Prepared for Waka Kotahi NZ Transport Agency

FRAMEWORK AND GUIDANCE FOR THE ASSESSMENT OF ENVIRONMENTAL HARM FROM ALTERNATIVE MATERIALS AND PRODUCTS PROPOSED FOR USE IN THE ROAD CORRIDOR

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This report ('Report') has been prepared by WSP exclusively for Waka Kotahi NZ Transport Agency ('Client') in relation to Framework for Environmental Harm Assessment of Materials and Products used in the Road Corridor ('Purpose') and in accordance with the Justification for Additional Services dated 16th February 2023. The findings in this Report are based on and are subject to the assumptions specified in the Justification for Additional Services dated 16th February 2023. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

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1 INTRODUCTION

This report provides a framework and guidance for the assessment of the potential for environmental harm from the proposed use of alternative products and materials (including recycled materials) in the road corridor. Environmental harm is defined as any actual or threatened adverse impact on, or damage to, the environment. The assessment framework presented suggests key factors to consider when evaluating potential environmental issues. Given the wide range of products and materials that may need to be considered, detailed test methods are not specified, but guidance is provided on the key principles for development or adaptation of appropriate procedures for assessing the most common modes of environmental harm.

1.1 SCOPE

This guide is intended to provide advice to aid in the assessment of environmental effects of alternative – that is any novel or not previously used products, materials and additives used in road pavement (such as alternative aggregate and bituminous materials) and, those used for road marking, road furniture, landscaping, drainage, footpaths and cycle ways within the confines of the road corridor.

This guide covers adverse environmental effects arising from use of alternative materials or products during construction and maintenance, over the service life and the ultimate disposal of the materials or products.

The potential of alternative materials or products for long-term effects from the gradual degradation and break-down of materials or products must be considered. Products and materials used in the road corridor are exposed to abrasion and weathering for decades.

Adverse environmental effects may arise from, but are not limited to:

- Leaching or wash-off of chemicals that are ecotoxic to aquatic or terrestrial environments
- Emission of volatile compounds such as solvents, or aerosols to the atmosphere
- Generation of micro-particulates such as micro-plastics through weathering and abrasion
- Adverse environmental impacts during manufacture of the material or product
- Materials that cannot be recycled or that complicate disposal or prevent the recycling of other materials to which they have been added
- Using materials or products that contribute to the inefficient use of resources particularly non-renewable resource (i.e. virgin plastics).

The guide does not cover:

- Direct effects on human health and safety that may arise from handling, storage and usage of materials and products
- Dust generation and sediment run-off from natural aggregate and soil materials that occurs during pavement construction and maintenance. These are controlled

through the Resource Management Act (1991) as well as local government regulations such as local authority district plans and unitary authority plans

  - Methodologies for modelling of movement or dispersion of contaminants in the environment or assessment of wider, long –term ecological effects. Note that data generated on leaching rates etc. that may be conducted as part of assessments under this framework may be useful for modelling purposes
  - High embodied greenhouse gas emissions / carbon equivalent CO_2e footprint of the material which are considered through the Waka Kotahi Resource Efficiency Policy.

This framework aligns with the Waka Kotahi Environment and Social Responsibility Policy (Waka Kotahi, 2022a) commitment to “Reducing emissions and mitigating the effects of land transport on the environment and public health” and also one of Auckland Transport’s strategic business objectives: improving the resilience and sustainability of the transport system and significantly reducing the greenhouse gas emissions it generates.

1.2 AUDIENCE

The target audience for this document is broad. It may be used by suppliers, engineers, contractors, roading agencies, road controlling authorities (RCAs) and government. It is intended to provide guidance for whenever there is consideration of use of alternative materials or products in the road corridor.

1.3 UNDERLYING PRINCIPLE

The person (e.g. supplier/contractor) proposing the alternative material will need to do the initial information gathering. If this process indicates that further assessment/testing is required they will need to engage a suitably qualified, credible, and competent assessor/subject matter expert (SME) to undertake the assessment.

The principal (e.g. Waka Kotahi project manager) or appropriate person in the relevant RCA will need to confirm the decision to use an alternative. In addition a technical departure may be required to be sought for the use of an alternative where a specification does not exist or does not specifically allow for alternative material use.

The aim of the assessments made using this guide is that the alternative materials and products used in the road corridor should have the smallest possible adverse environmental effect. And to ensure any unintended environmental impacts are transparently evaluated before alternative materials are utilised. The assessment process might have to consider a variety of materials or products for the specific purpose, before choosing one. A conservative approach should always be taken to minimise the risk of potential environmental issues.

1.4 ASSESSORS

Decisions and assessments made on the potential for adverse environmental effects through the use of alternative materials are based on interpretation of the technical literature, standards and potential physical test or Life Cycle Assessment (LCA) results. In many cases standard methodologies and specifications for comparisons may not be available. Assessments must therefore be made by a suitably qualified, credible, and competent subject matter expert (SME) in each case. The expert must hold a nationally recognised qualification in the relevant field (e.g. environmental science) with at least 8 years' experience in the subject area and if appropriate, professional registration in the discipline.

2 PRINCIPLES OF ASSESSMENT

The following describes the principles that should be applied, when required, throughout the assessment.

2.1 COMPARISON TO SPECIFICATIONS

The simplest approach to making assessments is to do a comparative analysis of the compositional data i.e. information from manufacturer or material supplier including safety data sheets (SDS), literature review, production route and material source; and (if available) contaminant emission rates on the material or product to the relevant specifications and the intended application.

Waka Kotahi specifications for materials and products used in the road corridor are almost exclusively concerned with various aspects of engineering performance. Compositional requirements are included only if they directly affect engineering performance. Two exceptions to this are the:

- M07 Specification for Road Marking Materials: which limits the concentration of certain heavy metals used in reflective glass beads and notes information around SDS and EPA approval
- M04 Specification for basecourse aggregate: which cautions against high pH leachate from recycled crushed concrete entering waterways.

There are currently no widely accepted standards specifically governing chemical composition for road construction or corridor materials aimed at preventing environmental harm.

The potential for environmental harm associated with alternative materials should be considered prior to use on the road corridor and a number of lines of evidence would likely be required to be investigated to understand if when used an environmental harm would result. Where relevant specifications or information for the material or product does not exist, one such line of evidence could include consideration of waste acceptance criteria. These are discussed in section 4.4.

2.2 BENCHMARKING

To provide benchmark values, it may be useful to use the properties or composition of existing equivalent conventional materials/products used in the same application as that of the proposed material/product.

For example, the ecotoxicity of leachate from a base course material containing a chemical stabiliser could be compared to that of the natural aggregate materials under the same leaching conditions. Similarly, volatile solvent emissions from a road marking paint could be compared to that arising from paints already in use or those from cut-back bitumens, to contextualise and understand the scale of the potential harm.

2.3 INTERNATIONAL DATA AND USAGE

For materials or products whose composition is well-defined, assessments made solely based on overseas experience or testing may be sufficient, especially if compliance with international specifications for controlling environmental harm is demonstrated. Such data must be credible, relevant, and importantly applicable to the New Zealand environment, maintenance and construction practices.

3 AVENUES FOR ENVIRONMENTAL HARM

This section sets out the key avenues for environmental harm covered in this guidance document.

The main three are direct contamination of the environment through:

- Leaching of contaminants by rain or ground water (this also includes the run-off of liquid products into waterways or soils and mechanical wash-off of unbound materials by the action of rain- water)
- Volatile emissions or aerosol formation (most likely during spraying operations)
- Particulate formation (e.g. microplastics) through breakdown and mechanical abrasion of surfaces from trafficking (including foot and cycle traffic) and wind and rain, or through UV degradation.

Other environmental considerations:

- The embodied carbon footprint (i.e. embodied CO_2e) of the material or product
- Resource efficiency (whether the application is an efficient use of resources - especially non-renewable resources)
- Recyclability and end of life disposal options.

LEACHING

Rain or groundwater running over or through materials or products used in the road corridor can result in extraction and dispersal of harmful contaminants to the adjacent environment. Leaching is a gradual process and is distinct to loss of the bulk material through the mechanical action of water producing sediment e.g. dust suppression chemicals or resulting in “wash-off” of bitumen emulsions for example.

Leaching and wash-off are the primary modes through which contaminants from roading construction materials could enter the environment.

VOLATILE EMISSIONS

In some cases, volatile compounds such as solvents or airborne liquid droplets (aerosols) may be generated during spray application of various products and disperse into the environment. The most obvious sources in the road corridor (excluding vehicular emissions) are from asphalt hot-mix, spraying of cut-back bitumen (hot or in emulsified form), road marking paints and weed killers. In the latter case existing EPA controls should be applied to minimise spray-drift into waterways etc. Potentially volatiles may also be emitted over a long period once materials have been applied and are in-service.

The most likely harmful effects on the environment from volatile emissions are in terms of contributing to global warming and photo-chemical, ozone formation. Volatile organic compounds (VOCs) for example are usually calculated to have Global Warming Potential (GWP) factors several times that of CO_2 and those for chlorinated solvents are thousands of times greater.

