NACOE P120/WARRIP-2021-016: Task 7 Review of the Potential Use of Recycled Plastics in Geosynthetics

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Investigating the use of recycled and reclaimed plastic in safe, sustainable future road infrastructure

This report forms one element of a multi-stage research project undertaken as a joint initiative between the Western Australian Road Research and Innovation Program (WARRIP) and the National Asset Centre of Excellence (NACOE).

Stage 1 (2020–21) aimed to:

- review local and international projects that used recycled waste plastic in road and transport infrastructure
- identify the potential uses for recycled plastics in road construction and the relative quantities of materials that could be realistically used by each application
- review plastic waste streams in Queensland and Western Australia to understand market trends and capacity
- investigate workplace health and safety (WHS) requirements and environmental considerations associated with the use of waste plastics in road construction.

The publications completed under Stage 1 include:

- **Task 2–4: Investigating the use of recycled plastic in road infrastructure**
  - **2: Literature review**
  - **3: Plastic waste management (industry survey)**
  - **4: Workplace, health and safety, and environmental implications**

Stage 2 (2021–23) aimed to:

- explore safe and sustainable ways to expand the potential uses of waste plastics in transport infrastructure
- understand the health, safety and environmental impacts of using waste plastics in asphalt and bitumen, including microplastics, leaching, fuming and emissions.

The publications completed under Stage 2 include:

- **Task 5: Recycled plastics in infrastructure (Factsheet)**
- **Task 6: Health and environmental effects of incorporating plastics in binders and asphalt**
  - **6A: Laboratory fuming and emissions**
  - **6B: Microplastics and leaching**
- **Task 7: Potential use of recycled waste plastics in geosynthetics**
- **Task 8: Potential use of recycled waste plastics in temporary traffic management devices**

Summary

The objectives of this research were to review the current status of geosynthetics that contain reclaimed and recycled plastics (RPs), identify barriers and opportunities, both from technical and practical points of view, for incorporation of recycled plastics in these products, and to develop a methodology to monitor field trials of geosynthetic applications (that include RPs) in roads. The objectives were pursued through reviewing current standards, literature and available products as well as through consulting with industry suppliers.

The key findings of this investigation include:

- There are no restrictions posed from current Australian standards and specifications on the incorporation of RP in geosynthetics for road-based applications as long as the products meet the specified performance and durability requirements.
- The currently available standards and specifications for geosynthetics for road-based applications are performance based and fit for purpose for the supply and installation of geosynthetics containing RPs.
- Of the products currently being used in Australia, recycled polyethylene terephthalate (PET) (up to 100%), polypropylene (PP) (up to 100%) and high-density polyethylene (HDPE) (up to 100%) are being incorporated into various geosynthetic products for different applications.
- RP feedstock for geosynthetics needs to be of high quality, i.e. free from contaminants. Sourcing high quality RP feedstock was identified as a challenge for suppliers, particularly as there is high demand for high quality RPs to be reused in other high value, circular products (e.g. packaging). Availability of high quality processed RPs is therefore a major limiting factor. Furthermore, most suppliers highlighted that the introduction of a lower quality geosynthetic product is not a practical option.
- It is cheaper to use virgin polymers rather than low quality RP during the manufacture of geosynthetics, as managing contaminants is costly.
- The availability of recycling plants that can produce high quality RPs in Australia is limited.
- The issue is not the amount of waste plastic created, but the processing capability and capacity. If processing infrastructure was improved, it is likely there would be enough RP available to meet higher end use application demand, with plenty of excess for the production of good quality geosynthetics.
- Based on typical geosynthetics currently produced in Australia, which contain 10–20% RP, it is estimated TMR and MRWA could utilise up to 3,600 and 1,800 tonnes of RP annually, respectively, by shifting to geosynthetics with RP. In terms of percentage of waste generated (O'Farrell et al. 2021), this is 0.44% for Queensland and 0.43% for Western Australia, respectively. For a high RP use scenario, where geosynthetics are comprised of 100% RP, this figure could increase to 18,000 and 9,000 tonnes for Queensland and Western Australia respectively, or 2.2% and 2.1% of waste generated, respectively. With a relatively small geosynthetics market, the use of RPs in geosynthetics offers a minor contribution to solving Australia's waste plastic challenge.
- Lowering production costs while maintaining product performance is a challenge for manufacturers using RPs due to the greater processing and transportation costs involved in recycling, especially when economies of scale cannot be taken advantage of due to the small market for geosynthetics in Australia.
- Long-term durability of geosynthetics containing RPs has been identified as a risk and is reflected in Australian and overseas guidelines (e.g. HB 154-2002).
- From a health, safety and environmental perspective, use of RP in the manufacture of geosynthetics is not expected to cause a different risk profile than that of virgin plastics currently being used, where the material used meets the technical specifications relevant to the product.

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1 Introduction

1.1 Background

As demonstrated through their respective plastic waste strategies (*Waste Management and Resource Recovery Strategy* (Qld Government 2021) and *Plan for Plastics* (Government of WA 2021)); Queensland and Western Australia are looking to limit the disposal of used plastics in landfill and find sustainable alternative applications for these materials. In response, the Department of Transport and Main Roads Queensland (TMR), Main Roads Western Australia (MRWA) and the Australian Road Research Board (ARRB), under both the NACOE and WARRIP agreements, have launched a multi-year project *Investigating the use of recycled and reclaimed plastic in safe, sustainable future road infrastructure*. One of the objectives of this project is to explore avenues to expand the potential uses of waste plastics safely and sustainably in transport infrastructure.

Following sustainable practices within the road infrastructure has the potential to positively impact Australia's economy by reducing the burden of waste management, lessen environmental issues and decrease the costs associated with building and maintaining transport infrastructure. A current major environmental concern is the generation and unsustainable management of waste plastics. In 2019–20, Queensland and Western Australia consumed approximately 819,500 and 422,100 tonnes of plastic respectively, and both states recycled approximately 15% (O'Farrell et al. 2021). For both states, high-density polyethylene (HDPE) and polyethylene terephthalate (PET) have some of the higher recovery rates, whereas polyvinyl chloride (PVC) is the least recovered plastic type, which Schandl et al. (2020) suggests is due to the long life of virgin PVC in piping applications.

This report has been prepared as part of the project to investigate the potential use of reclaimed and recycled plastic (RP) in geosynthetics (geotextiles, geogrids, geofoams and geocomposites) - including drainage, spray seals, asphalt, pavement and earthworks applications. This report aims to provide a comprehensive review of the current availability and barriers to the wider use of sustainable geosynthetics containing RPs.

1.2 Scope of the Project Task

This project task identifies gaps and/or barriers and provides recommendations on the safe and appropriate incorporation of geosynthetics in transport infrastructure applications.

This report is prepared based on a thorough review of the relevant standards and specifications on the use of plastics in geosynthetics, particularly those of Queensland and Western Australia, as well as currently available products and consultations with the industry suppliers, between 24 and 26 November 2021. A suitably qualified professional (SQP) was consulted for the assessment of potential harm to human health and the environment by using RPs in the manufacture of these products. The applications considered in this project task include:

- geotextiles for sprayed seals
- geotextiles and geogrids for earth works
- geogrids, geotextiles and geocomposites for earthworks, subgrade and granular layers
- geotextiles and geogrids for reflective cracking mitigation or as interlayers within bound pavement structures
- geotextiles for drainage elements (e.g. rock blankets, pavement drains, subsoil drains, sheet filters etc.), erosion prevention (erosion control blankets, turf reinforced matting)
- geofoam as a fill substitute.

The main outcomes of this project task are:

- identifying in what applications RP geosynthetics are and can be used and best practice advice on their use to provide maximum benefit to the long-term performance of the road infrastructure asset
- understanding the approximate impact to the waste stream
- developing a methodology to monitor field trials of geogrid and geosynthetic applications.

2 Geosynthetic Construction Requirements and Sustainability

2.1 Geosynthetic Types

As defined in technical specifications such as MRTS58:2022 geosynthetics are products made of polymeric material and used in geotechnical and pavement applications (MRTS58:2022). They can be broadly divided into two major categories (Austroads 2009):

- impermeable fabrics referred to as geomembranes
- permeable fabrics referred to as geotextiles.

There are a wide range of applications for geosynthetics, however, the primary purpose is characterised by the following five functions; separation, filtration, drainage, protection, and reinforcement.

Geosynthetics are further divided into the following categories:

- **Impermeable geosynthetics**: act as an impermeable barrier, where it is desirable to protect a soil layer from water ingress or potential contaminants from adjacent soil layers via leaching. Impermeable layers are generally utilised in applications outside of road applications such as mining, landfill and waterways.
- **Geotextiles**: are fibrous products which can have a wide range of characteristics dependent on the method of manufacture used. These methods are further categorised into:
  - woven geotextile: a geotextile which is produced by interlacing the polymer fibres as a filament. The fibres have a consistent, bi-directional orientation. Woven geotextiles are commonly used in reinforced embankments.
  - nonwoven geotextile: a geotextile which is produced with randomly orientated polymer fibres which are mechanically (needle punched) or thermally bonded. Nonwoven geotextiles are commonly used in separation and filtration applications.
- **Geogrids**: are polymeric meshes with relatively large openings, and their primary purpose is to act as reinforcement to distribute tensile loads or interlock pavement layers with overlying asphalt and granular layers. These are often placed in combination with geotextiles.
- **Geonets**: are a geosynthetic comprising of thick polymeric ribs with large openings. The thick ribs allow the geonets to withstand a high compressive force and filter large objects when used in drainage systems. Geonets are primarily used in drainage and protection applications (not reinforcement).
- **Geofoam:** is a lightweight alternative to fill materials, which is made from expanded polystyrene (EPS) (Aabøe et al. 2018).
- **Geocomposites**: are a combination of two types of geosynthetics, to create a product with broader desirable geosynthetic properties. For example, the most common geocomposite used in road construction is the combination of a geogrid and a geotextile which can provide reinforcement, whilst maintaining separation and filtration.

Most geosynthetics are manufactured from polypropylene (PP), polyethylene terephthalate (PET), and high-density polyethylene (HDPE) with applications requiring high strength and low creep using PET. Biodegradable geosynthetics are rarely used as by their nature, they degrade when exposed to soils and moisture (Austroads 2009). Some examples of recycled geosynthetics are depicted in Figure 2.1.

Figure 2.1: Examples of recycled geosynthetics

Geosynthetics type	Example
Geotextile	
Geogrid	
Geonet	

Source: Geofabrics (2021), Huesker (2022), Geohex (2019).

2.2 Current Geosynthetic Offerings

A series of meetings with main Australian geosynthetic suppliers were held to identify what geosynthetic products containing RP are available, to understand barriers and opportunities of using RPs in the manufacture of geosynthetics, and whether there is interest from the industry to do so. From these meetings, the recycled geosynthetic products in Table 2.1 were identified as being available in Australia. Several of these products are used widely in industry, while some are considered niche products or alternatives to commonly used products.

Table 2.1: Available RP geosynthetics in Australia

Supplier	Geosynthetic type	Applications	Type of recycled plastic	Content of recycled plastic	Current environmental product declaration
A	Geotextile (including geocomposites incorporating the geotextile)	Separation Filtration Drainage	PET	Up to 20%	No
A	Geocomposite	Panel drain	PET (as above) HDPE (drainage core)	Up to 20% 100%	No
A	Geotextile	Reinforcement (geotextile reinforced seals)	PET	Up to 20%	No
C	Geonet	Protection (cushioning)	PP	100%	No
C	Geonet	Stormwater drainage	PP or HDPE	100%	No
D	Geocomposite	Reinforcement (asphalt)	PET	100%	Yes

Supplier	Geosynthetic type	Applications	Type of recycled plastic	Content of recycled plastic	Current environmental product declaration
D	Geogrid	Reinforcement (earthworks/ slope stability)	PET	100%	Yes
D	Geocomposite	Reinforcement (geotextile reinforced seals)	PET	100%	No
E	Geocomposite	Strip filter	HDPE	100% (core only)	No

Note: No information is included in the table for Supplier B, as Supplier B does not currently advertise products made from recycled materials.

2.3 Key Geosynthetic Requirements

The geosynthetic requirements of TMR, MRWA, Department of Transport (DOT) Victoria and Transport for NSW (TfNSW) were assessed. This was undertaken as a review of existing specifications relevant to geosynthetic applications. The key parameters which a RP must consistently achieve are summarised in Table 2.2. A detailed list of each road agency's requirements is provided in Appendix A.

Table 2.2: RP requirements for geosynthetics

Application	Property	Remark
		Geosynthetics
All	UV stabilisation	Must retain minimum strength of at least 50% after 500 hours of test exposure. Specific applications require a higher level of UV stabilisation.
Protection	UV stabilisation	Limited loss in strength after significant UV exposure.
		Geotextiles
All	Strength	G rating
	Filtration	Equivalent opening size (mm)
Geotextile reinforced seals (GRS)	Strength	Wide strip tensile strength
	Melting point	A melting point of at least 10 °C above the seal spray temperature
	Bitumen retention	The absorption of bitumen by the geotextile must be factored into the relevant road agency seal design
		Geogrids
Pavements	Strength	Ultimate strength
	Strength	Service strength (at 2% strain)
	Strength	Junction strength (at 2% strain)
	Durable	Resistance to installation damage
	Melting point (for those used in asphalt)	A melting point of at least 10 °C above the asphalt or seal application temperature

Uncontaminated RPs can achieve similar properties to an equivalent virgin plastic, however where there is contamination the RP may not achieve the required standards. Long-term degradation of RPs has been identified as a concern. RP degradation can be much faster than virgin polymers and it is important that the RP feedstock for geosynthetic applications is of a high enough quality to give long-term degradation properties similar to virgin plastic equivalents. To control this risk of contamination, suppliers using RPs rely on their quality systems and geosynthetic thickening as a redundancy to ensure the geosynthetic meets the performance standard. As the use of RPs increases the risk of contaminants and localised sub-standard performance of geosynthetics, geosynthetic suppliers must ensure the risk of sub-standard performance is acceptable for their production methodology.

For the purposes of this report, RP contaminants are defined as any material which will lower the desired quality characteristics of a particular type of RP. For geosynthetics, common contaminants include:

- organics
- other types of plastic (particularly PVC)

- metal ions
- ash/char associated with the thermal reprocessing techniques.

Additionally, the suppliers were asked whether the creation of a lower standard specification (for use in lower order applications) would increase the use of RPs. The suppliers were not supportive of this as the primary processing issue for recycled geosynthetics is being able to consistently achieve a standard level of quality. The use of a lower standard product specification would not reduce the need for these quality controls.

2.4 The Use of RP in Specifications

There were no specific state or territory road agency technical specifications identified that were perceived as a barrier to the usage of RP in geosynthetic applications. The reviewed technical specifications are designed such that any material may be employed, provided they meet performance requirements. Furthermore, the international standards which major suppliers use as a benchmark for geosynthetic performance (BS EN 15381:2008 and AASHTO M288-21:2021) for most road-based applications similarly focus on the characteristics of the plastics which are used, regardless of whether it is virgin or RP. An exception to this is that geotextiles and geogrids used to reinforce soil under AASHTO M288-21:2021, are required to either satisfy additional testing requirements or a higher long-term strength if any RP is used in the geosynthetic. It was noted that in the case of geosynthetics such as geomembranes for landfill applications, the use of RP is prohibited, due to the consequences of poor long term separation performance.

