Insufficient knowledge of the nature of road marking microplastics, through abrasion where they are found, and in what quantities:**

   The estimates for emissions of particles through the wear of road markings are largely theoretical. The particles have rarely been sampled and identified in the environment and the dominant mode of wear (e.g. weathering vs. abrasion) and exact pathways are unknown due to their diffuse nature. The wear rates for different road types are only understood from a qualitative perspective (i.e. visual quality standards) to help make replacement a straight forward task. It is assumed that road markings will wear quicker in urban areas, but there is not enough data to account for this in the modelling presently. The total paint use and locations where it is applied in Scotland are not well understood either.

2) **Insufficient knowledge of the rate of wear of alternative marking types:**

   A key problem is that there is insufficient understanding as to precisely how well different road marking materials on the market and application method (solvent, thermoplastic or cold plastic etc.) perform from a wear perspective. The RSMA reported that while contractors are aware of the relative performance of different broad categories of marking with regards to their bonding performance and lifetime before replacement is needed, the lack of a road trial site in the UK where different markings could be comparably tested means that well-informed purchasing decisions cannot easily be made by non-experts such as buying authorities. The RSMA commented that Highways England and Transport Scotland have been approached to obtain a piece of road to use as a test site.

   Even if a catalogue of product performance was available it might not be a simple task to substitute for better performing (abrasion resistant) materials. Different materials are favoured in different contexts. Road types, traffic levels, visibility requirements, drying speed and ease of maintenance all play a role in material and application method choices. Until transparent data is available regarding the relative contributions of different products to emissions, buying authorities and contractors will be unable to mitigate against emissions through purchasing decisions.

3) **Inconsistent specification of the functional life required of road markings in contracts for procurement and application:**

   In contracts for road marking procurement and application, the functional life required is not consistently stated, and related to this there is insufficient testing during and after construction in order to ensure the product meets the requirement set for a project which has specified outcomes related to durability. The RSMA noted that there is considerable variation amongst local authorities of the degree of testing that is carried out, and that where testing has been carried out very infrequently, the skills required have been lost.

4) **Poor programming of surfacing works:**
Poor programming of surfacing works, in particular surface-dressing, has historically caused premature failures of road markings where this has resulted in road marking operations being performed during the colder and wetter months of the year, when markings may not bond with the road surface as effectively. The RSMA noted that while programming of works is a perennial problem, there is much more early-contractor involvement going on which gives Road Marking appliers the opportunity to voice concerns/needs and inform programming. It was also noted that if a road marking applier is following a surfacing contractor, then the surface will be warm which can almost remove the negative impact of seasonality.

5) **The poor condition of the existing road surfaces:**
The poor condition of the existing road surfaces, such as cracking and potholing, affects the bonding performance of TRMs. The RSMA highlighted that the highway maintenance budget of a road authority has a strong bearing on quality of the surface and that since 2008 cuts to LA funding and reduced ringfencing of funds for highway maintenance have meant that road pavement surface condition has continued to decline.

6) **Insufficient technical knowledge within buying authorities:**
The RSMA suggested that there is a skills shortage at a Local Authority level amongst those responsible for procuring road markings maintenance not necessarily having any technical knowledge which prevents informed specifications being developed or procurement decisions from being made.

7) **Financial constraints on road authorities:**
Financial constraints on local authorities contracting services have meant that price and quality are not always suitably balanced such that procurement is driven by price, forcing some local authorities to purchase cheaper rather than value-for-money products. The RSMA noted that national highway authorities tend to focus on quality over price.

8) **Insufficient financial or regulatory incentives to capture microplastics through roadside capture:**
The environmental science community’s recognition of roads as pathways/sources of microplastics is comparatively recent and as such there has been relatively little pressure on local authorities to mitigate against loss of microplastics from the road environment.

**A.1.6.2 Options for Measures**

As the main problem identified for this source of microplastic is the lack of knowledge that would justify action at this time, the following are options to help remove this barrier:

**Option 1: Funding primary research into road marking wear processes, products and flows**

Given that estimates for emissions of particles through the wear of road markings are largely theoretical, and the resulting particles have rarely been sampled and identified in the
primary research to define the nature of road marking particles is needed. This research could also define the dominant mode of wear (e.g. weathering vs. abrasion) and begin to establish the pathways that particles take from the road environment.