The effect can normally be calculated without need for physical measurements, from the percentage solvent in the material (assuming complete evaporation). In certain cases of semi-volatile solvents for example, simple laboratory measurements may be needed to assess whether the rate of evaporation and hence total expected volatile emissions are significant.

PARTICULATE FORMATION

In-service weathering or mechanical abrasion of materials and products used in the road corridor may result in the formation of airborne particulates (dust) or larger particulates (including microplastics) that may be washed via road run-off during rain or storm events into drains, waterways, or the surrounding environment. Dust and particulates may settle or be washed onto road-adjacent agricultural land with possible consequences for livestock or crops (Wu et al. 2021).

Particulates can be harmful to organisms in the environment directly through ingestion and also due the large surface area to mass ratio increasing the potential rate of leaching. The main concern is the transmission of particulates into the aquatic and terrestrial environments.

OTHER ENVIRONMENTAL CONSIDERATIONS

CARBON FOOTPRINT

The manufacturing and transport processes associated with the products and materials used in the road corridor contribute to global warming through the emission of greenhouse gases (GHG), including CO_2. The Climate Change Policy for Land Transport Infrastructure Activities (Waka Kotahi 2023) requires Waka Kotahi infrastructure activities to assess and reduce GHG emissions throughout the whole of life of land transport infrastructure. For infrastructure delivery projects, applying the requirements of P48: Specification for resource efficiency for infrastructure delivery gives effect to this policy as the specification requires emissions associated with construction projects and maintenance activities to be measured, reported and, for larger projects, reduction targets set.

An indication of the GHG emissions attributable to a product or material can be assessed by reviewing the Environmental Product Declaration (EPD or undertaking an LCA).

The embodied carbon footprint refers to the total CO_2e per kg associated with the manufacture, transport, use and ultimate disposal of a material or product.

Key steps in undertaking a LCA include:

- Definition of the system boundaries (i.e. at which points in the life cycle to begin and end the analysis). For example, the energy required to extrude a plastic product may be included in calculations but not the energy required to manufacture the steel needed to make the extrusion plant.
- Determining the materials used, energy inputs and outputs of emissions. The calculation will depend on how and from what materials the product is manufactured, its transport and how it is used and ultimately disposed of.

The principles of LCA methods have been standardised, including:

- ISO 14025 Environmental labels and declarations - Type III environmental declarations - Principles and procedures

- ISO 14040, Environmental management – Life cycle assessment - Principles and framework. An overview of the LCA process, critical review and limitations of the LCA method
- ISO 14044, Environmental management — Life cycle assessment - Requirements and guidelines.
- ISO 14048, Environmental management - Life cycle assessment - Data documentation format
- ISO 14067, Greenhouse gases — Carbon footprint of products - Requirements and guidelines for quantification.

The product may already have an existing Environmental Product Declaration (EPD), which should be registered with an independent organisation such as EPD Australasia (https://epd-australasia.com/) is essentially an LCA summary and describes the environmental impacts over the lifespan of the material or product. The EPD should comply with ISO 14025. An example of an LCA for road marking paints used in Germany has been published by Cruz et al. (2016).

Additional information on undertaking LCAs relevant to New Zealand can be found at the Lifecyle Assessment Association of New Zealand (https://lcanz.org.nz/).

RESOURCE EFFICIENCY & RECOVERY

Resource efficiency is defined as “using the earth’s limited resources in a sustainable manner while minimising impacts on the environment” (European Commission, 2022). The supply of natural resources is of course limited and as the population increases the pressure on these resources continues to increase, this creates risk in resource scarcity and ensuring security of supply.

The Waka Kotahi strategy for resource efficiency for infrastructure delivery and maintenance in New Zealand is presented in *Te Hiringa o te Taiao* (Waka Kotahi 2021b). The intention is for it to be adopted by its partners and contractors. A key focus area is waste minimisation through use of alternative (renewable) materials and recycling.

Waka Kotahi standards and specifications setting out the principles of resource use efficiency at the project level include:

- Z/19: Taumata Taiao - Environmental and sustainability standard
- P48: Specification for resource efficiency for infrastructure delivery. Only required for Waka Kotahi infrastructure improvement projects. It is a tiered system based on the total capital value of a contract and outlines resource efficiency requirements in each case.
- P49: Sustainability rating scheme specification.

Find all the above at: https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/resource-efficiency/tools-standards-and-specifications/

Resource efficiency measures have also been embedded in the network outcome contract (NOC) maintenance key results area key performance indicators. This can be found at: https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/network-outcomes-contracts/resources-and-manuals/guidelines-and-reference-documents/

Examples of how resource efficiency has been implemented on New Zealand projects can be found here: https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/resource-efficiency/what-resource-efficiency-looks-like-in-practice/

RECYCLABILITY AND END OF LIFE DISPOSAL

Recycled materials can potentially be used in many different road corridor products from the pavement to road furniture (e.g. road signs, edge markers). Waka Kotahi specifically allows a limited number of types of recycled materials to be used on projects (Waka Kotahi 2022, NZTA 2006), namely:

- Crushed glass
- Crushed concrete
- Glenbrook smelter slag (otherwise referenced as Ground Granulated Blast-furnace Slag (GGBS)
- Recycled asphalt pavement (RAP)
- Recycled aggregate

Use of other recycled materials such ground tyre rubber and other type of demolition waste are not necessarily excluded but their suitability would need to be considered on a case-by-case basis by Waka Kotahi or the relevant road controlling authority.

Although the use of recycled materials aids the goal of resource minimisation, care needs to be taken that other environmental risks/dis-benefits are not inadvertently introduced. This is most likely through the introduction of contaminants (e.g. heavy metals in recycled electronics glass or crushed concrete from a galvanising factory site) or by contamination of another material that can now no longer be used as clean fill at the end of its life. To minimise such risks the source of the recycled material should be verified and recorded by the supplier. If this is not feasible as may be the case for manufactured products such as geo-textiles or road marking posts the overall chemical composition of the product would need to be used in the assessment.

4 FIRST STAGE ASSESSMENT

To minimise potentially expensive testing to assess risk to the environment an initial assessment should be made based on the:

- chemical composition
- existing Government or local authority regulations
- scope of the application
- potential receiving environment for contaminants
- international practice and experience if available
- comparative analysis with existing materials/products.

Figure 1 shows the preliminary decision tree that can used to determine whether more detailed assessment or second stage physical testing is necessary, and the specific types of evaluation required. The following sections provide more detailed explanation of the elements in Figure 1.