2.5 Design Requirements

No documents have been identified to suggest design requirements of RP geosynthetics should be any different to those for virgin plastic products.

After reviewing the TMR and MRWA technical specifications, the closest document to a design guide for geosynthetics found in the project is MRTS27, which specifies the strength and filtration requirements of a geotextile depending on its application and construction method. However, there is no mention of RP requirements in MRTS27.

2.6 Installation and End-of-Life

2.6.1 State Agency Storage & Installation Requirements

A summary of the MRWA & TMR storage & installation requirements is shown in Table 2.3. There are no specific requirements unique to the use of RP products, compared to virgin plastic or other materials.

Table 2.3: Geosynthetic installation requirements

Requirement	MRWA technical specification	TMR technical specification
Geosynthetics are to be stored off the ground	Spec 403:2021; Spec 406:2017; Spec 501:2022, Spec 511:2021	MRTS27:2020, MRTS57:2022, MRTS58:2022, MRTS100:2019; MRTS104:2022
Geosynthetics must not be exposed to excessive temperatures		MRTS27:2020, MRTS57:2022, MRTS58:2022, MRTS100:2019; MRTS104:2022
Geosynthetics must not have been exposed to moisture	Spec 511:2021	MRTS104:2022, MRTS57:2022, MRTS58:2022
Geosynthetics must be packed in waterproof, UV protective sheeting	Spec 403:2021; Spec 406:2017; Spec 501:2022; Spec 511:2021	MRTS27:2020, MRTS57:2022, MRTS58:2022, MRTS100:2019, MRTS104:2022

Requirement	MRWA technical specification	TMR technical specification
Conformance testing within specified time periods of installation	Spec 201:2022	MRTS27:2020; MRTS57:2022; MRTS58:2022; MRTS100:2019; MRTS104:2022
Used within 2 years of manufacture date	Spec 511:2021	
Comply with relevant labelling requirements	Spec 403:2021, Spec 406:2017, Spec 501:2022, Spec 511:2021	MRTS27:2020; MRTS57:2022; MRTS58:2022; MRTS100:2019, MRTS104
Covered within 14 days of installation	Spec 403:2022; Spec 406:2017, Spec 501:2022	MRTS57:2022(1), MRTS58:2022 (2), MRTS104 (1)
Delivered to site minimum 14 day prior to installation		MRTS57:2022, MRTS58:2022, MRTS100:2019; MRTS104:2022

1. Immediately.
2. Within 24 hours.

For geotextiles used in a GRS, both MRTS57:2022 and MRWA Specification 503:2018 include detailed installation requirements such as the plant, rolling technique and minimum overlap requirements. In addition, TMR has provided technical specifications on the material and construction for asphalt geosynthetics used to retard reflective cracking (MRTS104:2022) and on the physical, material, and construction requirements of geosynthetics used in subgrade reinforcement applications (MRTS58:2022).

2.6.2 Expected Life of Geosynthetic

From the correspondence with suppliers, it was identified that the life of a geosynthetic is heavily dependent on its application.

For separation and filtration functions, most of the damage to the geotextile will occur during the installation and compaction of adjacent material layers. This is reflected in the parameters used by road agencies to assess the suitability of a geosynthetic, such as the nominal maximum size of the overlying material or the depth of the trench which the geosynthetic is installed within.

For reinforcement functions, the life is dependent on the specific application of the geosynthetic. For GRS, a design life of 8 to 15 years is expected, which aligns with the design life of sprayed seals in general (Austroads 2018). Geogrids used in reinforcement applications are expected to become permanent components of the structure, with design lives at or above 100 years being common. This is reflected in MRWA specification 802:2021’s requirement for a geotextile installed at a bridge, to have a design life at least that of the bridge (100 years minimum).

2.6.3 Geosynthetic End-of-Life Disposal

For most road applications (excluding GRS) it is expected that the geosynthetics will remain as a permanent component within the earthworks, drainage or pavements at the end of their service life. This is due to little economic benefit and practical constraints in accessing the geosynthetic when compared to the cost of removing the overlying materials and structures. Furthermore, in accessing the geosynthetic, it is likely that further damage will occur to the geosynthetic.

Where the geosynthetic is applied near the wearing surface of pavements (such as geosynthetic reinforced seals and geogrids), the complete removal of the geosynthetic from the adjacent pavement layers is both time consuming and costly, despite the geosynthetic being more accessible. Queensland Department of Transport and Main Roads (2020) and VicRoads (2004) both advise taking extreme care to ensure that geosynthetics are removed and separated from any adjacent pavements to be recycled. This is due to the geosynthetic potentially contaminating the recycled pavement with plastic fibres and the difficulties which geosynthetics cause during the milling and processing of a recycled pavement. Due to these difficulties, it is typical to avoid removing the geosynthetics and use a corrective treatment to repair the wearing surface.

From the correspondence with suppliers, it was identified that both recycled and virgin plastic geosynthetics are made of the same type of plastic, therefore there is no anticipated difference for the management of the geosynthetics at the end of their life. The suppliers recommended not attempting to reuse geosynthetics as feedstock as they have been contaminated by the adjacent materials. In general, the separation of plastics from contaminants is a broader issue, this is further discussed in section 2.8.2.

2.7 Requirements for Using Recycled Plastic in Geosynthetics

Currently none of the reviewed road agency technical specifications provide direction on the use of RPs in geosynthetics. However, it is expected that components manufactured using RPs should have the same or improved performance when compared to their virgin material counterparts. There are restrictions placed on the type of plastic to be used on certain reinforcement applications (e.g. MRWA TMR requiring polyester in GRS); however, this is due to the higher standard of geosynthetic required in these applications to ensure that the product has a high strength with low creep.

As identified during the correspondence with suppliers, HB 154-2002 (Standards Australia 2002) advises to not use post-consumer recycled polymer without proof of its long-term durability, as the durability of the material decreases every time the material has been reprocessed. With regard to whether HB 154-2002 was perceived as a barrier by suppliers, each supplier view of HB 154-2002 aligned with their general view on the use of recycled plastics – as below:

- The suppliers that discourage the use of recycled plastics in geosynthetics saw the guideline as a significant barrier, with both Standards Australia and the International Standards Organisation (as the guideline is based on an international guideline) advising against the use of recycled plastics.
- The suppliers that encourage the use of recycled plastics recognised the potential durability issues which the guidelines outline, however, as the document is only a guideline, they do not view it as a significant barrier as it is not a limiting requirement for geosynthetics.

Therefore, it is recommended that MRWA and TMR provide a clear stance on their interpretation upon this guideline to provide clarity for suppliers.

2.8 Sustainability of Geosynthetics

As highlighted in the TMR (2021) *Environmental Sustainability Policy* and MRWA (2016) *Sustainability Policy* the aims to minimise the environmental footprint of business and develop a culture of sustainability within the roads industry are key commitments that both road agencies share. For geosynthetics, the primary methodology of assessing sustainability is to compare the environmental footprint of the engineering activities whole life cycle from material extraction to disposal, whether directly or indirectly associated with the activity against alternative engineering activities (Dixon et al. 2017).

As outlined in the TMR (2022) *Waste 2 Resource Strategy* and MRWA (2021) *Recycled Materials at Main Roads Reference Guide*, both road agencies prefer the use of recycled materials (over conventional materials) where they are:

- cost competitive
- locally available
- comply with specifications.

2.8.1 General Sustainability of Geosynthetics

In Dixon et al. (2017), six life cycle analysis studies were reviewed to assess the sustainability of geosynthetics in comparison to alternative construction techniques. The six studies all agreed that the use of geosynthetics is more sustainable as they promote the use of lower quality fill materials which are generally sourced closer to the project site and therefore reduce the transport emissions (Dixon et al. 2017). It is noted however that there is now a widely accepted design approach for the use of lower quality materials or reduced thickness of materials associated with the use of geosynthetics.

Beyond this point, however, this section will further focus on the sustainability benefits when manufacturing geosynthetics using recycled materials.

2.8.2 Sustainability of Recycled Geosynthetics

When assessing the sustainability of materials containing recycled plastics, a number of key factors need to be considered, including:

- GHG emissions
- waste reduction and improving resource efficiency from a circular economy approach

Any sustainability assessment needs to consider the highest and best use of the materials being proposed. For example, if very high-quality recycled plastic materials are needed to produce geosynthetics – will this reduce the feedstock that is available for other applications (such as containers) which in turn may increase their demand for virgin plastics and limit the overall sustainability benefit?

To compare the sustainability of geosynthetics made from virgin plastics or RPs, the whole life cycle of carbon emissions, value received and any other environmental impacts must be considered. It should be noted, that as highlighted in section 2.6.3, it is not recommended that geosynthetics be reused as feedstock at end-of-life. Thus, this application is not a true circular economy, though it offers benefits in replacing use of virgin plastic with RP.

Where available, the environmental product declarations of geosynthetics sold in Australia made from recycled and virgin plastics were compared to assess the relative emissions of each. This comparison showed that the emissions from the virgin product were approximately 14% higher than that of the recycled product. Additionally, the environmental product declarations suggest that the emissions associated with transport are minimal, with over 97% of emissions attributed (in decreasing order) to: raw material supply, waste processing, manufacturing and installation for both recycled and virgin products.

In the case of recycled geosynthetics, the material used has been repurposed from a prior product with its own value and associated emissions. During their disposal, these products are transported to the processing plant and then reshaped into a geosynthetic. King et al. (2021) identified that the most suitable plastic processing technique is dependent on the type of plastic being processed. In addition, the suitability of the reprocessing option utilised should factor into whether recycling plastic as a geosynthetic is sufficiently sustainable.

The plastic processing techniques can be generalised into the following categories:

- Mechanical processing: This involves the softening, melting and reshaping of plastics. Suitable for thermoplastics, although the stress of the process can lower the tensile strength and elongation of the recycled plastic.
- Purification processing: The plastic is dissolved in a chemical solvent, with other immiscible solvents used to extract impurities. A drawback to purification is that the solvents are generally hazardous and environmentally harmful.
- Depolymerisation processing: The plastic is broken down into its constituent monomers via chemical, thermal or biological processes. The process has the benefit of a limited impact to the material properties of the plastic, however the feedstock of the plastic for most depolymerisation processes must be relatively pure.
- Conversion processing: The plastic is broken down into smaller molecules, which can be used for new polymers, chemicals or fuels (King et al. 2021).

The suitability of the processing categories of plastics currently used in geosynthetics is summarised in Table 2.4.

Table 2.4: Suitable processing for plastic types used in geosynthetics

Plastic type	Processing type
PET (1)	• Ideal for depolymerisation processing • Good for mechanical processing
HDPE (2)	• Good for mechanical processing • Otherwise, suitable for conversion processing
PVC (3)	• Best suited for purification processing
LDPE (4)	• Suitable for mechanical processing • Suitable for conversion processing
EPS (6)	• Excellent for purification processing • Good for conversion & depolymerisation processing

Source: King et al. (2021).

Correspondence with suppliers highlighted the following insights into the sustainability of geosynthetic products:

- Producing sustainable products is a key concern for all the suppliers, irrespective of whether their product is made from virgin or RPs.
- Transporting plastic over large distances to be processed and become recycled geosynthetics is not the most sustainable option when these plastics can be repurposed into other high value products in Australia such as packaging.
- There are significant environmental impacts of recycled geosynthetics due to the large amounts of water and electricity required during the reprocessing of plastics.

However, it is unclear what the environmental impacts of chemicals used to process plastics and what the total carbon emissions for transportation and the manufacturing process are, as these are heavily dependent on the supply chains, location of the processing plant and the processing equipment of the geosynthetic supplier.

Presently, waste PET in Australia is not processed at significant volumes to meet all the demand for higher end applications, such as packaging. However, the restriction is not the amount of waste PET created, but the processing capability and capacity. If processing infrastructure was improved, it is likely there would be enough recycled PET to meet higher end application demand and produce good quality geosynthetics.

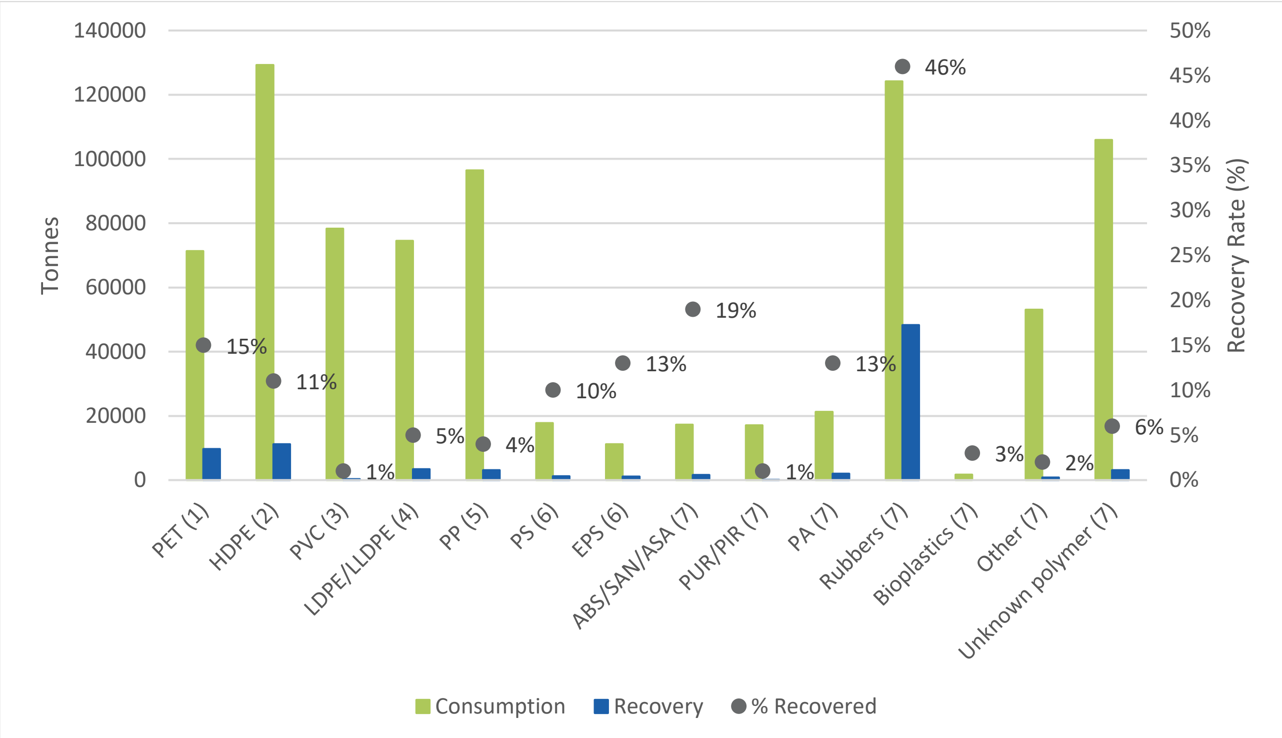
3 Viability of Utilising Recycled Plastics in Geosynthetics