**Option 2: Funding primary research into relative durability of road marking products**

This research could build on that suggested in Option 1.

Further research could assess the performance from a wear/abrasion perspective of the variety of road marking products available on the market. The RSMA reported that while contractors are aware of the relative performance of different broad categories of marking with regards to their bonding performance and lifetime before replacement is needed, the UK lacks a road trial site where different markings could be comparably tested. The RSMA suggested that a road trial site and a database of product performance information which might be produced from it would allow non-experts to objectively compare products. If a standard and comparable means of testing the wear performance of road markings was achieved, then one can envisage an environmental rating of road markings indicating their emission of microplastics, which might be based upon a ratio of their dosage and durability, to prevent the life of painted surfaces only being improved through adding a larger quantity of marking.

There are a number of other knowledge gaps which Scottish Government might fund research to help close which are outlined in Appendix A.1.6.3.

**Option 3: Encourage or mandate use of procurement and end-product performance requirements linked to payment schedules**

Previous research into the durability of road markings in Scotland highlighted the benefits to road marking performance that have been achieved in Ireland as a result of the procurement and end product performance requirements used by the Irish National Roads Agency (NRA).  

The NRA uses a performance-based specification whereby they set challenging requirements for reflectivity, adhesion/durability, skid resistance, luminance and quality of colour, as well as specifying certain conditions under which application must occur such as favourable weather/climatic conditions. The payment schedule for works completed is then linked to achieving these performance outcomes such that contractors receive:

- 60% of payment after installation;
- 20% on initial proof of quality (typically at year end); and
- 20% after demonstration of continued performance after 36 months.

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The benefits of this approach which increases the strength of incentives to have a more durable road marking, as reported by the NRA, are that: 376

- “contractors place emphasis on quality and high-quality work is rewarded;
- contractors frequently check the depth of embedment and spread of glass beads as well as material thickness;
- contractors thoroughly clean and prepare the surface prior to installing the new road markings;
- work is only undertaken in favourable weather conditions;
- contractors make use of well-maintained equipment; and
- contractors make use of the best available materials (incorporating enhanced binding properties).”

It is notable that a number of these outcomes relate directly to the problem drivers identified for Scotland in the previous Scottish Road Research Board report. 377

In order for this measure to operate most effectively, contractors would ideally have good knowledge of the relative performance of different road marking products across a range of characteristics including wear performance/durability to inform purchasing decisions. This would be facilitated by the existence of a UK Road Trial Site and database of product performance information with possible related rating. In the absence of this level of transparency, a performance-based procurement approach would have to make the best use of existing knowledge. Such a rating system would help to avoid a situation where the wear life of road markings is improved to meet procurement specifications simply by adding a thicker layer of marking.

The RSMA is generally supportive of a procurement method similar to that used by the Irish NRA, given that all involved parties’ needs are met by it; in that the client and end user get a high-quality and long-life road marking which requires fewer maintenance interventions and the contractor is usually well paid for it. The RSMA did however caution that the NRA-method focuses attention on the contractors rather than client, however, clients can be demanding about exactly what product they want despite the contractor knowing it might not last for as long as another product. In this situation a contractor could end up being penalised unfairly if end-product performance specifications linked to payment schedules were in place. This does not however seem an unsurmountable challenge.

Option 4: Increased capture at roadside and reducing vehicle kilometres driven

Options 4 and 5 for reducing tyre wear emissions are also applicable to road paint (see Section 7.1.2). They have similar pathways through storm water and a reduction in driving will also mean that the paint will wear away more slowly.

Transport Scotland and SEPA could collaborate to co-locate a road test trial site for road markings with tests of different drainage infrastructure for capturing road environment microplastics to make better use of resources, and to share knowledge.

A.1.6.3 Monitoring and Knowledge Gaps

Literature review and consultation with the RSMA highlighted a number of knowledge gaps related to road marking adhesion/durability: 378,379

- A lack of understanding as to the relative importance of the following factors in influencing the bonding performance of TRMs, which will influence loss rates;
  - Road marking thickness, with a view to potentially defining a minimum thickness,
  - Surface characteristics, e.g. positive and negative textures, road surface material; and
  - Moisture and temperature conditions at the time of application including understanding what the critical temperature ranges are outside of which subsequent performance will suffer.