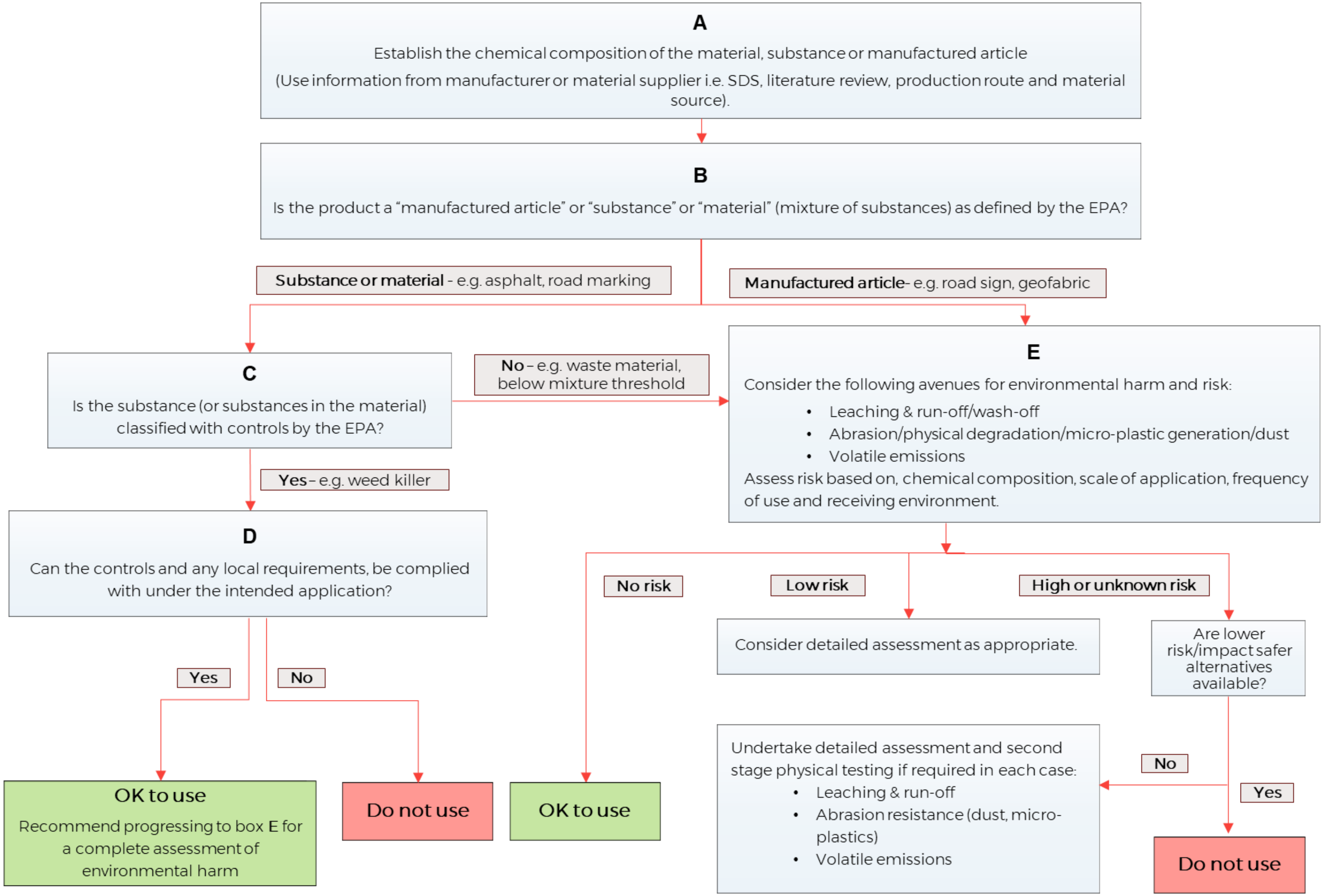

Figure 1 Initial assessment process

4.1 (A) CHEMICAL COMPOSITION

Knowledge of the chemical composition of the material or product being assessed is essential for properly assessing its potential for environmental harm. Detailed information on composition, including minor additives and contaminants may be available from the supplier (e.g., as quality control certificates, SDS or environmental product declarations) or may be able to be calculated from data for the raw materials used. Usually, the substance comprising the bulk of the material will be known. But in many cases for recycled materials, the materials or products being considered will be highly complex mixtures and it is not practicable to fully characterise their compositions. In that case chemical analysis to identify the presence of likely specific contaminants or additives known to be environmentally harmful will be required.

Standard methods exist to analyse for many of the compounds of interest, but these may require an initial extraction step or other sample treatment processes so that the analysis method will need to be tailored to the specific material in question.

For a specific material, the specific compounds to be analysed for may be able to be identified from existing knowledge of that type of material or product and its production route. For recycled materials, the source of the material, if known, may be a good indicator of potential contaminants.

Examples of potentially harmful components include but are not limited to:

- Dioxins, Polychlorinated biphenyls (PCBs)

These are examples of Persistent Organic Pollutants (POPs). They are such named because they are extremely stable and do not readily breakdown. There are several hundred of these compounds, with varying degrees of toxicity. They have high affinity for fatty substances and tend to accumulate in plankton, plant leaves and soil. Once ingested, they can quickly accumulate to high concentrations in the biota, as it travels up the food chain i.e. one organism ingested by another, resulted in high concentrations in tissue. This can result in reproductive and developmental problems, damage to the nervous and immune systems, disruption of hormonal processes, cause cancers and even result in death (US EPA, 2023a, 2023b).

- Heavy metals i.e. lead, cadmium, chromium, arsenic etc.

Heavy metals such as lead, cadmium, chromium and arsenic are highly toxic and if released into the environment accumulate in soils, sediments, water and air. Exposure through these avenues can result in exposure and ingestion by the biota. The most common effects are decreased or inhibited growth, disrupted photosynthesis, neurological effects on aquatic or terrestrial organisms and death (Briffa et al., 2020)

- Polyaromatic hydrocarbons (PAH)

PAHs are found in oil deposits and are produced in the combustion of organic matter. Once released, they can accumulate in the air, water and soil. They are most often ingested by algae and some invertebrates which have limited ability to metabolize PAHs. PAHs therefore accumulate in these organisms, causing endocrine disruption, tissue-specific toxicities and cancer in aquatic life (Honda and Suzuki, 2020),

- Volatile organic compounds (VOC)

These are a group of compounds which have a low vapour pressure at ambient temperatures. Their most common environmental effects are their reaction with oxides of nitrogen to form ozone in the troposphere (ground level). Ozone is protective to our atmosphere in the upper levels, but at ground level it is hazardous to plants and negatively affects crop growth (CROWCON, 2023).

- Phenols

Phenol is a chemical used widely in industrial processes. In the environment it mostly persists in the air and in water. Once introduced to the environment, it can have adverse effects on ecosystems – effecting algae, protozoa, invertebrates and vertebrates. The effects can range from reduced fertility, decreased juvenile survival rate, inhibition of growth and death (Babich and Davis, 1981).

- Phthalates

Phthalates are most commonly found as plasticisers in industrial processes. They are well known endocrine disruptors and can interfere with reproduction and development of aquatic organisms (Oehlmann et al.. 2009, Tran et al., 2022).

- Compounds that raise or lower the pH of ground or surface water

The main risk is to organisms and plants that are sensitive to pH and can result in inhibited growth of plants or animals and in some cases death of certain species.

- Water soluble salts

The main risk of compounds that are water soluble is that they can dissolve in water. This can lead to the uptake of such materials by the biota accumulating within organism or alteration of the pH of the water or soil, or salinity of freshwater which could lead to altered functioning or death depending on the type of organism involved.

The Environmental Protection Agency (EPA) maintain databases, that may be useful, with information on hazardous substances:

- The Chemical Classification and Information database (EPA 2022a)
- New Zealand Inventory of Chemicals (EPA 2022b)

4.2 (B) CLASSIFICATION OF THE PRODUCT OR MATERIAL

The EPA classifies and controls hazardous substances under the Hazardous Substances and New Organisms (HSNO) Act (1996).

Manufactured articles are normally not covered by the HSNO Act however if manufactured in New Zealand, their component substances may be. Manufactured articles are considered by the EPA to be those for which the intended use is primarily to do with physical form or shape, rather than chemical composition. In the road construction context, road signs, drainpipe and geofabrics, for example, would be considered manufactured articles, but asphalt mix would not.

4.3 (C & D) EPA CONTROLS

The EPA classifies and controls hazardous substances under the HSNO Act (1996).

Under the HSNO Act, a hazardous substance is any substance that exceeds the level defined in regulations of any of the following properties:

- An explosive nature (including substances, articles and pyrotechnics such as fireworks)
- Flammability
- Ability to oxidize (i.e. to accelerate a fire)
- Corrosiveness
- Acute or chronic toxicity (adverse human health effects). This is further broken down into subclasses: oral, dermal, inhalation, aspiration hazard, skin irritation, eye irritation, respiratory or skin sensitisation, germ cell mutagenicity, carcinogenicity, reproductive toxicity and specific target organ toxicity
- Ecotoxicity, with or without bioaccumulation (i.e. it can kill living things either directly or by accumulating in the environment). This is further broken down into subclasses: Hazardous to the aquatic environment acute or chronic, to soil organisms, terrestrial vertebrates, hazardous to terrestrial invertebrates and substances designed for biocidal action.
- Can generate a hazardous substance on contact with air or water. Note that exposure of materials to ultra-violet (UV) light or other environmental conditions for extended periods has the potential in some cases to result in formation of ecotoxic compounds.

The Act requires that approval is sought (from the EPA) for all hazardous substances that are deliberately manufactured, formulated in, or imported to New Zealand (including naturally occurring substances), for the first time (i.e., if not legally present in New Zealand before 2 July 2001). Existing hazardous substances (i.e. those legally present before 2 July 2001) have been transferred from the older legislation (such as the Dangerous Goods Act 1974 and the Toxic Substances Act 1979). If there is uncertainty about whether or not the alternative material or product has been approved for use in New Zealand under the HSNO Act it is possible to search the EPA website for further information, alternatively a Status of Substance determination can be requested from the EPA. The EPA have published a guide: “Risk Assessment Methodology for Hazardous Substances” for applicants outlining the type of data needed and methods used by the EPA to assess potentially hazardous substances (EPA 2020).

The Act does not normally require approval to be sought for hazardous waste materials, which fall outside its purview unless imported. ‘Waste materials’, in this sense are materials that have no value or present a disposal cost to the generator at the time of initial generation. However, wastes that are subsequently processed or modified (i.e. manufactured) may be considered a new material and, if hazardous, require EPA approval. Clarification as to whether a given material can be considered a waste or not, and whether it may be exempt from the Act, should be sought from the EPA. Non-hazardous new substances or wastes do not need approval. The creation of waste by-products and materials should be avoided or minimised.

Controls imposed by the Act extend for the lifetime of the substance. Hence use of materials derived by processing post-consumer wastes for example may still be governed by the original controls on the component substances.

4.4 (E) RISK ASSESSMENT

This section outlines the risk assessment considerations for the material or product. The most likely avenues for environmental harm are considered (set out in section 3) and the overall risk is then assessed taking into consideration chemical composition, type and scale of application, frequency of use and the receiving environment.

4.4.1.1 CHEMICAL COMPOSITION

It may be possible to assess risk of release to the environment/environmental harm by comparing compositional information on the material to existing national or international standards, or to benchmark against equivalent existing materials used in the same application and already accepted for use.

If it is difficult to find any information available, presented below are a few alternative examples of lines of enquiry for understanding and assessing risk that may be useful. However these should be used as a last resort.