3.1 Current Recycled Plastic Feedstock

In 2019–20, Queensland and Western Australia consumed 819,500 and 422,100 tonnes of plastic, respectively. Of the plastic consumed, both states recovered approximately 15% of the consumed plastic which is slightly lower than the national average of 18% (O'Farrell et al. 2021). A breakdown of consumption and recovery by polymer type is provided in Figure 3.1 for Queensland, and Figure 3.2 for Western Australia. As well as polymers already discussed in this report, the plastic types included in these figures are:

- low-density polyethylene (LDPE)
- Linear low-density polyethylene (LLDPE)
- Polystyrene (PS)
- Acrylonitrile butadiene styrene (ABS)
- Styrene acrylonitrile (SAN)
- Acrylonitrile styrene acrylate (ASA)
- Polyurethanes (PUR)
- Post-industrial resin (PIR)
- Polyamide nylon (PA)

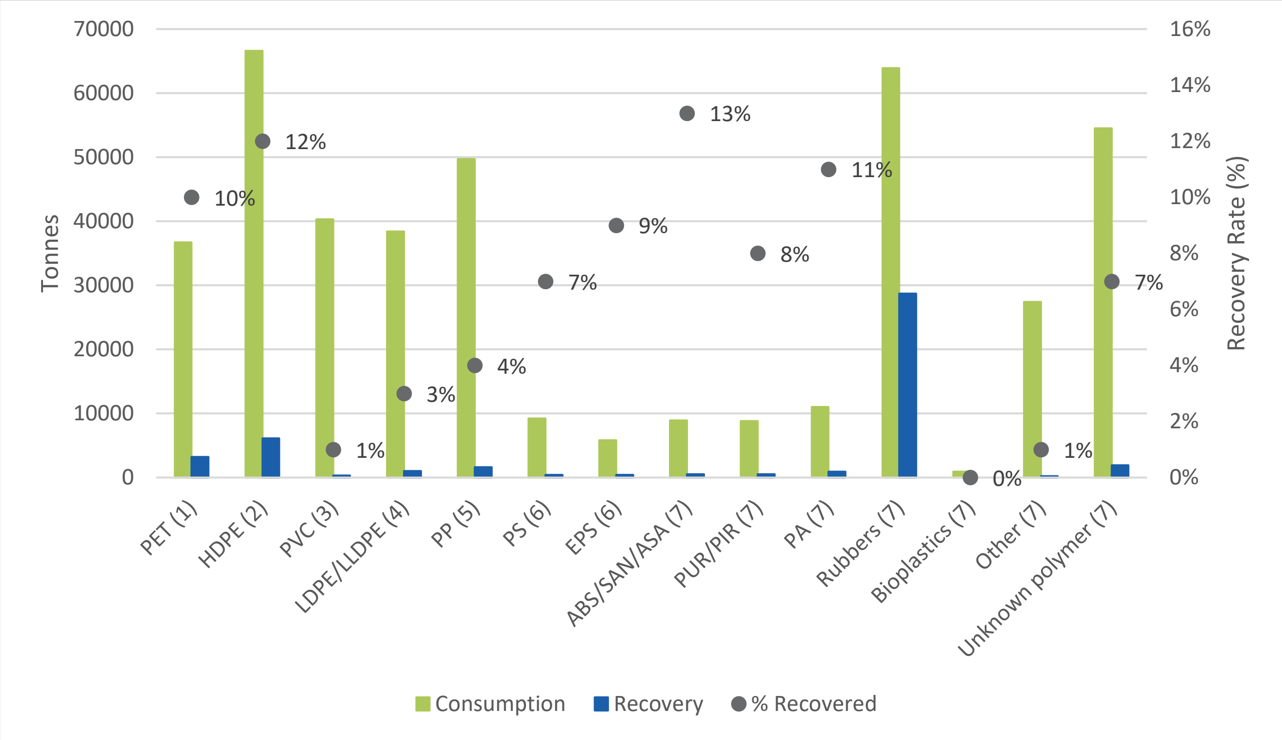
Figure 3.1: 2019–20 Queensland plastic consumption and recovery by polymer type



Note: The bracketed number for each plastic type corresponds with the plastic's identification code.

Source: Adapted from O'Farrell et al. (2021).

Figure 3.2: 2019–20 Western Australian plastic consumption and recovery by polymer type



Note: The bracketed number for each plastic type corresponds with the plastic's identification code.

Source: Adapted from O'Farrell et al. (2021).

For both Queensland and Western Australia, HDPE is the most recovered plastic type; both in terms of total tonnes and as a percentage of consumption. PVC is the least recovered plastic type which Schandl et al. (2020) suggests is due to the long life of virgin PVC that is used in piping applications.

The applications utilising these recovered plastics are dominated by energy production in cement kilns and the production of packaging, that combined account for 62% of the market (O'Farrell 2020). Their use in geosynthetics is likely to be a very small portion of the Australian recovery plastics industry, given that only a small volume of geosynthetics is used in Queensland and Western Australia annually, and only a small proportion of that is likely to contain RP. While challenging to understand exact volumes, given the use of varied installers and contractors, one supplier advised that approximately 6,000 and 3,000 tonnes of geosynthetic products were provided to TMR and MRWA projects, respectively, on an annual basis.

Of the lower grade plastics, thermoplastics such as PVC and PP currently can be mechanically processed without significantly changing the mechanical structure of the material, depending on the waste source (Schandl et al. 2020). Furthermore, many of the applications where lower grade thermosetting plastics are utilised include lower value applications when compared to the plastics virgin use, such as a filler material in insulation or concrete.

With regard to geosynthetics, this report has identified the following geosynthetic applications for various types of plastic:

- PET is used across various geosynthetic applications as it retains similar desirable qualities to virgin plastics.
- PP and HDPE are used as coring in applications such as panel drains where the plastics primary function is compressive strength.
- EPS as in geofoam, has the potential for various road construction applications such as fill for bridge abutments and behind retaining walls and slope stabilisation (Unipod 2021). The drawback with geofoam is that the product has a very low density, therefore the tonnage of material which is recycled is relatively low.

However, it must be noted that geosynthetic materials are proprietary products and the type of recycled plastic used needs to be determined by industry. Associated testing needs to be undertaken to ensure that the end product is fit for purpose and compliant with the relevant specifications.

3.2 Sourcing Recycled Plastic Feedstock

From the correspondence with suppliers, it was identified that Supplier A was the only supplier which currently sources Australian RP as part of their plastic feedstock for geosynthetic products and manufacturers in Australia. Most of the suppliers identified that the availability of high quality, low contaminated RPs was the major barrier for sourcing Australian RP feedstock. Furthermore, most suppliers highlighted that the introduction of a lower quality controlled geosynthetic product is not a practical option, as it is not considered sustainable to increase the likelihood of failure and rework due to a poor performing geosynthetic.

Supplier A stated that they are using Australian RP feedstock through an established business relationship with a supplier of high-quality feedstock. Supplier A is already utilising 100% of the available supply of the RPs through their supplier and cannot presently expand their usage of RPs. Furthermore, Supplier A understands it to be unlikely that the supplied volume will change significantly in the future as there is a competing demand for high quality RP for a wide range of non-road related applications. This finding, however, does not mean that there are no other waste streams or waste material suppliers that could be investigated should an expansion be required.

Whilst it would be highly desirable to utilise recycled plastic feedstock from Australia, given the limited access to high quality, low contaminated RP; utilising internationally sourced RP is the next desirable alternative to meet sustainability objectives discussed in section 2.8. Most of the suppliers identified that they were able to source and supply high quality, low contaminated RP feedstock at a production cost competitive to virgin plastics from locations such as Europe and Asia.

According to Locock et al. (2017), the global RP market is increasing in size by approximately 6% per annum, with some key factors influencing the market including:

- strong regulation and incentives for companies in Europe, which drive investment to place a higher emphasis on the circular economy
- large population Asian countries such as China and India implementing low-tech, labour-intensive solutions into their waste management processing systems
- the cost of virgin materials, which is tied to oil and plastic prices
- while this may not be the optimum outcome (i.e. use of Australian waste plastic), the use of overseas recycled plastic may provide sustainability benefits when compared to virgin plastic

3.3 Processing Recycled Plastics in Australia

It was identified that currently two of the five suppliers that put forward tenders on geosynthetics for MRWA and TMR produce some of their products in Australia. As noted in Section 3.2, only one of these suppliers uses Australian RP and the other supplier sources from overseas.

The suppliers distributing products manufactured overseas highlighted that a major barrier to creating processing plants in Australia for both virgin and RP products is the small size of the Australian market, in comparison to the global market for geosynthetics. Furthermore, the ease of freight from these global markets makes it difficult to economically justify the creation of processing facilities in Australia for both virgin and RPs to be converted into geosynthetics. The one high volume producer of geosynthetics in Australia has a focus on geotextiles, which are produced in sufficient capacity to overcome this barrier.

The responses from the suppliers align with the industry consultation from CSIRO (n.d.), where it was identified that the key strategic issues facing nonwoven manufacturers were:

- lowering production costs

- increasing the value add of the product
- increasing the sustainability when manufacturing the product.

3.4 Recycled Plastic Geosynthetic Usage Case

As part of this project, usage calculations have been undertaken to understand the volumes of RP that could be absorbed by different applications. This section looks into some usage cases for RP in geosynthetics, based on the findings of this report and discussions with the major suppliers.

To undertake the usage case calculations, the starting point is to understand the volumes of geosynthetics that are installed in Queensland and Western Australia annually, be they made from virgin plastic or RP. To get a better handle on these volumes, the major suppliers were contacted and asked to supply figures on the geosynthetics they supply for use in each of the two states.

One supplier provided as estimate of 6,000 and 3,000 tonnes annually, for TMR and MRWA projects respectively. From the consultations undertaken in this project, it is understood there are four major geosynthetics suppliers, thus may be assumed this value can be multiplied by four. Additional historical data was available for Queensland, where it was estimated in 2020 that approximately 72,000,000 m^2 of geosynthetics were supplied for use in transport infrastructure in Queensland, or 18,000 tonnes. This gives additional confidence to the above estimates. These figures form the basis of the initial usage calculations provided in Table 3.1. It should also be noted any usage volumes are improvements to the current practice of utilising 0% recycled plastic in geosynthetics.

The potential RP use cases are based on typical geosynthetics currently produced in Australia, which contain 10–20% RP, as well as forward thinking 50% and 100% recycled plastic scenarios, should feedstock availability increase to allow higher volumes to be incorporated. These volumes are not yet feasible due to waste plastic processing capabilities in Australia, however, demonstrate higher opportunities for use of RP than in asphalt applications.

Table 3.1: Recycled plastic geosynthetic usage case

Scenario	MRWA estimate (tonnes)	Percentage of WA waste stream (%)[1]	TMR estimate (tonnes)	Percentage of Qld waste stream (%)[2]
All geosynthetics contain 10% RP	1200	0.381	2400	0.393
All geosynthetics contain 20% RP	2400	0.763	4800	0.786
All geosynthetics contain 50% RP	6000	1.907	12000	1.964
All geosynthetics contain 100% RP	12000	3.813	24000	3.929

Source: O'Farrell et al. (2021), correspondence with geosynthetics suppliers.

1. 314,700 tonnes plastic reaching end of life, 2019–20
2. 610,900 tonnes plastic reaching end of life, 2019–20

4 Performance Impacts of Using Recycled Plastics in Geosynthetic Applications

The potential performance impacts of using RP in geosynthetic applications were discussed with the suppliers. It was identified that:

- Both virgin and RP have similar storage requirements. UV radiation causing a deterioration of the plastics is one of the main concerns for both products. Suppliers typically include protective layers to prevent UV radiation damage prior to the installation of geosynthetics. These protective layers are made from RP. The UV resistance performance of RP-made geosynthetics is currently being investigated by one of the suppliers.
- Suppliers highlighted that contaminants decrease the consistency of recycled materials during the manufacturing process. This leads to an increased risk for the supplier that their products will not conform to the relevant technical specifications, or that costs will increase due to expanded manufacturing quality controls required to filter such products. This includes quality controls in sourcing and processing the RP, blending the RP with virgin plastics or thickening the geosynthetic.
- Some suppliers noted that manufacturers use rejuvenating additives to improve the characteristics of RPs. However, there is a threshold where rejuvenating additives cannot offset the decrease in consistency due to contaminants within RPs without increasing the thickness of the geosynthetic. It was suggested that the threshold was at around 20% of the product incorporating RP, based on current knowledge. For products beyond 20% RPs, one supplier noted inconsistency may be offset by producing thicker products to improve its characteristics.

  From the consultation it was clear that the composition of rejuvenating additives was considered proprietary information, with a supplier suggesting that carbon was the key additive utilised to increase strength.
- A supplier noted that with the similarities of recycled and virgin plastics after production, it is difficult for suppliers to verify the amount of RPs used within geosynthetics without auditing of the manufacturing plant.
- Multiple suppliers expressed interest in collaborating with new clients/ road agencies to develop new products, with general uncertainty on product market with road agencies and local government being a barrier in committing to research and development.
- Although recycled samples of different types of plastic may exhibit similar or equal strength parameters to their virgin equivalents, it was noted that except for PET, recycled options exhibit poor long-term creep performance or otherwise exhibit a noticeable degradation of strength over time compared to virgin plastic products.

Furthermore, the suppliers highlighted that it was difficult to provide quantitative information regarding the performance impacts of using a RP due to:

- the design life of geosynthetics being heavily dependent on the application
- the actual life of the geosynthetic being heavily dependent on specific site conditions
- the difficulty in determining whether the geosynthetic is the cause of failure without destructive investigation.

It must be noted that this report has not independently validated performance outcomes via testing; this may be applicable in subsequent stages of this research.

5 Monitoring of Field Trials

5.1 Introduction

This section provides a general methodology for TMR & MRWA to utilise in planning, establishing and monitoring field trials, which was developed based on the outcomes of the literature review and the feedback from suppliers. This is a broad methodology that may be applied to a range of geosynthetic applications, and discusses the types of field trial that may be undertaken, the recommended methods of data collection and their usefulness.