- A lack of understanding of the influence of manual versus mechanical application on performance in terms of the bonding strength of TRMs.

- The potential to increase understanding regarding how different types of road marking material and application method (solvent, thermoplastic or cold plastic etc.) are likely to perform better from a wear perspective; and

- A lack of understanding as to whether areas exposed to heavy snowfall and salt operations could potentially be exposed to more aggressive abrasive action, and how this would influence road marking abrasion.

The RSMA noted that establishing a road trial site where test conditions can be somewhat controlled would contribute to closing a number of the above knowledge gaps. A potential barrier to monitoring road marking wear from the road environment will be the small amount

378 Personal communication with the Road Safety Markings Association (02/10/2019)
that is removed which will therefore be difficult to collect; the only study that has achieved this previously was sampling downstream of a road that had a large proportion of its surface painted red. Sampling paint wear from typical white lines is likely to be much more difficult considering the other debris on the road surface will be far greater in volume.

Another approach is to set up lab experiments that replicate the tyre movement over a simulated surface. This will not verify a reduction in environmental concentrations, but can validate any new materials or design approaches.

A.2.0 Appendix 2 – Prioritisation of Sources
Table A-1: Long list of Microplastic Emission Sources

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub Category</th>
<th>Intentionally added/ Created during use</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial Sports Surfaces</td>
<td>artificial turf Infill</td>
<td>Intentionally added</td>
<td>Eunomia’s 2017 Study for the European Commission developed estimates of the loss to the environment and consulted relevant stakeholders on mitigation and so we have a high level understanding of this source.</td>
</tr>
<tr>
<td></td>
<td>artificial turf Fibres</td>
<td>Created during use</td>
<td>Rubber crumb and cut up carpets used as surfaces. Little is known about how much is used and the loss rates</td>
</tr>
<tr>
<td></td>
<td>Equestrian Surfaces</td>
<td>Intentionally added</td>
<td></td>
</tr>
<tr>
<td>Vehicles</td>
<td>Tyres</td>
<td>Created during use</td>
<td>Tyres are a well-known microplastics source as a result of wear. Tyre wear data is available and pathways are relatively well developed. Eunomia’s 2017 Study for the European Commission developed estimates of the loss to the environment.</td>
</tr>
<tr>
<td></td>
<td>Brake dust</td>
<td>Created during use</td>
<td>Eunomia’s 2017 Study for the European Commission developed estimates of the loss to the environment.</td>
</tr>
<tr>
<td>Synthetic Textiles</td>
<td>Synthetic clothing</td>
<td>Created during use</td>
<td>Direct pathway to surface water identified and a great deal of research has been and continues to be undertaken in this area. Eunomia’s 2017 Study for the European Commission developed estimates of the loss to the environment.</td>
</tr>
<tr>
<td></td>
<td>Carpets</td>
<td>Created during use</td>
<td>This is less known with no direct pathways identified as yet</td>
</tr>
<tr>
<td></td>
<td>Cleaning cloths</td>
<td>Created during use</td>
<td>Similar to clothing, but no research currently</td>
</tr>
<tr>
<td></td>
<td>Hygiene products</td>
<td>Created during use</td>
<td>It is not known how much of these products contain plastic fibres</td>
</tr>
<tr>
<td>Sponges</td>
<td>Household dishwashing sponges</td>
<td>Created during use</td>
<td>Little is known about loss rates</td>
</tr>
<tr>
<td>Pre-Production Plastics</td>
<td>Pellets/powders/flakes</td>
<td>Intentionally added</td>
<td>Eunomia’s 2017 Study for the European Commission developed estimates of the loss to the environment.</td>
</tr>
<tr>
<td></td>
<td>3D printing</td>
<td>Intentionally added</td>
<td>Relates to the feedstock for 3D printing which can be in powder form but to what extent is not known currently.</td>
</tr>
<tr>
<td></td>
<td>Plastics recycling</td>
<td>Created during use</td>
<td>Very little data exists on this, but it may be covered under the measures for pellets in terms of improving the handling to reduce loss.</td>
</tr>
<tr>
<td>Oil and gas</td>
<td>Drilling fluids</td>
<td>Intentionally added</td>
<td>The ECHA estimates 270 tonnes (~0 - 550) to the environment</td>
</tr>
<tr>
<td></td>
<td>Mulch films</td>
<td>Created during use</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Sub Category</td>
<td>Intentionally added/ Created during use</td>
<td>Status</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------</td>
<td>----------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Baling films</td>
<td>Created during use</td>
<td>May be a significant source for terrestrial plastics, but the pathways to water are not well established. May also incorporate biodegradable/oxo-degradable plastics.</td>
</tr>
<tr>
<td></td>
<td>Fertilisers (controlled release fertilisers)</td>
<td>Intentionally added</td>
<td>The ECHA estimates 10,000 tonnes (1,000 - 17,000) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Fertiliser additives</td>
<td>Intentionally added</td>
<td>ECHA estimates 12 500 tonnes (4 000 - 21 000) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Treated seeds</td>
<td>Intentionally added</td>