- **Comparison is to regulations governing contaminant levels in waste that can be disposed of in 'uncontrolled' Class B landfills.** The New Zealand the Ministry for the Environment defines Class B landfills as those that have, 'limited or no engineered systems designed to collect landfill leachate or gases and may be in areas that pose a risk to the environment (for example, sited over highly permeable sands and/or gravels, active faults, or floodplains)", (MfE 2022). These landfills typically only accept the least contaminated waste because rainwater ingress and leachate runoff are not well controlled. This is similar to materials proposed for use in the road corridor which are exposed to water and water movement but where leachate or other emissions are not controlled. Materials placed in such landfills must meet limits for various contaminants such as metals, PAH and phthalates.
- **Comparison to the the New Zealand Waste List (L-Code)** – it is neither an Act nor regulation, but is a database maintained by the Ministry for the Environment that provides guidance on wastes generated by various industry sectors and municipal wastes (MfE 2015). The L-Code contains a wide range of wastes including those that are regarded as hazardous. Another option would be to consult the L-Code to evaluate whether a recycled material for use in road construction is likely to contain hazardous substances that may have an adverse impact on the environment.

However, it may not be possible to assess risk adequately based only on compositional information in which case it will be necessary to conduct testing to assess the potential for leaching and particulate loss. These processes are discussed in section 5.

4.4.1.2 SCALE OF APPLICATION AND FREQUENCY OF USE

Materials or products that are considered should be further assessed in terms of their expected lifetime, the extent of their application over the network and frequency at which they are likely to be used. Products that are to be used only in very limited quantities or in a very localised area or only infrequently would also have only a limited total harmful impact. Materials or products that will be used widely or very frequently should be considered further.

4.4.1.3 RECEIVING ENVIRONMENT

Assessments should consider the sensitivity and use of the receiving environment. The sensitivity would include factors such as, but are not limited to the biota of the area, the type of receiving environment e.g. freshwater vs. marine or whether the environment is actively flushed, flowing or estuarine (if water movement is slow or infrequent – contaminants may accumulate in ecologically significant levels).

An example of how the sensitivity of an aquatic environment can be assessed but could be modified and applied to other environments can be found in Table 1.

Table 1 Sensitivities of aquatic environments (Gardiner and Armstrong: page 26. LTNZ 2007)

	HIGH SENSITIVITY	MODERATE SENSITIVITY	LOW SENSITIVITY
Environment	Strongly depositional e.g. Enclosed/sheltered harbour, embayment, Estuaries, low gradient or velocity streams or rivers, small lakes, some larger lakes, wetlands.	Moderately depositional e.g. Semi-enclosed harbours, embayments, moderate gradient or velocity streams or rivers, large lakes.	Dispersive e..g Open/exposed coastal environment, high gradient or velocity streams or rivers.
Ecological values	Water body has high formal conservation status e.g. national park, reserve, marine reserve, wildlife refuge, protected natural area or identified as regionally or naturally significant, or Rare, threatened, endangered species present (flora or fauna), or Plant or animal community with high species diversity, or Rare habitat or good representative example for region, or Particularly valuable habitat e.g. whitebait spawning area, or Particularly high-quality habitat/water present e.g. upper reaches of some streams or springs.	No formal conservation status, and Absence of rare, threatened, endangered species, and Moderate species diversity, and Moderate habitat diversity, and Habitat values moderate.	No formal conservation status, and Absence of rare, threatened, endangered species, and Low species diversity, and Low habitat diversity, and Habitat values low e.g. significant physical modification and/or contaminant inputs from sources other than road runoff.

The end use of the receiving environment may also be considered. In protecting harm to the environment, it ensures these activities are also protected (LTNZ, 2007).

- Areas used or valued for food gathering including traditional Māori food sources (e.g. shellfish, koura, watercress), or
- Areas of contact recreation (e.g. swimming, paddling), or
- Areas of non-contact recreation (e.g. fishing, canoeing, windsurfing, boating), or
- Areas of cultural/spiritual values associated with water body, downstream water supply, or
- Areas of economic value e.g. tourism.

Assessments of impacts on receiving environments are usually qualitative, in which the likelihood of contamination of the environment and the resulting severity of the impact are scored on a scale of, for example ‘insignificant” to “critical”.

If the substance or material or the receiving environment are considered high risk and there are no lower risk alternatives, a quantitative assessment may be required. Quantitative assessments require data on the rate of specific contaminant release and inflow or deposition into an environment which is then compared to specific allowable limits based on ecotoxicity. It requires detailed knowledge of the rate of release of contaminants as well as modelling to predict movement and dispersion of the contaminants from the road corridor into the environment. Wind may contribute to dispersion but dispersion primarily occurs by stormwater runoff.

Waka Kotahi have developed a simplified stormwater runoff model (LTNZ 2007, Waka Kotahi 2016), which estimates potential levels of harm in freshwater and marine aquatic receiving environments due to copper and zinc metal contamination from vehicle tyres and brake linings. The model assesses total copper and zinc loads deposited onto roads in a given catchment area based on traffic levels, surface water drainage and flow in waterways in the catchment, soil type, and the likely environmental harm based on the type of receiving environment. This can be found in Waka Kotahi Research report 585 *Risk assessment of stormwater runoff*. Adaptation of the model (or similar international models) to cover other contaminants possibly emitted by products in the road corridor, would require specific knowledge of the ecotoxicity of the contaminants as well as an estimate of emission rates. Development of a specific model is thus likely to be a significant exercise but may be warranted in some cases if concerns exist about a specific material or product and no safer alternative product or material is available.

4.4.1.4 FURTHER ASSESSMENT

If the material or product has been deemed high risk/unknown risk (and no lower risk alternatives are available) further more detailed assessment including laboratory testing, may be necessary to properly determine risk. Guidance on how to approach design of laboratory test procedures and methods of assessing and interpreting the results are provided in section 5.

5 SECOND STAGE ASSESSMENT-PHYSICAL TESTING

If a clear assessment based on the considerations given in section 4 is not possible or if there is a need to validate or confirm assessments made with respect to possible direct contamination of the environment, then physical testing should be carried out.

Given the potential variety of products and materials used in the road corridor specific test and assessment procedures will need to be tailored for each case and possibly for each specific application. For this reason, detailed test procedures are not provided in this guide, but further examples of applicable standards and type of testing that can be used can be found in the appendix. Key considerations in selecting or developing suitable assessment methods are discussed below.

It is recommended that before undertaking a specific test programme, the intended methodology is discussed with Waka Kotahi to ensure that the methodology used, and the results of the test program are adequate.

5.1 TEST CONDITIONS

5.1.1 GENERAL CONSIDERATIONS

Sample preparation and testing conditions used for leaching and micro-particulate assessments (sections 3) should:

- Ensure that representative sample or samples of the test material or product is used. This may require sampling over time to account for production variability. The potential for weathering of materials stored outdoors that may affect the composition of the test samples taken, should be considered. Variability is likely to be higher for recycled materials (e.g., crushed concrete, recycled plastic, or demolition waste) whose source may vary widely.

  Agreement on what constitutes a representative sample should be reached with the supplier or manufacturer before assessments are made. The supplier should operate under a recognised quality assurance standard (e.g. ISO 9001), controlling record keeping, sampling methods and frequency etc. However, an exception to may be required for trials of innovative new materials e.g. waste products.
- Be planned so that the test procedure provides sufficient sample for subsequent chemical analysis or ecotoxicity testing and minimises additional work-up or isolation needed for contaminants of interest.
- Use the physical form of the material or product as it will be used in practice (e.g., the same particle grading) and in the intended concentration in the appropriate matrix (a bitumen matrix is likely to strongly mitigate leaching). For example, road marking paints should be tested as dried films and asphalt mix containing recycled plastic tested as compacted specimens. It is likely that some products such as large, manufactured articles (e.g. such as plastic boardwalk components) or the materials

they are manufactured from will need to be modified (e.g., cut or ground) to generate a sample for testing. In such cases allowance must be made for changes in surface area when assessing test results and if size reduction is needed this must be done in such a way that the results are relatable to the product when installed.

  - Materials that are designed to react or cure rapidly after construction such as basecourse stabilisers, should be tested in the uncured state and after at least 30 days (or other period that is relevant to the curing process).
  - Simulate as far as possible the actual exposure conditions experienced by the products or materials concerned in service (including storage and handling if relevant). The degree of exposure to rain, wind, traffic abrasion (dependent on traffic volumes and vehicle types), walking or cycling, and UV degradation should be considered and modelled appropriately. Where assumptions concerning exposure-conditions are made these must be as far as possible be supported by evidence.
  - Studies undertaken to assess the leaching or emission of volatile compounds from test materials may require special precautions to prevent errors from losses from the water phase or experimental during testing or subsequent handling and testing.