5.2 Types of Field Trial

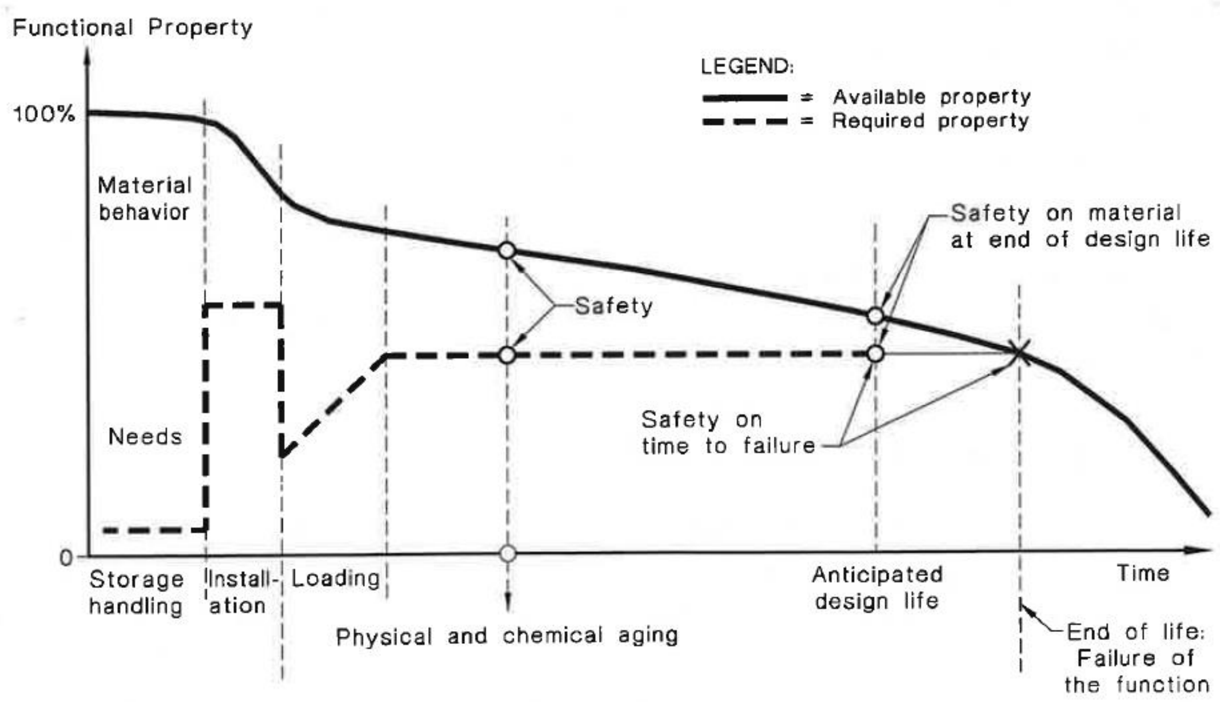
It is common for field trials to have a primary goal falling into one of two different categories; durability or sustainability.

5.2.1 Durability

Durability field trials assess how the effects of time impact the functional properties and the eventual degradation of the geosynthetic. As shown in Figure 5.1, the life of a geosynthetic typically involves:

- property changes during storage and installation due to weathering and mechanical damage
- a slow degradation during the product's design life due to loading and/or physical and chemical ageing
- a critical defect of the geosynthetic which causes it to fail in performing its function.

Figure 5.1: Typical durability of geosynthetics over time



Source: HB 154-2002 F1 (Standards Australia 2002).

Therefore, durability field trials tend to focus on the design life of the geosynthetic, and compare the effect of various designs on when critical failure occurs. As the durability performance of geosynthetics is dependent on the site conditions, it is recommended that a control is used.

5.2.2 Sustainability

Sustainability field trials assess the relative safety and environmental impacts of various designs. Unlike durability field trials, they generally take a broader focus of the geosynthetic material over its whole life cycle from material extraction to disposal (which is typically to remain buried & undisturbed yet non-functional). Examples include:

- calculated CO_2 emissions of geosynthetics
- safety of installation assessment
- end-of=life contamination of soil, pavement or water.

As the sustainability performance of geosynthetics is dependent on the site conditions, it is recommended that a control is used.

The sustainability of geosynthetic products can typically be assessed through desktop studies, and the requirement for field trials to investigate this aspect would only be necessary if all other available avenues have been exhausted.

5.3 Project Planning

The planning phase of a field trial should follow the systematic steps as outlined in Table 5.1.

Table 5.1: Systematic steps for planning a geosynthetic field trial

Step	Item	Remarks
1	Define objectives & controls of field trial	• the aim of the field trial • the type and content of RP in the trial product • the assessment method for the performance of RP geosynthetics • the controls that will be implemented
2	Define project conditions	The site conditions and the constraints on the field trial (See Table 5.2)
3	Define the purpose of the instrumentation	Determine appropriate instrumentation. Do not include instrumentation where the goal of the instrumentation cannot be identified in the planning phase, as it is unnecessarily bloating the field trial.
4	Select the parameter(s) to be monitored	The primary parameters of a geosynthetic can be varied depending on the application and its associated function. Variables can include deformation, load, strain, water pressure. (See Table 5.4)
5	Predict the magnitude(s) of change	Make a hypothesis on how significant the change in the variable will be. This will impact the location, frequency, accuracy and orientation requirements of the instruments and measurements.
6	Devise solutions to the anticipated observation findings	As the field trial is conducted on a public asset, solutions to anticipated failures need to be factored and planned for rehabilitation.
7	Assign relevant tasks	Create a project plan which outlines the project tasks and the responsibilities of those involved in each task.
8	Select the type of instruments appropriate for the project	Ensure all the above tasks are completed prior to selecting the type of instruments. Instruments should be selected based upon their reliability, sensitivity, accuracy, durability, and the value they are able to provide the project.
9	Plan for factors influencing the measured data	These factors need to have plans to minimise their impact on collected data where practical. These factors include climatic conditions, instrument installation requirements and the project conditions (Step 2). (See Table 5.2)
10	Establish procedures for ensuring data reading correctness	These procedures provide confidence to the collected data. These include instrument calibration and maintenance requirements, and verification checks on collected data.
11	Select instrument locations	The locations should be selected in a way that represents the targeted parameter(s) and/or predicted behaviour best.
12	List the purposes of each instrument	The function of each instrument should be identified, and each instrument be given a unique identifier to avoid any potential confusion.

Step	Item	Remarks
13	Prepare an instrument procurement specification & acquire instrumentation	Identify the minimum requirements of an instrument. This can be done by: • selecting a specific instrument based upon previous experience • selecting required characteristics of the instrument or its components (e.g. minimum size) • specifying the performance requirements of the instrument.
14	Book/procure instrumentation services	Ensure that qualified personnel are booked or procured to undertake services for the field trial.
15	Plan the installation	Ensure step-by-step procedures are developed well in advance of the field trial. Documented procedures and record systems are preferred for quality and accountability.
16	Plan post-installation requirements	All personnel should be aware of their obligations for the field trial to minimise any potential variables. Obligations include calibration, maintenance, data collection, data processing and data interpretation.

Source: Adapted from Dunnicliff (1988).

Some of the environmental factors which should be considered in the planning stage (e.g. Step 1 of Table 5.1), are listed in Table 5.2 for the applications in which geosynthetics are used.

Table 5.2: Environmental factors to consider for a field trial monitoring

Function/Application		Environmental factors to consider	
		Factor	Effect
Filtration		Rainfall	Sediment accumulation and clogging
Drainage		Rainfall	Discharge rate
Reinforcement	Earthworks/slope stability	Rainfall	Porewater pressure
	Asphalt and sprayed seal	Temperature	Softening/hardening
General (All)		Temperature, groundwater level, soil acidity and/or salinity	Microplastics, release of hazardous materials into soil, pavement or water

Table 5.3 presents the functions/applications for each geosynthetic type, whilst Table 5.4 presents the parameters and/or properties of constructed geosynthetics that are recommended for monitoring of each function/application type.

Table 5.3: Geosynthetics types and their relevant functions for field trial monitoring

Geosynthetic type	Function/application												
	Separation				Filtration	Drainage	Protection		Reinforcement				
	Pavement layers	Fill	Embankments	Rock armour			Erosion control	Cushioning	Earthworks/ slope stability	Embankments over soft soils	Granular pavement layers	Delay reflective cracking[1]/ bound layers	Asphalt and sprayed seals
Geotextile	X	X	X	X	X	X	X	X	X	X	X	X	X
Geogrid							X	X	X		X	X	X
Geocomposite	X	X	X	X	X	X	X	X	X	X	X	X	X
Geonet							X	X					

Table 5.4: Parameters and properties to measure for a field trial monitoring

Parameters/properties	Methodology	Function/application													
		Separation						Protection		Reinforcement					
		Pavement layers	Fill	Embankments	Rock armour	Filtration	Drainage	Erosion control	Cushioning	Earthworks/slope stability	Embankments over soft soils	Granular pavement layers	Delay reflective cracking(1)/ bound layers	Asphalt and sprayed seals	All
Deflection	FWD	X										X		X	
Surface roughness	Truck mounted accelerometers	X										x	x		
Rutting	Truck mounted ultrasonic height measurements	X										x	x	X	
Crack lengths and density patterns	Physical measurements	X										x	x	X	
Displacement	Strain gauge, extensometer		X	X	X			X	X						
Observe defects	Visual observation		X	X	X	X		X	X	X	X	X	X	X	
Excessive clogging	Pore pressure, outflow, sediment yield					X									
Liquid heads	Measuring within the geosynthetic or adjacent stream soil						X								
Pore water pressure							X								
Sedimentation	Sediment collection gauge							X	X						
Lateral soil displacement	extensometer									X					
Soil moisture content/saturation	Instrumentation, soil testing									X					
Lateral earth pressure	Earth pressure cells									X					
Soil temperature	Thermometer									X					
Geogrid extension	Strain gauge									X					
Strain	Strain gauge										X				
Deformation	Inextensible flexible cables										X				
Bearing capacity	CBR, PLT, FWD, TSD(2)											X		X	
Load transfer efficiency	FWD												X		
Crack detection	Visual assessment, NSV(3)												X	X	
Bond strength	Coring and Leutner shear test(4)												X	X	

Parameters/properties	Methodology	Function/application														
		Separation				Filtration	Drainage	Protection		Reinforcement					All
		Pavement layers	Fill	Embankments	Rock armour			Erosion control	Cushioning	Earthworks/slope stability	Embankments over soft soils	Granular pavement layers	Delay reflective cracking(1)/ bound layers	Asphalt and sprayed seals	
Emissions and fuming(5)														X	
Position and alignment	Visual inspection														X
Concentration of contaminants(6)	Ecotoxicity														X

Notes:

1. Geosynthetics installed to delay reflective cracking typically utilise a spray seal to assist with bonding interlayers. Consider monitoring methods for ‘Asphalt and sprayed seal’ application.
2. Traffic speed deflectometer.
3. Network survey vehicle.
4. Not applicable for thin asphalt and sprayed seals.
5. Refer to section 5.4.1.
6. Refer to sections 5.4.2 and 5.4.3.

Source: Partly adapted from Geosynthetic Institute (2013).

5.4 Health, Safety and Environmental SQP advice of Using RP in Geosynthetics

ARRB engaged an SQP to assess the findings from this report and provide advice on any health, safety and environmental concerns over using geosynthetics containing RPs. Some of the advice is particularly applicable to this section. Below is the SQP's advice taken from Wright (2022). For more details, please refer to the full report in Appendix C.

For RPs to be safely incorporated in geosynthetics, the exposure of workers to fumes and emissions during their high temperature processing needs to be considered. Additionally, leachates and microplastics release need to also be investigated as their presence would directly affect the environment and indirectly affect human health. It should be noted that the advice provided by the SQP does not suggest any different approach to the evaluation of RPs compared to virgin plastics.

5.4.1 Fuming

The SQP report stipulates that efficient measuring of fumes and emissions needs to be conducted at processing temperatures, where materials are exposed to heat and the release of fumes is probable. It is important for the presence of chemicals, as listed in Table 1 of Appendix C to be quantified. The sample collection needs to be carefully planned, taking into consideration the presence of such chemicals in air near the breathing zone of the workers. A comparison between fumes and emissions generated during the high temperature processing of virgin materials and those of RPs is required to ensure that other chemicals which could influence the results are controlled.

5.4.2 Leaching

Similarly to what was proposed for the fumes and emissions analysis, a comparative study on the leachates from virgin and recycled polymers is recommended. Geosynthetics placed at ground surface or below/within permeable materials are to be examined. Such examinations should be undertaken following Australian Standard Leaching Procedure tests (AS 4439.3:2019). Leachate analysis should include chemicals as listed in Table 2 of Appendix C. Relevant waste regulations for Queensland and Western Australia also need to be understood to ensure that the generated waste at the end-of-life will not be regulated or controlled. Measured leachates should be assessed according to limits as reported by the guidelines of Table 2 in Appendix C.

5.4.3 Microplastics

The release of microplastics needs to also be investigated when RPs are to be used. Microplastics are a concern when geosynthetics are installed at the ground surface where they can be weathered. There are currently no guidelines or test methods that may be followed for the analysis of the presence of microplastics and their effect on human health and the environment. Therefore, it is proposed that the most reasonable approach is a comparative analysis between recycled and virgin plastics.

6 Conclusions

6.1 Key Learnings and Opportunities

Following the literature review, supplier consultations and seeking SQP advice, the key learnings and identified were:

- Currently none of the relevant Australian road agency specifications or guidelines restrict the use of RP in geosynthetics. Instead, the technical specifications are structured to ensure a minimum level of quality and performance for geosynthetic products irrespective of the material. This creates an opportunity for the RP materials to be utilised provided the performances meet the requirements.
- Suppliers have been able to demonstrate that geosynthetics containing up to 100% RP are able to be manufactured. Table 6.1 presents the current types and percentages of RPs utilised in various geosynthetics being used in Australia.
- Suppliers must submit conformance reports to meet specification requirements for both TMR and MRWA to demonstrate the performance of the product prior to use, which is a requirement for all geosynthetics regardless of whether they contain RP.
- Usage calculations were made after having discussions with the major geosynthetics suppliers in Australia about their markets in Queensland and Western Australia. Based on typical geosynthetics currently produced in Australia, which contain 10–20% RP, it is estimated TMR and MRWA could utilise up to 4,800 and 2,400 tonnes of RP annually, respectively. In terms of percentage of waste generated (O’Farrell et al. 2021), this is 0.79% and 0.76% of waste generated annually for Queensland and Western Australia, respectively. With a forward-thinking scenario, of 100% recycled plastic geosynthetics, this figure could increase up to 24,000 and 12,000 tonnes for Queensland and Western Australia respectively, or 3.9% and 3.8% of plastic waste generated annually.
- It is not expected that the use of RPs in geosynthetics for road applications would result in a different risk profile than the use of virgin plastics, where the geosynthetic meets the technical specifications relevant to the product. It is desirable that field trials be undertaken to test that the specifications and application of the materials in the field do not result in changes to the risk profile.
- Market factors such as the increase in the global recycling plastics market and the cost of sourcing virgin materials have the potential to increase the competitiveness of recycled geosynthetics compared with virgin materials.