<td>ECHA estimates 500 tonnes (250 - 1 000) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Capsule suspension PPPs</td>
<td>Intentionally added</td>
<td>ECHA estimates 500 tonnes (100 - 700) to the environment, based on identified pathways</td>
</tr>
<tr>
<td>Paints/coatings</td>
<td>Building</td>
<td>Both</td>
<td>For most kinds of paint there are two states in which the paint could possibly become microplastic; at the solvent stage before setting and after the product is set and is either removed or abraded. The ECHA estimates 2700 tonnes (0 - 5200) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Road</td>
<td>Both</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marine (commercial and domestic)</td>
<td>Both</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anti-skid powder</td>
<td>Intentionally added</td>
<td>Microplastics are manufactured and intentionally added to paint to increase friction in yacht decks, household outdoor decking/playground surfaces</td>
</tr>
<tr>
<td></td>
<td>Laser printer inks</td>
<td>Intentionally added</td>
<td>It is unclear presently what this particular source refers to other than the inference that printer toner may contain microplastics.</td>
</tr>
<tr>
<td>Personal Care Products</td>
<td>Rinse-off containing microbeads (exfoliators/cleansers)</td>
<td>Intentionally added</td>
<td>ECHA estimates 55 tonnes per year to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Other rinse-off (other than exfoliating or cleansing)</td>
<td>Intentionally added</td>
<td>Estimated emissions to the environment by ECHA are 3100 tonnes (1400 - 4900) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Leave on</td>
<td>Intentionally added</td>
<td>ECHA estimates 650 tonnes (300 - 1000) to the environment, based on identified pathways</td>
</tr>
<tr>
<td>Category</td>
<td>Sub Category</td>
<td>Intentionally added/ Created during use</td>
<td>Status</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------------</td>
<td>----------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Detergents</td>
<td>Detergents containing microbeads</td>
<td>Intentionally added</td>
<td>ECHA estimates 100 tonnes to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Detergents containing fragrance encapsulation</td>
<td>Intentionally added</td>
<td>ECHA estimates 80 tonnes (0 - 150) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Other detergents</td>
<td>Intentionally added</td>
<td>ECHA estimates 3 600 tonnes (600 - 6 700) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Waxes and polishes</td>
<td>Intentionally added</td>
<td>ECHA estimates 700 tonnes (300 - 1 200) to the environment, based on identified pathways</td>
</tr>
<tr>
<td></td>
<td>Fishing gear</td>
<td>Created during use</td>
<td>Both of these sources are theoretical losses due to abrasion. Data is likely to be sparse as there is very little data on the use of fishing gear and losses in general.</td>
</tr>
<tr>
<td></td>
<td>Aquaculture</td>
<td>Created during use</td>
<td></td>
</tr>
<tr>
<td>Marine</td>
<td>Abrasive media</td>
<td>Intentionally added</td>
<td>This has been previously identified, but not quantified.</td>
</tr>
<tr>
<td></td>
<td>Ion Exchange Resins</td>
<td>Intentionally added</td>
<td>ECHA estimates 300 tonnes (100 - 500) to the environment, based on identified pathways</td>
</tr>
<tr>
<td>Industrial</td>
<td>Abrasives</td>
<td>-</td>
<td>ECHA estimates 800 tonnes (300 - 1 300) to the environment, based on identified pathways</td>
</tr>
<tr>
<td>Abrasives</td>
<td>Matrix or polymer film for controlled release</td>
<td>Intentionally added</td>
<td>ECHA estimates 0.27 tonnes (0.25-0.29) to the environment, based on identified pathways</td>
</tr>
<tr>
<td>Medicinal</td>
<td>Dentist polish</td>
<td>Intentionally added</td>
<td>Little is known about loss rates</td>
</tr>
<tr>
<td>Products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Insulation</td>
<td>Intentionally added</td>
<td>Small polystyrene balls are often used as an insulation product in buildings. Their application may be controlled, but building demolition may be an issue.</td>
</tr>
<tr>
<td></td>
<td>Furniture</td>
<td>Intentionally added</td>
<td>Small polystyrene balls are often used inside furnishings to provide a filling.</td>
</tr>
<tr>
<td>Others</td>
<td>Kitchen utensils</td>
<td>Created during use</td>
<td>Wear of kitchen utensils during use. Little is known about loss rates</td>
</tr>
<tr>
<td></td>
<td>Buildings</td>
<td>Created during use</td>
<td>The wear of plastic building materials (not paint) during use. Little is known about loss rates</td>
</tr>
<tr>
<td></td>
<td>Indoor dust</td>
<td>Created during use</td>
<td>A generic term that can include a number of different sources of microplastic from in the home. Some of this may already be included under ‘carpets’.</td>
</tr>
<tr>
<td></td>
<td>Biobeads</td>
<td>Intentionally added</td>
<td>Used in some wastewater treatment plants in UK. Some research undertaken by one NGO and EU quantification by Eunomia undertaken based on this.</td>
</tr>
<tr>
<td>Category</td>
<td>Sub Category</td>
<td>Intentionally added/ Created during use</td>
<td>Status</td>
</tr>
<tr>
<td>------------------------</td>
<td>--------------------</td>
<td>----------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Shoe sole wear</td>
<td>Created during use</td>
<td></td>
<td>Little is known about this source, but is due to wear and tear whilst walking</td>
</tr>
</tbody>
</table>