5.1.2 LABORATORY ACCREDITATION

As far as practicable standard test procedures (e.g. ASTM or US EPA test methods) should be carried out by laboratories accredited for that test method by International Accreditation New Zealand (IANZ) or equivalent international body (e.g. NATA in Australia). “Non-standard” assessment methods may need to be developed or adapted for particular materials, products and applications and there will be no accredited testing laboratories. In those cases testing laboratories should at the least operate under ISO 9001 or ISO 17025 accreditation.

5.2 WEATHERING

The potential for materials and products in the road corridor to cause environmental harm may be significantly affected by chemical changes and physical degradation brought about by exposure to UV light, wind, rain and temperature variations in the field. Weathering of samples as part of a testing program should be considered, especially for assessment of particulate loss (section 3). If practical, weathering of test specimens outdoors for extended periods is the best way to assess degradation.

The alternative is to use an accelerated weathering method. This should as far as possible, include simulation of weather conditions likely to be experienced in the field. Where relevant, accelerated weathering should include the effects of:

- UV exposure (photo-degradation)
- Humidity and hydrolytic breakdown in water
- Salt spray
- Temperature
- Biodegradation (especially for natural materials)

- Freeze-thaw cycling

For plastic materials, UV-exposure is especially important, as this is a primary mechanism by which plastics oxidise and begin to physically degrade in the environment. Numerous standard methods exist for carrying out accelerated weathering and commercial instruments are available. Relevant standards can be found in the appendix.

5.3 LEACHING/RUN-OFF/WASH-OFF

5.3.1 BACKGROUND

Rain or groundwater running over or through materials or products used in the road corridor can result in extraction and dispersal of harmful contaminants to the adjacent environment. Leaching is a gradual process and is distinct to loss of the bulk material through the mechanical action of water producing sediment.

Leaching and wash-off are the primary modes through which contaminants from roading construction materials enter the environment. Leaching tests can be used to evaluate possible environmental harm through chemical analysis or ecotoxicity testing of the leachates (either through direct interpretation of the results or as input to dispersal models as discussed in section 4.4.1.3). Examples of potential leaching testing tests are detailed in section 6.2.

Selection of a given method will depend on the nature of the material and the analytes in question as well as cost and availability in New Zealand. Advice on the analyses required should be sought from an appropriate laboratory before any leaching tests are undertaken to ensure the test can meet sample size, storage time or other necessary conditions. Detailed information on testing and analysis of results can be found in the appendix in section 6.2.

5.3.2 ASSESSMENT OF LEACHATE CHEMICAL ANALYSIS RESULTS

Concentrations of contaminants in the leachates can be assessed against appropriate water quality standards to provide a qualitative assessment of potential for environmental harm. The Australian and New Zealand Governments have developed a set of ‘Guidelines for Fresh and Marine Water Quality (ANZECC 2018), however these apply to receiving environment rather than to the discharge. Comparisons to water quality guidelines must therefore consider the fact that in the field leachate may be highly diluted as it enters waterways, and soil adsorption or other processes may also act to significantly reduce the contaminant concentrations as the leachate moves through the road shoulders or verges.

If the leachate in question is not included in the water quality guidelines, or those guidelines are not deemed appropriate for the situation, another approach would be to compare the leachate analysis results to that from a relevant benchmark material or product currently in service. This would establish whether the test material or product is likely to be more or less harmful.

Alternatively, if those two approaches are not appropriate the leachate analysis results could be compared to the limits given for leachate concentrations provided by the Ministry for the Environment for waste acceptable in Class B landfills (MfE 2022). Although these limits were derived based on the TCLP leaching procedure (see section 6.2.1) which may not be appropriate for the material in question, the limits are still useful for comparison if no other data is available as long as the leaching method provides a realistic leachate.

5.3.3 LEACHING TESTS FOR ECOTOXICITY TESTING

Ecotoxicity tests assess structural or functional changes (including lethal effects) that may occur in plants or other organisms in contaminated soils or water ways. These tests do not require detailed knowledge of the chemical composition of the material and provide a more comprehensive assessment of potential ecotoxicity affects than specific chemical analyses which may miss harmful components. For further information on these methods see the appendix.

5.4 MICROPARTICULATES

5.4.1 BACKGROUND

In-service weathering or mechanical abrasion of materials and products in the road corridor may result in the formation of airborne particulates (dust) or larger particulates (including microplastics) that may be washed into drains, waterways, or the surrounding environment. Dust and particulates may settle or be washed onto road-adjacent agricultural land with possible consequences for livestock or crops (Wu et al. 2021). Particulates may also be generated during installation of road furniture and landscaping products and maintenance and ultimate disposal of pavement materials. Loss or dispersion of particulate materials applied in an un-bound form, through wind and rain are also an obvious potential source of particulate emissions.

Dust generation and sediment run-off from working with natural aggregates during construction and maintenance is a serious issue but is controlled through the Resource Management Act as well as local government regulations such as the Auckland Unitary plan and local authority district plans and is not considered in this guide. Similarly, the dust hazard arising from natural aggregates on unsealed roads is outside of the scope of this guide.

Other than aggregate wear (and excluding tyre wear), the most likely source for significant particulate emissions from road corridor materials is from traffic wear of road marking paints and thermoplastic markings (including reflective glass beads) (Boucher and Friot 2017). Weathering and mechanical breakdown of rubber or plastic components of road furniture or landscaping products (e.g., geofabrics) may also result in micro-plastic generation either directly or through eventual erosion of larger fragments. Dust suppressant substances applied to unsealed roads may be bound to aggregate dust particles and eventually distributed by traffic and wind into the environment in this way. Asphalt mix containing plastic materials may also result in micro-plastic generation through the usual initial wear of bitumen from the upper surface of the mix in the wheel-paths after construction, although the bulk of the bituminous binder in asphalt or chip seal surfacings is not directly exposed to traffic.

Particulates can be harmful to organisms in the environment directly through ingestion and also due the large surface area to mass ratio increasing the potential rate of leaching. The main concern is the transmission of particulates into the aquatic and terrestrial environments. In practice it is unlikely that materials and products used in the road corridor (other than natural aggregates) will generate particulates at a sufficient rate or quantity to generate dust at levels that would be problematic in terms of air quality.

5.4.2 PARTICULATE GENERATION

To determine the likelihood of particulate formation from road corridor products, testing should include a weathering process (section 5.2) and some form of mechanical abrasion of the material or product. Generation of particulates from weathered materials may be due to the mechanical action of wind, rain, foot or vehicular trafficking. The severity of the abrasion method used should be tailored for the product in question. Obviously more severe conditions are needed to adequately assess for example a synthetic aggregate material or road marking paint that will be trafficked by heavy vehicles compared to the plastic components of a road sign, which are not. In practice the stresses experienced by the test material are unlikely to be known exactly and simulation of full-scale traffic loads is impracticable due to the cost and difficulty in collecting the resulting particulates for analysis.

A key consideration in development of a test procedure is to anticipate how the test results will be related to rates of particulate generation in the field and used to make assessments of potential risk. The amount of particulate generation may be negligible over a short time frame but may be significant over decades in-service. Anti-skid or slip coatings for example are likely to be subject to high wear and tear and often comprise chemical additives which have chronic environmental toxicity affects eg.Al_2O_3.

For information on specific test methods helpful to this process see the appendix.

5.4.3 ASSESSMENT

To assess the risk from particulate generation it is important to determine:

- The quantity (mass, number) of particles produced per unit area (or other relevant measurement unit) and the rate of formation in terms that can be extrapolated expected product lifetimes in the field. In some cases it may be useful to determine the average particle size and distribution. Size will have an impact on how easily the particles are dispersed by wind and rain. The particle surface area to mass ratio will affect the potential rates of leaching of eco-toxic compounds into the environment. Size has a significant effect on potential risks to organisms from ingestion of particulates.
- If microplastic generation is of specific concern, then a method to identify plastic particulates amongst a non-plastic particle matrix may be required, for example when testing asphalt mix or concrete with added plastic materials. Such analyses generally require sophisticated instrumental methods such as Fourier transform infrared (FT-IR) spectroscopy which can used to chemically differentiate plastic types, bitumen and other matrix components. An ASTM standard is currently in development (ASTM WK67565) for the quantification of microplastic particles in water using Raman and IR spectroscopy (size range 20 um – 5 mm). The method aims to confirm microplastic particle size, shape and surface features with appropriate instruments such as a scanning electron microscope.

Harmful effects associated with particulates such as most micro-plastics, are related to ingestion by organisms and (depending on the material in question) the potential for greater rates of leaching due to the large surface area to mass ratio.

Another harmful effect (though less likely) could arise if sufficiently large quantities of particulates are generated over a short time resulting in sediment smothering steam beds etc. (as is the case with sediment from natural aggregates).

The risk associated with ingestion of small particulates by organisms is not fully understood and the effects of micro-plastic particles on the environment and human health is the subject of on-going research (Campanale et al. 2020, Amobonye et al. 2021). For example, recent studies have demonstrated that 500 µm microparticles penetrate and cause intestinal disorders in fish from initial ingestion, while smaller particles ca. 20 nm can penetrate further and accumulate in organs and tissues and have been found to impact the nervous system of fish (Yin et al. 2021).