Whilst there are higher end uses for RP than in road infrastructure, RP use in geosynthetics has been identified as a potentially higher end use than utilising them in asphalt, which is limited for road agencies at this stage. It is recommended to investigate their usage in low-risk non-structural applications, with field trials an important starting point to compare their performance against virgin plastic products. For use in higher risk or structural applications, laboratory testing to assess conformance to specifications and compare to virgin products is recommended before moving again to comparative field trials. Laboratory testing should be carried out by independent NATA accredited laboratories and data from suppliers should not be relied upon. Section 5 details parameters that should be monitored during field trials. The following details some key opportunities:

- Recycled EPS (up to 100% content), used in the production of geofoam, has been identified as an opportunity. However, the feedstock needs to be clean.
- The biggest opportunities lie in non-structural applications where there is a much lower risk in the use of RP geosynthetics.
- Short-term applications such as RP geotextile use in spray sealing reinforcement are the next most desirable, as these applications have a relatively low risk profile due to their shorter service lives.
- The use of RP geogrids in pavement reinforcement and/or crack mitigation seems to be a good option provided suppliers can demonstrate their RP products conform to the testing requirements currently stipulated by the road agencies.

- Until more evidence of performance has been gained, long-term applications such as embankment reinforcement should be avoided as creep properties of RP-containing products is currently unknown.

Table 6.1: Current recycled plastic types and contents used in geosynthetic products in Australia

Geosynthetic type	Application	Type of recycled plastic	rontent of Recycled plastic	Plastic feedstock	Production
Geotextile (including geocomposites incorporating the geotextile)	Separation filtration drainage	PET	Up to 20%	Australia	Australia
Geocomposite	Panel drain	PET (as above) HDPE (drainage core)	Up to 20% 100%	Australia	Australia
Geotextile	Reinforcement (geotextile reinforced seals)	PET	Up to 20%	Australia	Australia
Geonet	Protection (cushioning)	PP	100%	Overseas	Australia
Geonet*	Stormwater drainage	PP or HDPE	100%	Overseas	Australia
Geocomposite	Reinforcement (asphalt)	PET	100%	Overseas	Overseas
Geogrid	Reinforcement (earthworks/ slope stability)	PET	100%	Overseas	Overseas
Geocomposite	Reinforcement (geotextile reinforced seals)	PET	100%	Overseas	Overseas
Geocomposite	Strip filter	HDPE	100% (core only)	Overseas	Overseas

* This is a niche supplier which allows them to overcome the barrier of production costs in Australia and is not entirely representative of the geosynthetics industry as a whole.

6.2 Barriers

Following the literature review and supplier consultations, the key barriers were identified as:

- Market factors (e.g. feedstock supply costs, production costs, market value of products) are the primary driver for change in the geosynthetic market, including where the material is sourced and how the material is processed.
- Sourcing high quality plastic feedstock was identified as a challenge for suppliers, particularly as there is high demand for RPs to be reused in other high value products (e.g. packaging) where greater amounts of RP volume can be used in comparison.
- One supplier advised that incorporation of more than 20% RPs in geosynthetics may result in an increase in thickness/mass of geosynthetics for the products to meet current specified performance and quality standard requirements.
- Potential poor long-term creep performance (degradation of strength over time) of geosynthetics containing RPs, compared to those containing virgin plastic, has been noted by suppliers.
- Suppliers highlighted the relatively small size of the Australian geosynthetic market, when compared to the global market, as a barrier for investing in RP geosynthetics production equipment in Australia. The one high volume supplier has achieved sufficient market share to overcome this barrier.

6.3 Gaps in Knowledge

Throughout the preparation of this report, it has been identified that quantifiable comparisons regarding the performance of geosynthetics are difficult to obtain. It should be noted that geosynthetics containing RP content are already used in the international market. Knowledge can be gained from international experience where RP containing products have been used successfully. It is important to bear this in mind in the context of Australian climatic conditions and likely applications, where they could differ from typical international usage.

This is likely due to the high number of applications in which geosynthetics are suitable and the corresponding number of variables for each application and variable site conditions. Whilst these variables can be designed for, it does make it difficult to compare performance results from different trials of products as these variations will influence the results. This has been reflected in the engagement with suppliers where it was difficult to determine the design life for certain geosynthetic products and therefore make comparisons of their performance.

Additionally, suppliers which act as distributors of internationally manufactured geosynthetics may not be informed of the extent of RP usage in the products they supply, as the process is considered proprietary information by the manufacturer.

As part of this research, no investigation into the performance and WHS of these products, in a laboratory or field setting, has been undertaken. This could be done in a subsequent stage of the project through laboratory testing or comparative field trials and with a formal WHS assessment. It is important that the WHS assessment considers the relative safety implications of using RP for workers during construction and their relative long-term environmental impacts in terms of potential to create harmful microplastics or leachates. Cost competitiveness with the virgin equivalents would also need to be demonstrated to meet with procurement policies.

6.4 Recommendations

Current standards and specifications for geosynthetic products are largely performance based and pose no restrictions for incorporating RP material use. There is no need to create a specialised standard for recycled geosynthetics as the outcome is the same. As the major barriers for increasing the use of RP's in geosynthetics are the quality and availability of RP feedstock, the onus is on the recycling industry to increase its capabilities in terms of recycling waste plastic to higher grades, whilst also increasing its capacity to deal with higher volumes. Other strategies such as mandating materials via road agency specifications or contractual requirements are undesirable, as they may introduce issues considering the current state of waste plastic processing and subsequent feedstock availability, quality, volumes and price.

Establishing economies of scale, overcoming market forces, and achieving domestic supply and production of RPs are difficult obstacles to initially overcome against the backdrop of current waste plastic industry infrastructure.

It is important that if any RP products are implemented that they perform as well if not better than the virgin products. They need to be safe to produce and place and must have acceptable environmental outcomes. Where possible, they should be recyclable at the end of their useful life and a life cycle assessment of their emissions should show that the products perform as well as if not better than conventional materials.

Testing to confirm the consultation findings of this report is recommended to ensure that RP geosynthetics meet the equivalent performance of virgin plastic products. This testing should look at mechanical performance but should also at properties such as resistance to UV degradation and long-term environmental breakdown. The same testing requirements are applicable for RP geosynthetics as they are required to perform in the same way. For structural applications strength testing is required to demonstrate RP products can meet the equivalent performance of virgin plastic products. For long-term structural applications such as embankment reinforcement, testing of the creep performance is important as this is a key parameter to demonstrate suitability. It has been flagged that products containing poorer quality RP or which included higher levels of contaminants could struggle to meet the creep performance of virgin plastic products. It has been noted above that suppliers should be submitting conformance reports (TMR) and have products tested to specifications on a routine basis (MRWA) to demonstrate performance, which is a requirement for all geosynthetics regardless of whether they contain RP. However, it is important that these reports and test results are verified by an independent NATA accredited laboratory or testing house.

This report has provided a comprehensive table of parameters that could be assessed during any field trials of RP containing geosynthetics for a number of different applications. This applies to performance, durability, WHS and environmental impacts.

In terms of potential implementation, the highest benefit of RP related measures is for use in non-structural applications, followed by short term structural applications such as GRS before long-term structural applications. This is due to the higher volumes and lower performance measures of these applications.

The question of sustainability of RP products is an important but complex one. According to the environmental product declaration analysis, using virgin plastics produces approximately 14% more greenhouse gas emissions than the equivalent RP product. However, sustainability is about more than just embodied energy. There is also a duty of care to the environment and at the present time it is not sustainable to continue to produce virgin plastic products when the volumes of waste plastic exist to allow manufacture of new products.

Aside from implementing ‘hard’ mandates and restrictions, a road agency may:

- continue monitoring/conducting research into geosynthetics (e.g. NACOE P49) both through laboratory studies on short- and long-term performance of geosynthetics containing various types and percentages of RPs, for different applications, as well as field trials and investigations to fill in knowledge gaps which this desktop level review was unable to resolve
- prioritise tender applications from contractors that utilise RP geosynthetics
- liaise with suppliers and manufacturers to encourage the use of RPs in their products.

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Appendix A Geosynthetic Technical Specification Requirements

A.1 Geosynthetic Functions

A brief description of each function is outlined below.

- **Separation** is the isolation of two different soil layers to prevent intermixing. The geosynthetic's strength, pore size and permeability are the important properties of geotextiles used for separation, to prevent the flow of clay particles through the geosynthetic.
- **Filtration** is the process of allowing water to pass across the geotextile whilst maintaining separation of the material layers. The balance of adequate pore size to be sufficiently permeable yet prevent intermixing is a primary characteristic for filtration geosynthetics.
- **Drainage** occurs when the geosynthetic is utilised to conduct water away from the adjacent material layers. To achieve good drainage, geosynthetics must maintain high in-plane permeability after compression from the overlying material.
- **Protection** occurs when the geotextile is used to act as a barrier for the underlying material, primarily to cushion any loads placed on the underlying material and prevent erosion.
- **Reinforcement** occurs when the geosynthetic adds a tensile load-carrying element which modifies the stress-strain behaviour of the system. The geosynthetic must have adequate tensile strength and creep characteristics to ensure long-term reinforcement is provided by the geosynthetic.

A.1.1 Woven vs Non-woven Geotextiles

As noted in MRTS27:2020, woven geotextiles will puncture at lower elongations compared to non-woven geotextiles, as the bi-directional configuration of woven geotextiles means that the geotextile has high strength and low elongation when tensile loaded in line with a thread direction. However, when a woven geotextile is tensile loaded in a direction not aligned with the thread, the geotextile is significantly weaker with a high elongation. In contrast non-woven geotextiles have no favoured direction for their strength and elongation of the threads are randomly oriented (Austroads 2009).

A.2 Standardised Geotextile Classification

TMR, TfNSW and NZ Transport Agency all use the same geotextile robustness classification system, as depicted in Table A.1. However, given that the strength requirements are similar in other road agencies, it is common for the geotextile suppliers to market their products based upon the standardised robustness classifications throughout all of Australia. The selection of the appropriate strength class is made by the client based upon their application and the relevant technical specifications.

Table A.1: Robustness geotextile classification

Strength class	Elongation	Grab strength (N)	Tear strength (N)	G rating
A	≥ 30%	500	180	900
	< 30%	800	300	1,350
B	≥ 30%	700	250	1,350
	< 30%	1,100	400	2,000
C	≥ 30%	900	350	2,000
	< 30%	1,400	500	3,000
D	≥ 30%	1,200	450	3,000
	< 30%	1,900	700	4,500
E	≥ 30%	1,600	650	4,500

Source: Austroads (2009) T3.1, MRTS27:2020 T6.2, TfNSW IC-QA-R63:2020 TE.2, TNZ F/7:2003 T2.

The dual parameter values for the same strength class in Table A.1, reflect the different characteristics of woven and non-woven geotextiles, with the non-direction strength and elongation properties of non-woven geotextiles, allowing for a lower strength requirement.

The strength requirements which are used in the robustness geotextile classifications system are defined by the following equation and corresponding test methods:

- The Grab strength is determined in accordance with AS2001.2.3.2:2001.
- The Tear strength is determined in accordance with AS3706.3:2012.
- The G rating is calculated using the following equation:

$$G = \sqrt{(L \times h_{50})} \quad \text{A1}$$

where

L = the load on the CBR plunger at failure (N) in accordance with AS 3706.4:2012

h_{50} = the Puncture resistance, which is the drop height (mm) required to make a 50 mm hole in the geotextile according to AS 3706.5:2014.

Whilst there are varied requirements for the filtration and drainage functions between the Australian road agencies, suppliers typically design their geotextile products to meet the most conservative technical specification requirements in Australia, therefore making the selection of geotextile products based on filtration redundant.

A.3 Separation and Filtration Applications

For geotextiles utilised primarily for separation, the parameters which are considered for the geosynthetic design are:

- the nominal maximum size of the material overlaying the geotextile: This parameter identifies the geotextiles resistant to damage as larger stones will apply a larger load on the geofabric during placement
- the strength and filtration properties of the material underlying the geotextile
- the minimum size of the overlying material as it will affect the ability of the geotextile to maintain separation as smaller highly plastic particles could pass through the geotextile openings and lower the adjacent layer strength. The geotextile requirement to prevent this is the equivalent opening size in accordance with AS 3706.7:2014.

Given the similarities between the functions, most road agencies assessed in this report require the geotextiles to meet the function requirements for both separation and filtration, with DOT being the exception (as noted in Table A.4, Table A.5 and Table A.6). Due to this some road agencies apply minimum flow rate and permittivity to ensure that the geotextile is not restricting the flow of water.

A.3.1 Strength Requirements

The road agencies which use the standardised geotextile strength classification system, as shown in Table A.2 are the only road agencies which consider the grab strength and tear strength as a part of their strength requirements of geotextiles. Other road agencies assessed in this report use the G rating and will be the main parameter used to compare the road agency requirements in Table A.2 and Table A.3.

Table A.2: Strength (G rating) requirements for geotextiles as a separation layer

Overlying nominal maximum particle size[1]	TMR		TfNSW			MRWA	DoT (Vic)
Application	Embankments, bridging layers, working platforms[2] and rock armour		Rock armour	Embankments, bridging layers and working platforms[2]		Rock armour	Rock armour
Underlying material requirement	Saturated (CBR ≤ 3)	Unsaturated (CBR > 3)		Saturated (CBR ≤ 3)	Unsaturated (CBR > 3)		
≤ 37.5	2,000/3,000[3]	900/1,350[3]	3,000/4,500[3]	2,000/3,000[3]	900/1,350[3]	2,000	3,000
≤ 75	2,000/3,000[3]	1,350/2,000[3]	3,000/4,500[3]	2,000/3,000[3]	1,350/2,000[3]	2,000	3,000
≤ 200	3,000/4,500[3]	2,000/3,000[3]	3,000/4,500[3]	3,000/4,500[3]	2,000/3,000[3]	2,000	3,000
≤ 400	4,500	3,000/4,500[3]	4,500	3,000/NA[3,4]	3,000/4,500[3]	4,500	3,000
≤ 600	4,500	4,500	4,500	NA[3]	4,500	4,500	3,000

1. Road agencies specify the overlying particle size at differing limits (85%, 90% or 100% of the PSD).
2. Bridging layers and working platforms as applicable where there is a saturated subgrade (CBR≤ 3) only.
3. The dual values reflect the different strength requirements depending on the elongation of the geotextile, with geotextile with an elongation < 30% required to have the higher G rating.
4. NA – Not applicable for this case. Specialist advice must be sought.

Source: TMR MRTS27:2020 Cl 6.2, TfNSW IC-QA-R63:2020 Ann. E, MRWA Spec 406.09:2017, VicRoads Spec 205.03:2013.

The DoT specification provides a G rating classification system as outlined in Table A.3 however, no guidance is given when the different classifications are applicable.

Table A.3: DoT robustness (G rating) classification system for general earthworks

Classification	G rating
Moderately robust	900
Robust	1,350
Very robust	2,000
Extremely robust	3,000

Source: VicRoads Spec 210.03:2018.

A.3.2 Filtration Requirements

Unlike the strength classifications where there is consistency for the robustness classifications as demonstrated by Table A.1, some road agencies require varied filtration requirements depending on the filtration application. Therefore, the filtration requirements for each application have been divided into Table A.4, Table A.5 and Table A.6. Austroads (2009) section 4.2.4 suggests the recommended minimum values for filtration are those from TfNSW IC-QA-R63:2020.