**Table A- 2: Prioritisation of Microplastics Sources**

<table>
<thead>
<tr>
<th>Microplastic Sources</th>
<th>Environmental impact in Scotland</th>
<th>Human Health</th>
<th>Ability to influence stakeholders in Scotland to reduce problem from this item</th>
<th>Public awareness of problem</th>
<th>Current level of public support for action on this item</th>
<th>Risk to Scottish Business</th>
<th>Scope for additional national control</th>
<th>Practicality of further reducing impacts of the plastic item</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial turf and Equestrian Surfaces</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2.20</td>
</tr>
<tr>
<td>Tyre wear</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.20</td>
</tr>
<tr>
<td>Brake dust</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1.45</td>
</tr>
<tr>
<td>Synthetic Clothing fibres</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1.95</td>
</tr>
<tr>
<td>Pre-production plastics</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1.45</td>
</tr>
<tr>
<td>Cosmetics</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1.70</td>
</tr>
<tr>
<td>Abrasion of Paints (Building and Automotive)</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.05</td>
</tr>
<tr>
<td>Washing of paint brushes</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.90</td>
</tr>
<tr>
<td>Road Markings</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.10</td>
</tr>
<tr>
<td>Artificial turf and Equestrian Surfaces</td>
<td>Tyre wear</td>
<td>Brake dust</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-----------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Env Impact - Losses estimated as being in 10s of thousands of tonnes by Eunomia</td>
<td>Env Impact - Losses estimated as being in 100s of thousands of tonnes by Eunomia</td>
<td>Env Impact - Losses estimated as being in 100s of thousands of tonnes by Eunomia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health - Some risk of ingestion via seafood</td>
<td>Health - Concern around health impacts of inhalation of non-exhaust particulate matter</td>
<td>Health - Concern around health impacts of inhalation of non-exhaust particulate matter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influence - Passes through sewerage licenses by Water Industry Commission for Scotland. Many pitches are specified by local authorities</td>
<td>Influence - Road drainage, over which Scottish Government agencies have control, could be improved to increase capture.</td>
<td>Influence - Road drainage, over which Scottish Government agencies have control, could be improved to increase capture.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public awareness and support - low awareness relative to other sources</td>
<td>Public awareness and attention - Growing awareness of this source as secondary microplastics have been given more attention by media.</td>
<td>Public awareness and attention - Growing awareness of this source as secondary microplastics have been given more attention by media.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Business Risk - low reputational or regulatory risk.</td>
<td>Scope - Low potential for Scotland to apply additional controls. European-level action is expected.</td>
<td>Scope - No existing efforts so large scope for national control.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope - No existing efforts so large scope for national control.</td>
<td>Scope - No existing efforts so large scope for national control.</td>
<td>Scope - No existing efforts so large scope for national control.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing impact - Some alternatives exist but have their own environmental impact associated with them.</td>
<td>Reducing impact - Some alternatives exist but have their own environmental impact associated with them.</td>
<td>Reducing impact - Some alternatives exist but have their own environmental impact associated with them.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing impact - Some alternatives exist but have their own environmental impact associated with them.</td>
<td>Reducing impact - No known viable alternatives, however compounds may be developed which improve durability of tyres.</td>