Currently there are no standards setting acceptable “safe” limits for release of micro-plastics into the environment apart from those applied to products with micro-plastics added intentionally i.e. micro-beads used in shampoos and cosmetics.

To assess the potential risk of particulate emissions comparative testing with existing products or materials, could be used to provide context. i.e. is the product under test better or worse than existing products? Another approach is to consider the total mass of particulates likely to be generated over the life of the product.

5.5 VOLATILE EMISSIONS

In some cases, volatile compounds such as solvents or airborne liquid droplets (aerosols) may be generated during spray application of various products and disperse into the environment. The most obvious sources in the road corridor (excluding vehicular emissions) are from asphalt hot-mix, spraying of cut-back bitumen (hot or in emulsified form), road marking paints and weed killers. In the latter case existing EPA controls should minimise spray-drift into waterways etc. Potentially volatiles may also be emitted over a long period once materials have been applied and are in-service.

Volatile emissions may also impact on air quality in terms of human health (road workers and the public) and nuisance odours. Although consideration must be given to these effects they lie outside the scope of the current guide.

The most likely harmful effects on the environment from volatile emissions are in terms of contributing to global warming and photo-chemical, ozone formation. Volatile hydrocarbons for example are usually calculated to have Global Warming Potential (GWP) factors several times that of CO_2 and those for chlorinated solvents are thousands of times greater. Release of volatiles should be included in calculation of the carbon footprint. The effect can normally be calculated without need for physical measurements, from the percentage solvent in the material (assuming complete evaporation). In certain cases of semi-volatile solvents for example, simple laboratory measurements may be needed to assess whether the rate of evaporation and hence total expected volatile emissions are significant.

6 SUMMARY

This document has outlined framework and guidance for the assessment of environmental harm from alternative materials and products for use in the road corridor.

It may be used by suppliers, engineers, contractors, roading agencies and government where there is consideration of use of alternative materials or products in the road corridor.

The aim of the assessments made using this guide is that the alternative materials and products used in the road corridor should have the smallest possible adverse environmental effect or risk of potential environmental issues.

The assessment framework presented suggests key factors to consider when evaluating potential environmental issues through an initial desktop assessment but provides supporting guidance on the key principles for development or adaptation of appropriate procedures for assessing modes of environmental harm if a second stage physical assessment is required.

APPENDIX – APPLICABLE STANDARDS AND TESTING

6.1 WEATHERING

Standard methods exist providing guidance on how such testing should be conducted such as:

- ASTM G7 - Atmospheric environmental exposure testing of non-metallic materials.
- ASTM G24 - Standard Practice for conducting exposures to daylight filtered through glass.
- ASTM G201 - Standard Practice for conducting exposures in outdoor glass-covered exposure apparatus with air circulation.
- ASTM G90 - Accelerated outdoor weathering of non-metallic materials using concentrated natural sunlight.
- ASTM D1435 - Standard Practice for Outdoor Weathering of Plastics.
- ASTM D1669 - Practice for Preparation of Test Panels for Accelerated and Outdoor Weathering of Bituminous Coatings.
- ASTM D1670 - Test Method for Failure End Point in Accelerated and Outdoor Weathering of Bituminous Materials.
- ASTM D4141 A - Standard Practice for conducting black box and solar concentrating exposures of coatings.
- ISO 105-B03 - Colour fastness to weathering – Outdoor exposure.
- ISO 877-1,2 & 3 – Plastics - Methods of exposure to solar radiation.
- ISO 2810 - Paints and varnishes - Natural weathering of coatings - Exposure and assessment.

For plastic materials, UV-exposure is a particularly important part of material degradation, relevant standards in include:

- ISO 4892-1 & 2– Plastics - Methods of exposure to laboratory light sources.
- ASTM G151 - Standard Practice for Exposing Non-metallic Materials in Accelerated Test Devices that Use Laboratory Light Sources.

- ASTM G154 -Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Non-metallic Materials.
- ASTM G155 - Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials.
- ASTM D1669 - Practice for Preparation of Test Panels for Accelerated and Outdoor Weathering of Bituminous Coatings.
- ASTM D1670 - Test Method for Failure End Point in Accelerated and Outdoor Weathering of Bituminous Materials
- ASTM D2565 - Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications.
- ASTM D4355 - Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture, and Heat in a Xenon Arc-Type Apparatus.
- ASTM D 4798- Standard Practice for Accelerated Weathering Test Conditions and Procedures for Bituminous Materials (Xenon-Arc Method)
- ASTM D5894 - Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet).
- ASTM D7869 - Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings.

For some materials and products specific test methods for accelerated weathering have been developed, e.g. ASTM D4355 and EN 12224 are designed to evaluate geotextiles (but could also be adapted for other plastic products and materials).

Note that the methods above are commonly aimed at studying changes in engineering properties and they may need to be adapted to enable data collection and measurement of parameters relevant to environmental assessments.

For outdoor weathering simulations xenon-arc lamps are recommended as they provide a more realistic sunlight simulation. Periods of weathering should be interspersed with mechanical abrasion of the material if relevant (see below) as this will prevent the unrealistic build- up of a protective oxidised surface layer.

Weatherometer testing will accelerate degradation but because of the many variables involved in natural weathering and different permutations of weatherometer test parameters possible, there is no generally applicable correlation between weatherometer ageing time and field ageing. Weatherometer tests are best viewed as comparative and for this reason the ASTM standard methods recommend using a control specimen of a product or material with known satisfactory performance (or at least one already used in the field) to provide a comparative benchmark.

A recent study of geotextile fabric compared the accelerated UV ageing tests given in ASTM D4355 and EN 12224 to outdoor exposure in Auckland and Christchurch over late summer-autumn, in terms of tensile strength loss (Stevens et al. 2018). It was found that the tests resulted in acceleration factors of 27 to 30 and 11-12 for Christchurch and Auckland respectively.

In other words one month in the accelerated test corresponded to about 29 months in the field in Christchurch but only about 12 months in Auckland. The difference was largely due to the difference in solar radiation at the two sites over the period of the study.

6.2 LEACHING/WASH OFF

Leaching and wash-off are the primary modes through which contaminants from roading construction materials enter the environment. Leaching tests can be used to evaluate possible environmental harm through chemical analysis or ecotoxicity testing of the leachates (either through direct interpretation of the results or as input to dispersal models as discussed in section 4.4.1.3.

However, laboratory leaching tests may not model field conditions very accurately; the test conditions tend to be more severe than leaching in the field and attenuation of leached contaminants, that can occur in the field through soil sorption, photo and biological degradation (removal, reduction and retardation, or RRR processes) (Harrington-Hughes 2000, Nelson et al. 2001) are usually not considered. Attenuation factors may be relevant in dispersal modelling, similarly chemical changes in specific contaminants due to reaction after leaching may occur that may need to be considered in test design.

A wide variety of parameters will affect leaching rates and leachate concentrations achieved in laboratory tests (Table 2). Many of these factors are site-specific and cannot be reproduced easily under laboratory conditions and they can be only adequately assessed using full scale field studies.

Table 2 Summary of the main factors influencing leaching processes

Chemical processes	Physical factors	External factors
·Dissolution rate from the matrix · pH of leaching water ·Chemical form (water solubility) ·Matrix composition (including changes over time) ·Acid-base buffering ·Composition of leaching water phase/ionic strength ·Temperature ·Time	·Water percolation rate (permeability) ·Molecular diffusion rate ·Surface wash off ·Sample form (surface area)	·Volume of leaching water ·Contact time ·pH of receiving environment ·Temperature ·Redox potential of receiving environment ·Dissolved organic matter (DOC) in water /Adsorption

Source: Adapted from Van der Sloot, H.A., and Dijkstra, J.J., 2004.

Leaching tests can be grouped into two broad classes, equilibrium (batch leaching under controlled pH) and non-equilibrium tests (column leaching under various water flow rates, and monolithic surface leaching). Batch leaching tests are intended to simulate equilibrium leaching behaviour (i.e., the concentration of a constituent that will leach under a defined pH, temperature and water/ solid ratio), whereas column percolation tests provide cumulative release data that describe leaching rates (concentration versus time) under conditions of constant surface renewal. Column tests model field conditions more closely than batch tests (which are primarily a measure of leaching 'potential') but are more difficult to undertake. Monolithic tests (sometimes called Tank tests) determine the leaching rates from a defined surface area where mass transfer across solid/liquid boundary controls the leaching or flux rate, such tests are suitable for formed materials such as impermeable concrete slabs.

A more detailed description of the generic leaching test methodologies is given below: in most of the procedures the pH of the water used is usually specified and lies in the range 4-8. If toxicity testing is to be carried out on the leachate the initial pH of the leaching water should be neutral at the start of the procedure. The tests are usually carried out at a temperature of 20-25°C. Many leaching tests in current use are discussed in a report from the US Washington Department of Ecology (DoE 2003).