Table A.4: Filtration requirements for embankments

Technical spec.	TMR					TfNSW				DoT (Vic)
Underlying material requirements	Saturated (CBR ≤ 3)			Unsaturated (CBR > 3)		Saturated (CBR ≤ 3)		Unsaturated (CBR > 3)		NA
Overlying material requirement	D_{15} ≥ 0.075 mm	D_{50} > 0.075 mm & D_{15} ≤ 0.075 mm	D_{15} ≤ 0.075 mm	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	NA
Flow rate Q_{100} (l/m²/s)	≥ 50	≥ 20	≥ 10	≥ 5	≥ 5	≥ 20	≥ 10	≥ 5	≥ 5	
Permittivity Ψ (1/s)	≥ 0.5	≥ 0.2	≥ 0.1	≥ 0.05	≥ 0.05	≥ 0.2	≥ 0.1	≥ 0.05	≥ 0.05	
Equivalent opening size (mm)	≤ 0.12	≤ 0.25	≤ 0.12	≤ 0.60	≤ 0.30	≤ 0.60	≤ 0.30	≤ 0.60	≤ 0.30	0.085–0.23(1)

1. Only required if both separation and filtration are specified as primary functions.

Source: TMR MRTS27:2020 Cl 6.3, TfNSW IC-QA-R63:2020 Ann. E, VicRoads Spec 210.03:2018.

Table A.5: Filtration requirements for rock armour

Technical spec.	TMR		TfNSW		MRWA	DOT (Vic)
Overlying material requirement	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	NA	NA
Flow rate Q_{100} (l/m²/s)	≥ 50	≥ 30	≥ 50	≥ 30		
Permittivity Ψ (1/s)	≥ 0.5	≥ 0.3	≥ 0.5	≥ 0.3		
Equivalent opening size (mm)	≤ 0.25	≤ 0.12	≤ 0.20	≤ 0.12	≤ 0.2	0.085–0.23(1)

1. Only required if both separation and filtration are specified as primary functions.

Source: TMR MRTS27:2020 Cl 6.3, TfNSW IC-QA-R63:2020 Ann. E, MRWA Spec 406:2017, VicRoads Spec 205.03:2013.

Table A.6: Filtration requirements for bridging layers and working platforms

Technical spec.	TMR		TfNSW		DOT (Vic)
Overlying material requirement	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	NA
Flow rate Q_{100} (l/m²/s)	≥ 20	≥ 10	≥ 20	≥ 10	
Permittivity Ψ (1/s)	≥ 0.2	≥ 0.1	≥ 0.2	≥ 0.1	
Equivalent opening size (mm)	≤ 0.25	≤ 0.25	≤ 0.60	≤ 0.30	0.085–0.23(1)

1. Only required if both separation and filtration are specified as primary functions

Source: TMR MRTS27:2020 Cl 6.3, TfNSW IC-QA-R63:2020 Ann. E, VicRoads Spec 210.03:2018.

The minimum strength and filtration requirements for geosynthetics as a separation layer could not be identified in the MRWA technical specifications, beyond those required for rock protection.

A.3.3 WA Rock Fill Separation

MRWA specification 302:2020 requires a geosynthetic to be used on top of rock fill where:

$$d_{15} \text{ (rock fill)} / d_{85} \text{ (finer material)} < 5 \quad \text{A2}$$

where

d_{15} (rock fill) = the sieve size at which 15% of the rock fill grading passes

d_{85} (finer material) = the sieve size at which 85% of the finer material grading passes

The specification does not provide details regarding the parameters which the geosynthetic needs to meet.

A.4 Requirements for Geotextiles and Geonets Used as Protection

For protection applications, it is common for either geotextiles or geonets to be used. For geotextiles used in permanent erosion control, MRTS52:2021 relies on MRTS27:2020 for specifying the geotextile's strength and durability requirements, as discussed in Section A.2. However, the UV resistance requirements of 50% retained strength after 500 hours of exposure are not appropriate for an application which is exposed to direct UV radiation during its design life. Due to this, suppliers are currently self-regulating these products with requirements of:

- UV resistance @ 1,000 hours of > 80% in accordance with ASTM D4355/D4355M:2021 being common for turf reinforcement matts provided by suppliers consulted for this report.
- UV resistance @ 10,000 hours of > 85% in accordance with ASTM D4355/D4355M:2021 being common for heavy duty erosion control geosynthetics provided by suppliers consulted for this report.

There was no guidance identified in the road agency technical specification review regarding the use of geonets for protection. This was confirmed when a consulted supplier of geonets for protection stated that the market is currently self-regulated.

A.5 Drainage Applications

A.5.1 Subsoil Drainage

Strength requirements

The road agencies which use the standardised geotextile strength classification system, as shown in Table A.1 are the only road agencies which consider the grab strength and tear strength as a part of their strength requirements of geotextiles. Other road agencies consulted in this report use the G rating, which is the primary parameter used to compare the road agency requirements, as shown in Table A.7.

Table A.7: Strength (G rating) requirements for geotextiles used in subsoil drainage

Overlying nominal maximum particle size(1)	TMR		TfNSW				MRWA		DoT (Vic)	
Application	Trench drains, edge drains, drainage blanket & counterfort drains		Trench drains, edge drains and counterfort drains		Drainage layers with subgrade CBR ≤ 3	Drainage layers with subgrade CBR > 3	Subsoil drains	Drainage blanket	First stage filters	Second stage non-woven filters
Trench depth	< 2 m	< 3 m	< 2 m	< 3 m						
≤ 37.5	900/ 1,350(2)	1,350/ 2,000()	900/ 1,350(2)	1,350/ 2,000(2)	2,000/ 3,000(2)	1,350/ 2,000(2)	1,700	1,350	900	600–900
≤ 75	1,350/ 2,000(2)	2,000/ 3,000(2)	1,350/ 2,000(2)	2,000/ 3,000(2)	3,000/ 4,500(2)	2,000/ 3,000(2)	1,700	1,350	900	600–900
≤ 200	2,000/ 3,000(2)	3,000/ 4,500(2)	2,000/ 3,000(2)	3,000/ 4,500(2)	4,500	3,000/ 4,500(2)	1,700	1,350	900	600–900
≤ 400					4,500	4,500	1,700	1,350	900	600–900

1. Road agencies specify the overlying particle size at differing limits (85% or 90% of the PSD).
2. The dual values reflect the different strength requirements depending on the elongation of the geotextile, with geotextile with an elongation < 30% required to have the higher G rating

Source: TMR MRTS27:2020 Cl 6.2, TfNSW IC-QA-R63:2020 Ann. E, MRWA Spec 403.06:2019, MRWA Spec 501.A3:2021 VicRoads Spec 702.06:2019.

Filtration requirements

A comparison of the various road agency's filtration requirements for subsoil drainage assessed by the report is shown in Table A.8.

Table A.8: Filtration requirements for subsoil drainage

Technical spec.	TMR			TfNSW			MRWA		DoT (Vic)	
Applications	Trench drains, edge drains, drainage blanket and counterfort drains			Trench drains, edge drains, drainage layers and counterfort drains			Subsoil drains	Drainage blankets	First stage filters	Second stage filters
Overlying material requirement	$D_{15} \geq$ 0.075 mm	$D_{50} >$ 0.075 mm & $D_{15} \leq$ 0.075 mm	$D_{15} \leq$ 0.075 mm	D_{15} > 0.075 mm	$D_{50} \geq$ 0.075 mm & $D_{15} \leq$ 0.075 mm	D_{15} < 0.075 mm	NA	NA	NA	NA
Flow rate Q_{100} (l/m²/s)	≥ 50	≥ 20	≥ 10	≥ 50	≥ 20	≥ 10	≥ 50	≥ 50		
Permittivity Ψ (1/s)	≥ 0.5	≥ 0.2	≥ 0.1	≥ 0.5	≥ 0.2	≥ 0.1				
Equivalent opening size (mm)	≤ 0.25	≤ 0.25	≤ 0.12	≤ 0.43	≤ 0.25	≤ 0.12	≤ 0.2	≤ 0.2	0.085–0.23	0.125–0.35

Source: TMR MRTS27:2020 Cl 6.3, TfNSW IC-QA-R63:2020 Ann. E, MRWA Spec 403.06:2019, MRWA Spec 501.A3:2021 VicRoads Spec 702.06:2019.

A.5.2 Drainage and Separation Behind Retaining Structures

Strength requirements

The road agencies which use the standardised geotextile strength classification system, as shown in Table A.1 are the only road agencies which consider the grab strength and tear strength as a part of their strength requirements of geotextiles. Other road agencies consulted in this report use the G rating, which is the primary parameter used to compare the road agency requirements, as shown in Table A.9.

Table A.9: Strength (G rating) requirements for geotextiles used behind retaining structures

Technical spec.	TMR		TfNSW		MRWA	DoT (Vic)
Application	Concrete retaining walls, segmental block walls and reinforced soil concrete panel walls	Gabion walls, crib walls and rock filled mattresses	Concrete retaining walls, segmental block walls and reinforced soil concrete panel walls	Gabion walls, crib walls and rock filled mattresses	Gabions and mattresses	Rock mattress and gabion retaining structure
G Rating	1,350/2,000(1)	2,000/3,000(1)	1,350/2,000(1)	2,000/3,000(1)	2,000	2,000

1. The dual values reflect the different strength requirements depending on the elongation of the geotextile, with geotextile with an elongation < 30% required to have the higher G rating.

Source: TMR MRTS27:2020 Cl 6.2, TfNSW IC-QA-R63:2020 Ann. E, MRWA Spec 406.09:2017, VicRoads Spec 715.07-.08:2013.

Filtration requirements

A comparison of the various road agency's filtration requirements for drainage and separation behind retaining structures assessed by the report is shown in Table A.10.

Table A.10: Filtration requirements for geotextiles used behind retaining structures

Technical spec.	TMR		TfNSW		MRWA	DoT (Vic)
Applications	Concrete retaining walls, segmental block walls, reinforced soil concrete panel walls, gabion walls, crib walls and rock filled mattresses		Concrete retaining walls, segmental block walls, reinforced soil concrete panel walls, gabion walls, crib walls and rock filled mattresses		Gabions and mattresses	Rock mattress and gabion retaining structure
Overlying material requirement	D_{15} > 0.075 mm	D_{15} ≤ 0.075 mm	D_{15} > 0.075 mm	D_{15} < 0.075 mm		
Flow rate Q_{100} (l/m²/s)	≥ 50	≥ 30	≥ 50	≥ 30		
Permittivity Ψ (1/s)	≥ 0.5	≥ 0.3	≥ 0.5	≥ 0.3		
Equivalent opening size (mm)	≤ 0.25	≤ 0.12	≤ 0.25	≤ 0.12	≤ 0.2	0.085–0.23(1)

1. Only required if both separation and filtration are specified as primary functions.

Source: TMR MRTS27:2020 Cl 6.3, TfNSW IC-QA-R63:2020 Ann. E, MRWA Spec 406.09:2017, VicRoads Spec 715.07-.08:2013

A.6 Reinforcement Applications

A geosynthetic used in pavement reinforcement needs sufficient tensile strength to withstand the tensile stress developed in the pavement's service life. A geosynthetic used in conjunction with asphalt or hot bitumen must retain its characteristics during and after exposure to the bitumen or asphalt's high construction temperatures (Austroads 2009).

A.6.1 Geotextiles Used in Geotextile Reinforced Seals (GRS)

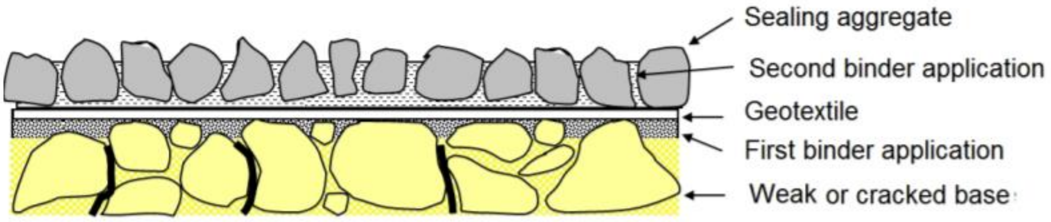
For geotextiles used in GRS, both TMR's MRTS57:2022 and DoT's (VicRoads) Section 408:2020 provide similar specification requirements with 2 grades of geotextiles for GRS that are defined by their mass per unit area. The restrictions around the use of each grade are specific to the road agency requirements with DoT's based upon the seal thickness and TMR's based upon the application. The lower grade GRS geotextile has a mass per unit area of 135 to 160 g/m^2, whereas the higher-grade GRS geotextile has a mass per unit area of 175 to 200 g/m^2. This two-grade specification is reflected in the geotextile products provided by suppliers.

MRWA's Specification 511:2021requirements are similar to the higher-grade GRS geotextile requirements from TMR & DoT. TfNSW's IC-QA-R106:2020 and IC-QA-R107:2020 are less restrictive and allow for the use of both grades.

A.6.2 Pavement Strengthening Using GRS

Geotextile reinforced seals (GRS) are produced by spraying a layer of bitumen onto a pavement (bond coat), then covering this bitumen with a layer of geotextile. As shown in Figure A.1, a single/single or double/double seal is then applied over the geotextile. According to Austroads (2009), GRS are currently the most effective sprayed sealing technique in strain alleviating membrane (SAM) and strain alleviating membrane interlayer (SAMI) applications used for treating badly cracked and distressed bound and unbound pavements, particularly when crack movements are slow. However, the reinforcement of the geotextile does have its application limits and has a short service life when used in pavements with large movement (Austroads 2009).

Figure A.1: Geotextile reinforced seal



Source: Austroads (2009).

The technical specification requirements for geotextiles in geotextile reinforced seals are shown in Table A.11.

Table A.11: Specification requirements for geotextiles in GRS

Property	Test method	TMR		MRWA	DoT (Vic)	TfNSW
Application	–	Geotextile reinforced seal over a pavement without a soft or clay subgrade and without a soft or clay material within it.	Geotextile reinforced seal over a pavement with a soft or clay subgrade, or with a soft or clay material within it.	Bituminous treatments		
Material	–	Polyester	Polyester	Polyester		Non-woven
Heat calendering	–	Acceptable without calendering. Unacceptable with calendaring on both sides. If calendaring is used on one side, the calendaring requirements of MRTS57:2022 Clauses 6.2.2 and 8.7.2 must be met.				
Wide strip tensile strength (kN/m)	AS 3706.2:2012	≥ 6.0	≥ 9.0	≥ 9.0		
Elongation (%)	AS 3706.2:2012	40% to 70%	40% to 70%	40% to 60%		
Mass per unit area (g/m²)	AS 3706.1:2012	130 to 160	170 to 200	170 to 200	> 135 for seals with ≤14 mm stone > 175 for seals with > 14 mm stone	≥ 130
G rating	AS 3706.4:2012 and AS 3706.5:2014	≥ 950	≥ 1,100			
UV Stabilisation – retained strength	AS 3706.11:2012, ASTM D4355:2021 or EN 12224:2000	≥ 50%	≥ 50%	≥ 50%		
Thickness (mm)	AS 3706.1:2012	≥ 0.8	≥ 1.2	1.6 to 2.0		
Melting point (°C)	ASTM D276:2012 or ASTM E794-06:2018	≥ 200	≥ 200	≥ 200	> 10 above spray temperature	≥ 165
Bitumen retention (loaded) L/m²	ASTM D6140-00:2014	≥ 0.9	≥ 1.1	0.9–1.4		≥ 0.9

Source: MRTS57:2022 T6.2.1, MRWA Spec 511.20:2020, VicRoads Section 408.07:2020, TfNSW IC-QA-R106:2020, TfNSW IC-QA-R107:2020.