<td>Reducing impact - No known viable alternatives, however compounds may be developed which improve durability of tyres.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificial turf and Equestrian Surfaces</td>
<td>Reasons for Ratings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>---------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Synthetic Clothing fibres**          | Env Impact - Losses estimates as being in the thousands of tonnes by Eunomia  
Health - Road related due to resuspension and concern around non-exhaust particulate matter  
Influence - Road drainage, over which Scottish Government agencies have control, could be improved to increase capture.  
Public awareness and support - minimal awareness of this source.  
Business Risk - some reputational risk as non-exhaust emissions become more important relative to exhaust emissions.  
Scope - Low potential for Scotland to apply additional controls.  
Reducing impact - |
| **Pre-production plastics**             | Env Impact - Losses in 10s of thousands of tonnes as estimated by Eunomia  
Health - Prevalence in airborne fallout and risk of ingestion via seafood.  
Influence - Passes through sewerage licensed by Water Industry Commission for Scotland. Scottish Government may be able to require some degree of communication on losses at point of sale.  
Public awareness and support - High following more recent media attention on microplastics.  
Business Risk - High risk from regulation, damage to reputation and liability.  
Scope - No current controls so there is scope.  
Reducing Impact - Alternatives exist however have their own negative environmental impacts associated with them. |
| **Cosmetics**                          | Env Impact - Losses in 10s of thousands of tonnes  
Health - some risk of ingestion via seafood  
Influence - Passes through sewerage licensed by Water Industry Commission for Scotland  
Public awareness and support - High awareness following media and NGO attention paid to Nurdles  
Business Risk - High risk from regulation and reputational damage  
Scope - European-level control expected and Scotland already trialling a supply-chain approach.  
Reducing impact - no alternatives or scope to reduce impact. |
<table>
<thead>
<tr>
<th>Artificial turf and Equestrian Surfaces</th>
<th>Reasons for Ratings</th>
</tr>
</thead>
</table>
| Abrasion of Paints (Building and Automotive) | Env Impact - Losses have been estimated in the thousands of tonnes per year by the ECHA. This includes leave on which may be lost as they include products like deodorants which may be washed off, though they have not typically been included in the scope of possible losses.  
Health - some risk of ingestion via seafood  
Influence - Passes through sewerage licenses by Water Industry Commission for Scotland  
Public Awareness and support - High following ban of microbeads and associated media attention  
Business Risk - High risk from further regulation at a national level, reputational damage, and liability  
Scope - Microbeads have been banned. UK Government has spoken about extending the ban to other rinse off cosmetic but has yet to take action. No action suggested for leave-on cosmetics. Scotland could take action sooner.  
Reduction Impact - alternatives exist for some product functions |
| Washing of paint brushes | Env Impact - Losses are estimated in 10s of thousands of tonnes by ECHA  
Health - some risk of ingestion via seafood  
Influence - Passes through sewerage licensed by Water Industry Commission for Scotland, where captured rates could potentially be improved upon.  
Public awareness and support - Not a particularly popularised source. Not been highlighted in the media.  
Business Risk - some risk from regulation, damage to reputation and liability, however low relative to other sources. |
| Road Markings | Env Impact - ECHA estimates 2700 tonnes (0 - 5200) lost to the environment.  
Health - Some risk of ingestion via seafood  
Influence - Further guidance could be issued to contractors and the public about disposal of waste paint.  
Public awareness and support - Not a particularly popularised source. Not been highlighted in media.  
Business Risk - some risk from regulation, damage to reputation and liability, however low relative to other sources. |
| Agricultural fertilisers and treated seeds | Env Impact - Losses are estimated to be in the 10s of thousands of tonnes by Eunomia  
Health - some risk of ingestion via seafood  