6.2.1 LEACHING TESTS FOR CHEMICAL ANALYSIS

Static leaching tests

Granular material is placed in a container which is filled with a specific amount of water. The solid and liquid fractions stand or are mixed over specified period of time (from several hours to days) without renewal of leaching solution with the object of reaching equilibrium. The time taken to reach equilibrium will vary for different constituents and depends heavily on the particle size of the material. In cases where specific constituents are of interest their concentration can be monitored and the test extended until equilibrium is reached. In most cases an exact chemical composition is unknown, and equilibrium assumed. Brannon et al. (1994) report that 24 hours is sufficient for PAH and inorganics to achieve equilibrium in the leachate of dredge sediments. For materials with larger particle sizes much longer times may be required; for a material with a maximum particle size of 2mm a period of 48 hours is suggested from theoretical considerations (Kosson et al. 2002). The leachate is removed from the container at the end of the test, filtered and then analysed. The amount of water in contact with tested material is referred as liquid/solid ratio (L/S) and expressed in L/kg. Tests are sometimes performed in multiple steps with different L/S ratios. The extracts are filtered, combined, and analysed for the components of interest. Results of chemical analysis of the leachate are normally expressed as mg/kg of tested material as a function of L/S ratio.

For materials used in or on the road surfacing layer (i.e., exposed to trafficking) the material being tested should pass or be crushed or cut to pass through a 300-micron sieve. Other materials and products should be tested in the form used in practice, if possible, but changes in surface area due to size reduction need to be allowed for when reporting test results.

A very commonly used batch leaching test is:

(https://www.epa.gov/hw-sw846/sw-846-test-method-1311-toxicity-characteristic-leaching-procedure):

EPA SW-846 Method 1311 Toxicity Characteristic Leaching Procedure (TCLP)(US EPA 1992a)
Particle size: <10mm.
L/S ratio: 20:1 L/S ratio
Leachant water: pH 4.93 (with acetic acid)
Time: 18 hours
Temperature: 23 °C
Designed for: Organic and inorganics, volatile and non-volatile. Intended to assess leaching from wastes in landfills where organic acids are produced through microbial action.

Other similar methods are given below. Note that these methods have been developed for relatively specific purposes (not assessment of road corridor materials) so modifications may be necessary to account for features of the test material or contaminant chemistry (e.g., reactivity with oxygen), or the material application. For further information see OECD (2000).

EPA SW-846 Method 1312 Synthetic Precipitation Leaching Procedure (US EPA 1992).
Particle size: <10mm.
L/S ratio: 20:1 L/S ratio
Leachant water: pH 4.92 or pH 5 (with nitric and sulphuric acid).
Time: 18 hours
Temperature: 23 °C
Designed for: Organic and inorganics, volatile and non-volatile. Intended for wastes in monofill dumps but subject to acid rainfall typical of that experienced in the US.

ASTM D 3987, Standard Test Method for Shake Extraction of Solid Waste with Water. (ASTM 2004)
Particle size: As found.
L/S ratio: 20:1
Leachant water: Natural pH.
Time: 18 hours
Temperature: 18-27°C
Designed for: Non-volatile inorganics.

NEN 7371 (development of the earlier NEN 7341). The Maximum Availability Test. (NENa 2004).
Particle size: <0.125 mm.
L/S ratio: 50:1
Leachant water: Sequential extractions at pH 7 then pH 4 (leachates combined for analysis).
Time: 3 hours each extraction
Temperature: 20°C
Designed for: Non-volatile inorganics

EN 12457 (parts 1 – 4) Characterisation of waste – Leaching Compliance Test for Leaching of Granular Waste Materials and Sludges, parts 1 – 4 (CEN 2002).
Particle size: <4mm or (part 4) <10mm.
L/S ratio: 2, 8 or 10.
Leachant water: natural pH.
Time: 24 hours
Temperature: 20°C.
Designed for: Non-volatile inorganics

DD CEN/TS 14429 Characterisation of Waste – Leaching Behaviour Tests – Influence of pH on Leaching with Initial Acid/Base Addition. (CEN 2005)
Particle size: <1mm.
L/S ratio: 10:1 L/S ratio
Leachant water: pH 2 to 12 (8 separate extractions).
Time: 48 hours for each extraction
Temperature: 20 °C
Designed for: Non-volatile inorganics.

Monolithic leaching tests

Monolithic materials defined (van der Sloot and Dijkstra 2004) as those where the release of constituents to the surrounding water during leaching tests is diffusion controlled (in contrast to loosen granular materials, in which release is percolation rate controlled). Examples of monolithic materials include formed products and materials such a bricks, plastic drainpipes, concrete slabs and bitumen films usually with small surface area / weight ratios compared to granular materials.

The extent of leaching from large particle size materials or monolithic products (even when reduced in size) may be very small, making measurement of leached compounds difficult. In these cases the test material is placed in a tank and water added. Over a specified period of time concentrations in the water are measured, ideally until equilibrium is reached.

Results of chemical analysis of the leachate are expressed as the cumulative mass of leached chemical per surface area of the sample (mg/m^2), as a function of time.

A commonly used method (originally developed for non-volatile inorganics such as heavy metals) is NEN 7375 (NEN 2004b). This method uses the following conditions:

Sample surface area: >75 cm^2.
Water /solid ratio: 2 to 5 times sample volume
Leachant water: Natural pH.
Time: 64 days
Temperature: 20°C
Designed for non-volatile inorganics

Percolation leaching tests

Percolation leaching tests simulate water flow through granular or permeable materials in the field. The column (up-flow percolation) test is performed using a column filled with granular test material and leached with slowly flowing water (so that the sample material is not mechanically agitated). In this way the test material is constantly exposed to fresh water. The risk of saturation of leachant water (and hence underestimation of leaching rates) is reduced but large volumes of water may be generated. Water flow is usually in an upward direction to reduce the possibility of blockage through the migration of fines. Concentrations of leached constituents are measured periodically in the eluant and are expressed as (mg/L) versus percolated water volume (L/S ratio) or as cumulatively leached concentration (mg/kg).

Commonly used column/percolation leaching tests for waste and recycled materials include the following:

ASTM D 4874 Standard Test Method for Leaching Solid Waste in a Column Apparatus. (ASTM 2006).
Particle size: <10mm.
Leachant water: natural pH.
Flow rate: Adjust to achieve column void volume exchange time of 24 hours
Temperature: Ambient.
Designed for: Non-volatile organics and inorganics

DD CEN/TS 14405 Characterisation of waste – Leaching Behaviour Tests- Up-flow Percolation test

(under specified conditions). (CEN 2004).
Particle size: <10mm.
Leachant water: natural pH.
Flow rate: 12 or 48 ml/hr depending on column size (5 or 10 cm diameter respectively).
Temperature: 20°C.
Designed for: Non-volatile organics and inorganics

6.2.2 CHEMICAL ANALYSIS OF LEACHATE

Analysis of the leachate for inorganic species can be readily undertaken by various methods including using atomic absorption spectrometry, inductively coupled plasma (ICP) - atomic emission spectrometry (AES), ICP-mass spectrometry (MS) or ion chromatography. The same methods can be used for analysis of the material itself after digestion (dissolution) in strong acid; however solid-state methods such as x-ray fluorescence are usually less expensive.

Analysis of the leachate for organic species will usually require extraction and concentration into an organic solvent and possibly derivatisation before analysis by gas chromatography - mass spectrometry (GCMS). The material itself can be extracted directly with solvent before organics analysis by GCMS (e.g., Loeper 1995).

Many standardised test methods are available, for example those provided by the US EPA (Table 3). A compendium of EPA methods of relevance is:

Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, 3rd Edition, EPA Publication SW-846 (USEPA 1992, http://www.epa.gov/epaoswer/hazwaste/test/main.htm)

Table 3 Representative US EPA methods for the chemical analysis of leachates and materials (http://www.epa.gov/ne/oarm/pdfs/testmeth.pdf)

Analysis	Method
Digestion	3051: Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils
	3050B: Acid Digestion of Sediments, Sludges, and Soils
Inorganics	6010B: Inductively Coupled Plasma-Atomic Emission Spectrometry
	6020: Inductively Coupled Plasma-Mass Spectrometry
	7000A: Atomic Absorption Methods
Organics	8015B: Nonhalogenated Organics Using GC/FID
	8100: Polynuclear Aromatic Hydrocarbons
	8260B: Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS
	8270C: Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)
	8275A: Semivolatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS)
	8310: Polynuclear Aromatic Hydrocarbons

6.2.3 LEACHING TESTS FOR ECOTOXICITY TESTING

Typically, tests are conducted using organisms such as the freshwater macroinvertebrate *Daphnia magna* (water flea), and the freshwater green alga *Selenastrum capricornutum*. Tests can also be conducted on fish and terrestrial organisms (e.g., earthworms) but these are more complex and less commonly used unless there are case-specific reasons to do so.

Water accommodated fraction method

Ecotoxicity tests are usually carried out in the laboratory using standard test species and known concentrations of compounds dissolved in water. As they are designed to function in wet conditions, most products, and materials (including leachable contaminants) used in the road corridor are likely to be only sparingly soluble in water. The traditional ecotoxicity approach of preparing water samples with differing concentrations of a test compound will not be applicable in most cases and tests will need to be conducted on water obtained from leaching experiments.