A.7 Geogrid Requirements

Of the Australian road agencies included in this report (TMR, TfNSW, DoT and MRWA), TMR has the most developed technical specifications for geogrids, with the following relevant specifications identified:

TMR

- MRTS06:2018 Reinforced Soil Structures
- MRTS58:2022 Subgrade Reinforcement using Pavement Geosynthetics
- MRTS100:2019 High Strength Geosynthetic Reinforcement in Road Embankments
- MRTS104:2022 Retarding Pavement Reflective Cracking using Asphalt Geosynthetics

TfNSW

- IC-QA-R67:2020 High Strength Geosynthetic Reinforcement

All of the above technical specifications are based upon international standards and testing methods which are specific for the application. From the correspondence with suppliers, the key parameters which geogrids need to satisfy were identified as:

- the serviceability tensile strength (the tensile strength required at a 2% strain).
- the resistance to construction damage.

A.7.1 Asphalt Geogrid Reinforcement

When reinforcing asphalt, geogrids enable the asphalt pavement layers above cracked rigid pavements to attain a highly efficient cohesion and stress transfer between rigid pavements whilst minimising the transfer of the underlaying rigid pavement defects. Of the road agencies reviewed, TMR was the only agency identified to have a technical specification for this application, with their technical requirements identified in Table A.12. To assist the installation and bonding of the geogrid to the rigid pavements, a temporary or permanent geotextile backing may be placed on the prepared pavement surface, which is required to meet the parameter as shown in Table A.13. The use of geogrids in asphalt should be avoided if pavement recycling is likely in the future as the geogrid is difficult to breakdown and will contaminate the recycled pavement (Austroads 2009).

Table A.12: TMR requirements for geosynthetics reinforcement to delay reflective cracking

Property	Test method	Unit	Polymeric geogrid
Material			Polypropylene, polyester or polyvinyl alcohol
Geogrid aperture size (MD and CMD)	'Centre of geogrid rib' to 'centre of geogrid rib'	mm	25–50
Melting point	ASTM D276:2012 or ASTM E794-06:2018	°C	≥ 180 (allowed to 140 if asphalt contact temperature is lower)
Resistance to construction damage	EN ISO 10722:2019	%	≥ 90
Resistance to UV	ASTM D4355:2021 or EN 12224:2000	%	≥ 90
Elongation (MD / CMD)	ASTM D6637:2015 or EN ISO 10319:2015	%	≤ 16
Serviceability tensile strength (@ 2% strain) (MD / CMD)	ASTM D6637:2015 or EN ISO 10319:2015	kN/m	≥ 6
Ultimate tensile strength (MD / CMD)	ASTM D6637:2015 or EN ISO 10319:2015	kN/m	≥ 20

Source: MRTS104:2022 T7.2(a).

Table A.13: TMR requirements for asphalt geotextile backings

Property	Test Method	Unit	Temporary geotextile backing	Permanent geotextile backing
Melting Point	ASTM D276:2012 or ASTM E794-06:2018	°C	< 180	≥ 180
Bitumen Retention	ASTM D6140-00:2014	L/m²	0.3–1.5	
Bitumen Impregnation Factor	–	%	Nominated by the asphalt geosynthetic supplier	
Mass per unit area	AS 3706.1:2012, ASTM D5261-10:2018 or EN ISO 9864:2005	g/m²	15–30	15–150

Source: MRTS104:2022 T7.2(b).

A.7.2 Subgrade Geogrid Reinforcement

Geogrids can be utilised to reinforce subgrade materials to reduce the required pavement thickness. The geogrid parameters as shown in Table A.13. However, care must be taken during the pavement design to ensure that the maximum strain developed in the geogrid does not exceed the allowable value for the geogrid (Austroads 2009)

Table A.14: TMR requirements for geogrid as a subgrade reinforcement

Subgrade Reinforcement Type	Test Method	Unit	Type 1	Type 2
Application			Reinforced subgrade with CBR > 3%	Reinforced subgrade with CBR ≤ 3%
Geogrid aperture size		mm	Min ≥ D_{50} ≈ 9.5 mm Max ≤ 2 x D_{85} ≈ 38 mm	Min ≥ D_{50} ≈ 9.5 mm Max ≤ 2 x D_{85} ≈ 38 mm
Geogrid junction strength at 2% strain	ASTM D7737:2015	kN/m	≥ 9.5	≥ 12.5
Tensile strength (T_s) at 2% strain in any direction of the MD and CMD	ASTM D6637:2015/ ASTM D4595:2017 or EN ISO 10319:2015	kN/m	≥ 10.5	≥ 14
Resistance to installation damage (R_d)	EN ISO 10722:2019	%	≥ 90	≥ 90
Resistance to UV (R_{uv})	ASTM D4355:2021 or EN 12224:2000	%	≥ 90	≥ 90
Coefficient of direct shear	ASTM D5321/D5321M:2021	%	≥ 75	≥ 75

Source: TMR MRTS58:2022 T6.1.1.

A.7.3 Geosynthetic Reinforcement of Embankments and Soil Structures

TMR MRTS100:2019 and TfNSW IC-QA-R67:2020 technical specifications cover the requirements for geosynthetics acting as a high reinforcement in embankments. Both technical specifications require the geosynthetic to be made of polyester or high-density polyethylene and that the geosynthetics are to be designed according to BS 8006-1:2010.

For geosynthetic reinforcement of soil structures, MRTS06:2018 requires that the geosynthetic's short term tensile strength meet the requirements of BS 6906-1:1987 (which has been superseded by BS EN ISO 10319:2015) and creep testing meet the requirements of BS 6906-5:1991 (which has been superseded by BS EN ISO 13431:1999 and BS EN ISO 25619-1:2008).

Appendix B Geotextile Standard Test Methods

B.1 Australian Testing Methods

The following Australian tests are used to determine the strength characteristics of a geotextile:

- AS 2001.2.3.2:2001 Methods of tests for textiles, Method 2.3.2: Physical tests – Determination of maximum force using the grab method
- AS 3706.2:2012 Geotextiles – Methods of test, Method 2: Determination of tensile properties – Wide-strip method.
- AS 3706.3:2012 Geotextiles – Methods of test, Method 3: Determination of tearing strength – Trapezoidal method.
- AS 3706.4:2012 Geotextiles – Methods of test, Method 4: Determination of burst strength – California bearing ratio (CBR) – Plunger method.
- AS 3706.5:2014 Geotextiles – Methods of test, Method 5: Determination of puncture resistance – Drop cone method.

The following test methods are used to determine the filtration characteristics:

- AS 3706.7:2014 Geotextiles – Methods of test, Method 7: Determination of pore-size distribution – Dry-sieving method
- AS 3706.9:2012 Geotextiles – Methods of test, Method 9: Determination of permittivity, permeability and flow rate
- AS 3706.10.1:2012 Geotextiles – Methods of test, Method 10.1: Determination of transmissivity – Radial method

The following tests are used to determine the resistance to degradation characteristics:

- AS 3706.11:2012 – Determination of durability – Resistance to degradation by light and heat.

B.2 International Testing Methods

For geogrids used for reinforcement functions, the following applications discussed in this report use international testing methods and standards:

- asphalt geosynthetic to delay reflective cracking
- geosynthetic subgrade reinforcement
- high strength geosynthetic reinforcement of embankments and soil structures.

Appendix C Suitably Qualified Professional Report

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25 October 2022

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Attention: James Grenfell

SQP review – Task 7: Potential use of recycled waste plastics in geosynthetics

1.0 Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by Australian Road Research Board (ARRB) to undertake a technical review of documents prepared by ARRB in relation to specific aspects or research work related to the recycled plastics research project (Investigating the use of recycled and reclaimed plastic in safe, sustainable future road infrastructure (Stage 2)).

This letter relates to review of the report prepared to address Task 7: Potential use of recycled waste plastics in geosynthetics.

The purpose of Task 7 is as follows:

> *This task will investigate available standards and guidelines within TMR and MRWA for the use of plastics in geosynthetics; review available products and practice; identify gaps or barriers to use of recycled plastics; provide recommendations on the safe and appropriate incorporation of geogrids and geotextiles in pavement infrastructure and refine recycled plastic usage calculations on based on new knowledge developed.*
>
> *The outcome of this task will be to identify in what applications recycled plastic geosynthetics can be used and best practice advice on their use to provide maximum benefit to the long-term performance of the road infrastructure asset.*
>
> *Develop a methodology to monitor field trials of geogrid and geosynthetic applications.*

The following report has been prepared by ARRB in relation to Task 7:

- Williams, B., Yaghoubi, J., and Grenfell J., 2022. NACOE P120/ WARRIP-2021-016: Task 7 Review of potential use of recycled waste plastics in geosynthetics. ARRB Project No.: 015430C/015611. Draft report, referred to as the **Task 7 report**.

The purpose of the work presented in this letter is as follows:

- undertake a review of the Task 7 report
- provide advice on any concerns over utilising geosynthetics incorporating recycled plastics in road infrastructure
- comment on any additional measures or tests that should be undertaken as part of any field monitoring program.

2.0 Qualification of author/SQP

This review has been undertaken by Dr Jackie Wright, Director of enRiskS. **Appendix A** presents a curriculum vitae for Dr Jackie Wright which demonstrates that she meets the requirements of a Suitably Qualified Professional (SQP) for the assessment of harm to human health and the environment.

3.0 Review comments

3.1 General

The Task 7 report was prepared for the Department of Transport and Main Roads Queensland (TMR), Main Roads Western Australia (MRWA) and the Australian Road Research Board (ARRB), under both the NACoE and WARRIP agreements. The focus of the report relates to the use of recycled plastic (RP) in geosynthetics in transport infrastructure applications, which include:

- Geotextiles to support sprayed seals
- Geotextiles and geogrids to support earth works
- Geogrids to support granular layers
- Geotextiles and geogrids as reinforcement or interlayers within bound pavement structures
- Geogrids for thin asphalt surfacings
- Geotextiles in drainage blankets
- Erosion prevention (erosion control blankets, turf reinforced matting).

The main purpose of geosythetics is to provide the following: separation, filtration, drainage, protection, and reinforcement. Section 2.1 of the Task 7 report details the categories of geosynthetic materials.

The following comments relate to the various aspects of Task 7.

3.2 Specific aspects of Task 7

Aspect: This task will investigate available standards and guidelines within TMR and MRWA for the use of plastics in geosynthetics

Comments:

Sections 2.2 and 2.3 of the Task 7 report provides an outline of the standards and guidelines relevant to geosynthetic materials. Additional detail is included in Appendices A and B. The standards and guidelines relate to engineering specifications. None of the specifications or guidelines include any specific requirements for the use of RP.

In relation to contamination this section identifies that the presence of contamination can result in a substandard product. The use of RP in place of virgin plastic increases the risk of contamination. It would be helpful to define what is meant by contamination, and how easy or difficult it is to screen or remove contamination from the RP waste stream prior to potential use in this area.

Aspect: *review available products and practice*

Comments:

This is included in Sections 2 and 3 of the Task 7 report. This discussion is appropriate, however it may benefit from the inclusion of some photographs or illustrations that show the products as used in road infrastructure. For example, a figure is included in Appendix A (Figure A.1) which is helpful – it would be good to include more of these (or photographs).

Aspect: identify gaps or barriers to use of recycled plastics

Comments:

This is included in Sections 4 and 5 of the Task 7 report and is generally appropriate. In Section 5 there is reference to the use of rejuvenating additives. It would be helpful to include an indication of what chemicals are used for this purpose. This section also references the presence of contamination. Again, it would be helpful to understand what is meant by contamination, what specific contaminants are of concern in the recycled plastics and can the presence of these contaminants be managed by the supplier.

Aspect: provide recommendations on the safe and appropriate incorporation of geogrids and geotextiles in pavement infrastructure

Comment:

This information is provided within the Task 7 report. No specific comments are provided in relation to this aspect.

Aspect: refine recycled plastic usage calculations on based on new knowledge developed

Comments:

This is included in Sections 3 and 4 (in particular Section 4.1) of the Task 7 report. Section 4.2 also provide information on sourcing Australian Recycled Plastic feedstock which is relevant to the availability of materials for use in geosynthetics.

Is it possible to include information whether contamination is a problem with such supplies, and if it is, what is the key issue?

Aspect: The outcome of this task will be to identify in what applications recycled plastic geosynthetics can be used and best practice advice on their use to provide maximum benefit to the long-term performance of the road infrastructure asset.

Comment:

This is largely covered by the Task 7 report. It is unclear whether the long-term performance of these materials has been determined.

Aspect: Develop a methodology to monitor field trials of geogrid and geosynthetic applications

Comment:

This is presented in Section 6 of the Task 7 report. The following comments relate to the proposed methodology for field trials:

- It would be helpful for the section to provide clear objectives for the work.
- It would be helpful to include materials that do not contain recycled plastics (i.e. comprise virgin plastics) so that it is possible to determine if the geosynthetics made of recycled plastics are different to the normal products in any of the tests.
- It is not clear what recycled plastic materials are to be considered in the trials and if the proportion (%) present in the geosynthetic material is to be varied.
- The section should include reference to standards that define specific tests and the guidelines that need to be met in the tests proposed.

- It is unclear how weathering of the geosynthetics is to be evaluated, and if the tests proposed would be repeated following a period (or a number of periods) of weathering.
- The last category in Tables 6.2 and 6.3 references general properties. For Table 6.2 the effects to be evaluated are microplastics, release of hazardous materials into soil, pavement or water. It is not clear what testing would be undertaken to measure these effects, or the list of chemicals to be included. Similarly with Table 6.3 there is reference to testing for total concentration of contaminants and microplastics, however it is unclear if this is for the material, leachate and what list of chemicals would be included in analysis.
- Similarly, in Table 6.3 assessment of emissions and fuming does not include any information on how this may be tested and the chemicals proposed to be analysed.

3.3 Additional considerations in relation to further testing of materials

In relation to the proposed field trials, the following should be considered when updating the Task 7 report. The following can be used to address some of the queries raised in the dot points above.

Sampling requirements

For the use of recycled plastics in geosynthetics as proposed, the following pathways of exposure are expected to be of key importance:

- Worker exposures to fumes generated during use (particularly relevant where the geosynthetics are heated such as where used in conjunction with hot bitumen). Where geosynthetics remain at ambient temperature then there is no need to consider or assess chemicals that may be released to air during fuming.
- Environmental exposures to chemicals that may leach (or migrate as may be the case for microplastics) from the products where geosynthetics are used. Where the environment is protected it is expected that human health (relevant to incidental contact).