Influence - Road markings applied by public authorities which Scottish Government could influence. Losses pass through sewerage licensed by Water Industry Commission for Scotland  
Public awareness and support - Not a particularly popularised source. Not been highlighted in media.  
Business Risk - some risk from regulation, damage to reputation and liability, however low relative to other sources.  
Scope - There may be scope to encourage green public procurement.  
Reduction impact - Alternative products which may be more robust and therefore less likely to abrade may be available. |
<table>
<thead>
<tr>
<th>Artificial turf and Equestrian Surfaces</th>
<th>Reasons for Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Detergents</strong></td>
<td>Env Impact - ECHA estimated losses of between 5,000 tonnes and 38,000 tonnes to the environment</td>
</tr>
<tr>
<td></td>
<td>Health - Some risk of ingestion</td>
</tr>
<tr>
<td></td>
<td>Influence - Controls could be imposed on products. Farmers could be advised on product selection.</td>
</tr>
<tr>
<td></td>
<td>Public awareness and support - Not a particularly popularised source. Not been highlighted in media.</td>
</tr>
<tr>
<td></td>
<td>Business Risk - some risk from regulation, damage to reputation and liability, however low relative to other sources. Terrestrial microplastics receiving greater attention so risks are likely to grow.</td>
</tr>
<tr>
<td></td>
<td>Scope - National controls such as bans on specific products could be imposed.</td>
</tr>
<tr>
<td></td>
<td>Reducing Impact - Some potential non-polymer alternatives but there is low industry confidence in them.</td>
</tr>
<tr>
<td><strong>Carpets / Soft furnishings</strong></td>
<td>Env Impact - Low losses - ECHA estimates 3 600 tonnes (600 - 6 700) to the Environment</td>
</tr>
<tr>
<td></td>
<td>Health - Some risk of ingestion.</td>
</tr>
<tr>
<td></td>
<td>Public Awareness and Support - Not a particularly popularised source. Not been highlighted in media. However, attention given to textiles may bring attention to detergents.</td>
</tr>
<tr>
<td></td>
<td>Business Risk - Some risk from regulation, damage to reputation and liability, however low relative to other sources.</td>
</tr>
<tr>
<td></td>
<td>Scope - No controls currently exist</td>
</tr>
<tr>
<td></td>
<td>Reducing Impact - Alternatives exist for some functions provided.</td>
</tr>
<tr>
<td><strong>Fishing/aquaculture gear</strong></td>
<td>Env Impact - the contribution of carpets/soft furnishing to the airborne concentration of microplastics is unknown however some studies have suggested elevated concentrations indoors. This source therefore warrants some analysis.</td>
</tr>
<tr>
<td></td>
<td>Health - Risk of inhalation - some sources suggest that polypropylene makes up a large fraction of airborne microplastics.</td>
</tr>
<tr>
<td></td>
<td>Public Awareness and Support - Not a particularly popularised source. Not been highlighted in media.</td>
</tr>
<tr>
<td></td>
<td>Business Risk - some risk from regulation, damage to reputation and liability, however low relative to other sources.</td>
</tr>
<tr>
<td></td>
<td>Scope - No controls currently exist</td>
</tr>
<tr>
<td></td>
<td>Reducing Impact - Alternatives exist, but may not be popular.</td>
</tr>
<tr>
<td>Artificial turf and Equestrian Surfaces</td>
<td>Reasons for Ratings</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>---------------------</td>
</tr>
</tbody>
</table>
| **Oil and Gas drilling fluids**        | Env Impact - No previous attempts have been made to quantify losses from this source. However, given the industry's importance in Scotland some analysis is warranted.  
Health - Some risk of ingestion via seafood  
Influence - Scope for Scottish Government to support the development of best practice and to raise awareness of alternative materials and practices within industry.  
Public Awareness and Support - Although public awareness of marine litter and ghost fishing might be quite high, awareness of this potential source of microplastics is likely low.  
Business Risk - some risk from regulation, damage to reputation and liability, however low relative to other sources.  
Reducing Impact - Some alternatives materials and fishing methods are being explored but are not yet extensively tested. |
## A.3.0 Appendix 3 - Supplemental Data and Calculations