In such cases toxicity tests are generally carried out using the water accommodated fraction (WAF) approach (King et al. 2001; OECD 2000).

The principle is that the test material is contacted with water until those components that are soluble in water have reached an equilibrium concentration in the water phase. Test temperature, the physical form, weathering, or other sample pre-treatment needs to be carefully considered to undertake a fair assessment.

The water is separated from the insoluble material and test organisms are introduced. The concentration of the test substance is expressed as the bulk 'loading rate' (milligram of substance per litre of water) rather than in terms of the aqueous concentration of the individual soluble components, which are unknown and impracticable to measure in most cases. For the same reason it is often not practical to determine quantitatively if equilibrium of contaminants with the water phase has been achieved. However, if one or more species of particular interest or environmental concern are known to be present and are readily amenable to analysis, then multiple tests using differing time intervals should be performed to confirm equilibrium.

The primary advantage of toxicity tests over the exclusive use of chemical analysis is the ability to assess the effect of chemically undetected or unidentified constituents, and to allow consideration of the toxicity that may occur in the presence of a complex mixture of chemicals. Ideally results of tests should be related to the actual leachate concentrations in the receiving environment at the time of testing (Harrington-Hughes 2000, Nelson et al. 2001).

Water used in leaching tests for ecotoxicity assessments should a neutral pH and may have special requirements depending on the type of ecotoxicity testing to be carried out; this needs to be confirmed with the agency undertaking the testing.

6.2.4 ECOTOXICITY TESTING OF LEACHATE

Ecotoxicity testing can generate a range of parameters depending on the design of the test, these include measures of mortality and growth inhibition.

It is recommended that aquatic ecotoxicity of the leachate should be measured using the freshwater macroinvertebrate *Daphnia* species (48-hour acute lethality), and the freshwater green alga *Selenastrum capricornutum* (72-hour growth inhibition). These tests are recommended because of their widespread acceptance for testing the ecotoxicity of industrial and other waste effluents. Numerous international bodies have designed and approved methodologies for these tests, and as such there is a great deal of literature available on these tests, including internationally standardised test methodologies (some of which are given in Table 4.3. In addition, New Zealand-specific standardised aquatic testing protocols using these and/or more appropriate native species (such as *Ceriodaphnia dubia* in place of *D. magna*) have been developed by the National Institute of Water and Atmospheric Research Ltd (NIWA) and are available for use in New Zealand (Hall and Golding 1998),

It is believed that in most cases the assessment of ecotoxic hazards of waste materials based solely on aquatic toxicity data would result in the same classification as an assessment that included terrestrial data (Environment Agency 2005). In the Environment Agency methodology for ecotoxicity testing, terrestrial tests are recommended only if there is reason to believe that a material contains substances that have specific effects on the terrestrial environment. If deemed necessary, the tests recommended for assessing soil ecotoxicity are a terrestrial plant germination and early growth test and the collembola reproduction test as these two tests represent both a plant species and a soil invertebrate and utilise commonly used test species for determining soil ecotoxicity.

Most of the test methods in Table 4 are designed to allow the determination of a median effect level which involves testing several concentrations (or dilutions). The recommended screening criteria for the ecotoxicity tests follows the approach of the European Community, whereby the leachate can be tested without dilution (i.e., 100% WAF) and compared to the control (dilution water) ('limit tests'). This is a simpler and more economical version of a typical toxicity test. Treatments should include a control, 100% WAF and a reference toxicant wherever possible.

Table 4 Test methods for toxicity studies

Test Protocol	OECD tests	US EPA tests	International Organisation for standardisation tests	European Community Tests	New Zealand tests
Crustacean *Daphnia magna* immobilisation *Ceriodaphnia dubia immobilisation*	202 (part I) OECD 2004a	850.101 USEPA (1996a)		C2 (EC 1992)	Hall and Golding, 1998 (appendix 5)
Algal *Selenastrum capricornutum* toxicity: growth inhibition	201 (OECD 1984)	850.5400 USEPA (1996b)		C3 (EC 1992)	Hall and Golding, 1998 (appendix 4)
Earthworm *Eisenia*	222 (OECD 2004b)		11268-2 (ISO 1998)		

fetida/andrei reproduction test					
Collembola *Folsomia candida* reproduction test			11267 (ISO 1999)		
Terrestrial plant tests	208 (OECD 2003)	850 4230 850 4200 USEPA (1996c & d))			

6.2.5 ASSESSMENT OF LEACHATE ECOTOXICITY RESULTS

The New Zealand HSNO minimum degrees of hazard regulations utilise screening or 'threshold' criteria to identify and characterise the degree of ecotoxicity. These criteria assume water soluble materials whose ecotoxicity can be expressed in terms of a concentration, i.e., mg substance/L water. As discussed above, in most cases for road corridor materials and products, concentrations will be unknown. Instead, an approach using screening criteria such as that from the UK Environment Agency (Environment Agency 2005) could be adopted:

- If the observed effect, relative to the appropriate control, during the testing of the 100% leachate (WAF) in either the 48-hour *daphnia* test, or the 72-hour algal test, is ≥ 50% (i.e. 50% or more of the *Daphnia* are immobilised or there is a 50% or greater reduction in algal growth) then the material is considered ecotoxic. Similarly, if ≥ 50% ecotoxic effect in either the terrestrial plant germination and early growth test, or the collembola reproduction test is observed, then the material is considered ecotoxic.

More complex screening criteria would require a higher level of testing using various percent dilutions of the leachate to define the median effect concentration. For example. the US ecotoxicity testing methodologies outlined in a NCHRP study (Eldin et al. 2000) categorise impact into 5 classes according to the % of pure leachate causing a 50% ecotoxic effect (i.e., the LC_{50} or EC_{50}):

Extremely high impact,	where LC_{50} or EC_{50} occurs at ≤10%
High impact,	where 10% < LC_{50} or EC_{50} ≤ 20%
Moderate impact,	where 20% < LC_{50} or EC_{50} ≤ 75%
Low impact,	where LC_{50} or EC_{50} > 75%
No impact	where no toxic effect is observed

Similarly, the following ecotoxicity limits are used by Lapa et al. (2000):

Very high ecotoxicity:	where LC_{50} or IC_{50} occurs at ≤1%

High acute toxicity: where 1% < LC_{50} or IC_{50} ≤ 10%
Significant ecotoxicity: where 10% < LC_{50} or IC_{50} ≤ 50%
No significant ecotoxicity: where LC_{50} or IC_{50} > 50%

6.3 MICROPLASTIC GENERATION

A wide range of methods have been employed for collection, sampling, and analysis of microplastics (Brander et al. 2020, Alimi et al. 2021). Several standard test procedures specific to assessment of microplastic particles have been, or are being developed and that may be adapted, these include:

- ASTM D8332 Standard Practice for Collection of Water Samples with High, Medium, or Low Suspended Solids for Identification and Quantification of Microplastic Particles and Fibers.
- ASTM D8333 Standard Practice for Preparation of Water Samples with High, Medium, or Low Suspended Solids for Identification and Quantification of Microplastic Particles and Fibers Using Raman Spectroscopy, IR Spectroscopy, or Pyrolysis-GC/MS.
- ASTM WK70831 New Practice for Standard Practice for the Development of Microplastic Reference Samples to enable calibration and proficiency evaluation of Microplastic Polymer Collection Practices, Preparation Practices and Identification Methods of Microplastic particles in all types of water matrices with high to low levels of suspended solids.

The following are illustrative examples of test procedures particularly relevant to road corridor materials and products:

Road surfacings

A draft test method is under development by Austroads for the measurement of microplastics generated by wear of asphalt road surfacings incorporating recycled post-consumer plastic materials (Austroads). The method could be adapted for assessing road marking paints or thermoplastic markings.

The method has adapted the AGPT-T272 road abrasion method “Determination of Abrasion loss of bituminous slurry (wet track abrasion test)”. This test simulates abrasion by dragging a rubber foot over the surface which is followed by the dissolution of bitumen, and extraction of sediment. The plastics and aggregate materials are separated through density, and the microplastics are fractionated by size-selective filtration. This gives a plastic amount by weight sorted according to size bands. Due to the difficulty in obtaining complete separation at small particle sizes, the recovered particles are stained with a hydrophobic dye which selectively bonds to plastic materials and analysed using fluorescence microscopy. Particles were individually counted. The method is aimed at measuring bitumen/plastic loss from the asphalt surface under traffic. This is complete within the first few weeks of trafficking so that weathering of the surface is not necessary. If the method was adapted for road markings, then accelerated weathering would be warranted.

Plastic products

The method used by Song et al. (2017) mimics the exposure to UV of various plastics for up to 12 months, followed by mechanical abrasion with sand and water for 2 months. Electron microscopy was used to observe the damage on the surface of the samples, as well as FTIR to measure oxidation status at the surface. IR is not only good for characterising the plastic type but also the carbonyl index is a very good measurement of the degree of weathering and surface photo-oxidation. The particles were extracted from the sand abrasive, stained with Nile red and particles counted, and sizes measured by fluorescence microscopy.

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