### A.3.1 Artificial Turf

**Table A-4: Calculation Method for Total Installed Infill in Scottish Football Pitches in 2017**

<table>
<thead>
<tr>
<th>Pitch</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Number Pitches</th>
<th>Installed Area (m²)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Size Football¹</td>
<td>106</td>
<td>71</td>
<td>7,526</td>
<td>288</td>
<td>1,754,302</td>
<td>64%</td>
</tr>
<tr>
<td>Small Football²</td>
<td>36</td>
<td>27</td>
<td>972</td>
<td>1,031</td>
<td>1,002,428</td>
<td>36%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2,756,730</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SBR Infill Installed Density (kg/m²)</th>
<th>16.1³</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Installed Infill (t)</strong></td>
<td>44,295</td>
</tr>
</tbody>
</table>

**Notes:**

1. *Football pitches can vary in size although the English Football Association specified a pitch of 106x71m in 2010. This has since been updated to 116x76m in 2012 but the earlier figure is used to account for legacy installations.*

2. *5-a-side recommended pitch size by Scottish FA.*

3. *Figure calculated by data provided by FIFA as an average of the SBR infill in pitches installed under the FIFA Quality Programme which accounts for around 20% of full sized pitches in Europe.*

4. *Figures calculated from data provided by ESTO.*
Table A- 5: Artificial Turf Estimated Infill Losses in Scotland

<table>
<thead>
<tr>
<th></th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infill Loss $^b$</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1%</td>
<td>4%</td>
</tr>
<tr>
<td>Tonnes</td>
<td>688</td>
<td>2,751</td>
</tr>
</tbody>
</table>

Pathways and Sinks

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Disposal</td>
<td>45%</td>
<td>1,238</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Drains $^a$</td>
<td>5%</td>
<td>138</td>
</tr>
<tr>
<td>Internal drains $^a$</td>
<td>5%</td>
<td>138</td>
</tr>
<tr>
<td>Soil/Grass</td>
<td>45%</td>
<td>1,238</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>688</td>
</tr>
</tbody>
</table>

Notes:

a) Indicative figures derived from Annet Weijer, and Jochem Knol (2017). Internal drains are from player transported infill into either a changing room or to their homes. It is unclear how much of this would actually end up in the drains at present.

b) Losses from overall installed infill from EU Study

A.3.2 Road Paint

Table A- 6: Typical thermoplastic road marking paint composition

<table>
<thead>
<tr>
<th>Material</th>
<th>Range, weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder (15-25%w)</td>
<td>8-15</td>
</tr>
<tr>
<td></td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>0-5</td>
</tr>
<tr>
<td>Fillers (75-85%w)</td>
<td>5-10</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbon resin</td>
<td></td>
</tr>
<tr>
<td>Plasticizer</td>
<td></td>
</tr>
<tr>
<td>Thermoplastic elastomer</td>
<td></td>
</tr>
<tr>
<td>Pigment (e.g. TiO2, ZnO)</td>
<td></td>
</tr>
<tr>
<td>Extender (e.g. CaCO3)</td>
<td></td>
</tr>
<tr>
<td>Glass Beads</td>
<td></td>
</tr>
<tr>
<td>Aggregates</td>
<td></td>
</tr>
</tbody>
</table>

### A.3.3 Artificial Turf

**Table A-7: Cost Estimates for Mitigation Measures per 11-a-side Pitch**

<table>
<thead>
<tr>
<th>Item</th>
<th>Normal</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Barrier – steel plate (pressure treated wood)</td>
<td>£4,400</td>
<td>£22,000</td>
</tr>
<tr>
<td>Drain filter</td>
<td>£4,400</td>
<td>£5,200</td>
</tr>
<tr>
<td>Granules collection at pitch entrances</td>
<td>£3,700</td>
<td>£4,600</td>
</tr>
<tr>
<td>Shoe brush at pitch entrances</td>
<td>£370</td>
<td>£460</td>
</tr>
<tr>
<td>Misc</td>
<td>£900</td>
<td>£9,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>£13,770</strong></td>
<td><strong>£61,260</strong></td>
</tr>
</tbody>
</table>