Fuming

It is expected that the materials would need to be heated to the same temperature as would occur during use with hot materials, and where fumes may be generated. The testing should consider geosynthetics made of virgin materials as well as those made from the recycled plastic (at the % incorporation expected to be used in the products).

The testing needs to be undertaken to evaluate the following chemicals (as a minimum), noting that the workplace exposure standards relevant to these gases are included in the table. The testing should quantify the concentrations of these chemicals in air, at a distance from the material consistent with where workers would be present. If not known, then sampling should be within 0.5 m of the material as heated.

Table 1: Chemicals to be evaluated for fuming from geosynthetic materials (where relevant to the use)

Chemical that should be evaluated in air (as a minimum)	Workplace exposure standard (mg/m^3)	
	STEL (15-min)	TWA (8-hour)
Hydrogen chloride	--	7.5 as peak
Formaldehyde	2.5	1.2
Acetaldehyde	91	36
Styrene	426	213
Vinyl chloride	--	13
Phenols (assume as total for all phenols)	--	4
Butadiene, 1,3-	--	22
Acrolein	0.69	0.23
Bis(2-ethylhexyl)phthalate (DEHP)	--	5

Where additional volatile organic compounds (VOCs) are detected in air, the relevant workplace exposure standard from Safe Work Australia should be used to determine significance in relation to worker exposures.

The sampling would require the use of sampling media that are relevant to the chemicals in the above table. For example, separate sample tubes would be required to target aldehydes, phenols and VOCs. The analytical laboratory (for example Envirolab or Eurofins would provide advice on which media to use for the sampling). The analytical methods adopted need to have a limit of reporting that is equal to or below the guidelines in **Table 1**.

Note that the data obtained should also involve comparison of fuming from materials manufactured from virgin plastics vs. recycled plastics to determine if the inclusion of recycled plastic in the materials makes any change to worker exposures.

It is noted that workplace exposure controls should also be considered. Where respiratory protection is required to address exposures to bitumen fume, these measures may also adequately address the presence of additional chemicals in air from heating the geotextile products. Where these controls are known, they should be considered in the context of the data obtained from analysis.

Leaching

The leaching of chemicals from the geosynthetic product would need to consider leaching from new and weathered materials – as geosynthetics manufactured using virgin materials and recycled plastic.

Where the geosynthetic is bound or beneath an impermeable surface, leaching would not be of concern to the environment. However, where the geosynthetic use used at the ground surface, or sits below or within permeable materials leaching to the environment may be relevant. The materials that would be used in these situations require further testing in relation to leaching.

The testing should be undertaken using representative samples of the materials using Australian Standard Leaching Procedure (ASLP) tests (Australian Standard AS4439). Where possible, it would be appropriate for the analysis to involve the geosynthetic material as manufactured (and as weathered) as a piece (not cut up or ground up into finer materials) as that would be more representative of the material as used.

Analysis of leach fluids should include the following chemicals (as a minimum). The guidelines that can be used for screening (noting these would not reflect a risk to human health or the environment) are also included in the table.

Table 2: Chemicals to be evaluated for leaching from geosynthetic materials (where relevant to the use)

Chemical that should be evaluated (as a minimum)	Relevant screening level guideline* (based on protection of freshwater ecosystems) (mg/L)	Reference
Formaldehyde	0.5	Australian drinking water(NHMRC 2011 updated 2021) adopted for all aldehydes
Acetaldehyde		
Bisphenol A	0.0013	Default guideline value (ANZG 2018)
Phthalates		
Bis(2-ethylhexyl) phthalate	0.001	Default guideline value (ANZG 2018)
Dibutyl phthalate	0.01	Default guideline value (ANZG 2018)
Diethyl phthalate	1	Default guideline value (ANZG 2018)
Dimethyl phthalate	3.7	Default guideline value (ANZG 2018)
Metals		
Antimony	0.003	Australian drinking water(NHMRC 2011 updated 2021)
Nickel	0.011	Default guideline value (ANZG 2018)

* Guidelines adopted are based on protection of freshwater environments and drinking water

It is also recommended that all chemicals listed in relevant waste regulations for Queensland[1] and Western Australia[2] be included in the analysis of the geosynthetic material or soil in the area where these products are used. This is important as any of the materials used may be required to be disposed, where compliance with waste regulations is relevant to ensure that the materials and waste generated is not considered regulated or controlled.

Where chemicals are detected in leachate from the recycled materials that are different or at higher concentrations than reported in leachate from the virgin materials, comparison with an appropriate water quality guideline should be undertaken to determine the significance of the concentrations reported. These guidelines would be based on the lower of drinking water guidelines and guidelines that are protective of freshwater environments. Analysis of leachate would need to be able to achieve limits of reporting that are equal to or below the guidelines in Table 2 (or equivalent guidelines for any other chemicals included).

Where the concentrations exceed a screening level guideline, further assessment should be undertaken to determine the potential for harm to human health or the environment. Such an assessment would consider the use of the materials. Where there may be the potential for an acceptable risk, controls such as restrictions on the locations where the materials may be sued, may be recommended.

Microplastics

Microplastics have the potential to be generated from the use of geotextiles as proposed, where these materials are present in areas where they may be weathered and microplastics can move from the material into the environment. Where the geotextile is incorporated beneath another later (permeable or impermeable) there are no risk issues. Where the geotextile material is at the ground surface where weathering can occur, there is the potential for microplastics to be generated. There are no guidelines for the presence of microplastics in the environment (as relevant to protecting human health or the environment, however it is recognised that microplastics are present in drinking water supplies as well as in fresh and marine waters.

Hence any assessment of the potential for microplastics to be of concern can only be done based on comparison of microplastics derived from geotextiles manufactured with virgin plastics and those with recycled plastics. These studies should consider weathered materials, from products that would be used at or above ground surface. Only where the potential for higher levels of microplastics from recycled materials is greater than from virgin materials, should further assessment be required to determine the potential for harm.

Analytical methods are available from commercial laboratories such as Eurofins.

3.4 Other general comments

It is not expected that the use of recycled plastics in geosynthetic materials for road applications would result in a different risk profile than the sue of virgin plastics, where the geosynthetic material met the technical specifications relevant to the product. It is relevant to complete field trials to test that the specifications and application of the materials in the field do not result in changes to the risk profile.

In addition to the comments above, the following should also be of note:

- Need to check the first sentence in Section 2.5.1 as it uses analyses and analysis close together and it is the second part of the sentence uses geosynthetics twice?

[1] Queensland guidance - where the list of chemicals relevant for analysis and determination of whether waste is regulated or not is provided in Appendix 2 of the following: https://environment.des.qld.gov.au/__data/assets/pdf_file/0026/89333/era-is-categorising-regulated-waste.pdf

[2] Western Australia guidance – based on list of chemicals required to be tested to determine waste classifications as detailed in the Landfill Waste Classification and Waste Definitions 1996 (as amended 2019), https://www.der.wa.gov.au/images/documents/our-work/licences-and-works-approvals/WasteDefinitions-revised.pdf

- Section 2.5.2, check the fist sentence of paragraph 4, perhaps “what” should be “was”
- Figures 4.1 and 4.2 – indicate what the number in brackets on x-axis mean, e.g. HDPE (2)
- Section 7.4, last list is assumed to be a bullet point.

4.0 Limitations

Environmental Risk Sciences has prepared this report for the use of the Australian Road Research Board (ARRB), Main Roads Western Australia (MRWA) and the Queensland Department of Transport and Main Roads (TMR) in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the **Section 1** of this report.

The methodology adopted and sources of information used are outlined in this report. Environmental Risk Sciences has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information provided for use in this assessment was false.

This report was prepared in March and April 2022. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

5.0 Closure

If you require any additional information or if you wish to discuss any aspect of this review, please do not hesitate to contact the undersigned on (02) 9614 0297.

Yours sincerely,

Dr Jackie Wright (Fellow ACTRA)
Principal/Director
Environmental Risk Sciences Pty Ltd

References

ANZG 2018, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, A joint initiative of the Australian and New Zealand Governments in partnership with the Australian state and territory governments, Online. viewed August 2018, <http://www.waterquality.gov.au/anz-guidelines>.

NHMRC 2011 updated 2021, *Australian Drinking Water Guidelines 6, Version 3.6 Updated March 2021, National Water Quality Management Strategy*, National Health and Medical Research Council, National Resource Management Ministerial Council, Canberra.

Attachment A: CV for Dr Jackie Wright

Dr Jackie Wright

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Director/Principal
Environmental Risk Sciences Pty Ltd
(+61 2) 9614 0297

Professional Profile

Jackie Wright has more than 30 years' experience in human health and ecological risk assessment in Australia. Experience includes leading and developing a national risk practice group for a major consultancy, training of staff, providing technical (and toxicological) direction, developing internal technical standards, participating in the development on industry guidance and standards, developing appropriate risk models and providing peer-review.

Areas of expertise include human and eco-toxicological review and evaluation of chemicals in line with Australian regulatory requirements, human health and ecological risk assessment, health impact assessment, impact of exposure to air and noise pollution, exposure modelling, indoor air quality assessment, fate and transport assessment, air dispersion modelling, environmental chemistry, environmental monitoring, and the assessment of air emissions and air toxics. Human health assessments have included a wide range of sites that involve the evaluation of emissions to air, waste sites, residential and recreation areas, operating industrial plants as well as other industrial plants that have been closed and are in the process of property sales or redevelopment and remediation. Ecological assessments have included screening level and detailed assessments of contamination, potential for contamination and remediation of contamination in soil and the aquatic environment. Risk assessments, ecological and human health, have been conducted for review by regulatory agencies (including Contaminated Land Auditors), with Jackie also providing expert support on both human health and ecological risk assessments (including detailed aquatic eco-toxicological assessments) for a number of Auditors in NSW, Victoria, South Australia, Western Australia and Queensland.

Jackie has been heavily involved in the development of national guidance and investigation levels as presented in the National Environment Protection Measure (NEPM) for Site Contamination (2013), CRC CARE Technical Guidance on Petroleum Vapour Intrusion and Silica-Gel Cleanup and Australian Crime Commission Assessment and Remediation of Clandestine Drug Laboratories (2011).

In addition, she has extensive experience in the assessment of vapour migration and intrusion, detailed evaluation of exposure by occupational, residential and recreational groups including the application of probability distributions to human health risk assessments. Jackie also been involved in a number of key projects that require regular risk communication with interest groups, including resident action groups.

- Toxicological (human and ecological) Review and Assessment
- Human Health Risk Assessment
- Environmental Risk Assessment
- Exposure Assessment and Modelling
- Occupational Exposure Assessment
- Clandestine Drug Laboratories
- Vapour Intrusion
- Indoor Air
- Health Impact Assessment
- Health impacts of air and noise pollution
- Environmental Chemistry, Fate and Transport
- Risk Communication
- Air Dispersion Modelling

Professional Accomplishments

Toxicology and Risk Assessment

- 2005 to 2022 (ongoing process of development and revision) - Prepared over 50 toxicity summaries for a range of chemicals relevant to the inclusion and assessment of these chemicals within human health and ecological risk assessments in accordance with Australian guidance. Toxicity summaries prepared provide detail on the chemical use, sources, exposures, chemical properties, ecotoxicity (terrestrial and aquatic), environmental fate and transport, health effects, review and identification of appropriate data relevant to acute and chronic exposures by the inhalation, oral and dermal routes, including assessment of carcinogenicity and genotoxicity. Range of compounds assessed includes particulate matter, petroleum compounds, chlorinated compounds, metals and more obscure industry-specific compounds. More specific, detailed review of arsenic dose-response has been undertaken based on current studies.
- 2014-2015 – conducting detailed toxicological review of TCE, particularly in relation to the quantification of inhalation dose-response.
- 2009 to 2013 – provided detailed toxicological review, determination of appropriate dose-response values, and derivation of proposed 2013 NEPM Soil Health Investigation Levels (HILs), including the interim soil gas HILs, and input into the petroleum Health Screening Levels (HSLs). The review included significant update and revision to Schedules B4 and B7 and involved incorporation of all comments from regulators, industry and the public.
- 2010 – provided detailed review of toxicological interactions, biomonitoring data and human exposure to metals (and metal mixtures) for a site in Tasmania.
- 2006 to 2022 (and ongoing) - Presentation and collaboration with regulatory bodies in Australia (New South Wales Environmental Protection Authority [EPA], New South Wales Department of Health and Victorian EPA) with regards to the approach adopted and information presented with toxicity summaries (addressing human health and aquatic toxicity where required) for key, high profile assessments.

Exposure and Risk Assessment (Human Health and General Environmental)

- 1992 to 2022 (ongoing) - Project management and evaluation of human health and environmental risks associated with over 350 contaminated sites in all states of Australia utilising national guidance that include NEPM, enHealth, ANZECC and NH&MRC guidance. Sites include operational sites as well as other industrial areas proposed for redevelopment for industrial, recreational or residential use. Most of the sites assessed are associated with petroleum contamination, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and metals. Other sites include those impacted with dioxins, phthalates, PCBs and PFOS/PFOA.
- 1995 to 2022 (ongoing) - Detailed assessment and ongoing evaluation of risks to human health associated with contamination issues derived from the Orica Botany site in Sydney. A number of assessments have been undertaken over a period of 17 years and has involved detailed review of risks to residents (including groundwater extraction and use), workers and recreational users of a large area affected by the discharge of contamination in shallow and deep groundwater to surface water within a drain and an estuary, historically deposited sediments and volatile chlorinated compounds in air. The assessment of risk has been tied closely with ongoing monitoring with detailed exposure reviews, including the collection of additional data and ongoing review of methods, being undertaken for many key aspects of the project. The process required evaluation within context of the NEPM

(1999) and enHealth (2002) guidance with regular liaison with the NSW OEH, NSW Department of Health and independent reviewers.

- 2009 to 2015 - Derivation of national guidelines for the investigation and remediation of clandestine drug laboratories in Australia. The work involved the derivation of investigation levels, protective human health and the environment (terrestrial and aquatic), associated with former clandestine drug laboratories in Australia. Project required identification of key indicator compounds from over 200 base, intermediate and waste products that may be associated with over 20 different drug manufacturing methods. This required consideration of human health and environmental toxicity, behaviour/fate and transport in the environment and manufacturing methods. Guidelines were derived for indoor surface residues, indoor air, outdoor soil and the environment (local waterways and soil) for residential, commercial and recreational areas. The guidelines developed have been published by the Australian Government in April 2011. Further development of state guidelines, such as those from NSW Health have been undertaken to 2015.
- 2010 to 2022 – Detailed evaluation of community exposures and risks to PM10 and PM2.5 derived from urban (combustion) sources as well as crustal (mining) sources. A number of urban projects have been completed, including major road infrastructure projects such as NorthConnex, WestConnex M4 East, WestConnex New M5, WestConnex M4-M5 Link, F6 Stage 1, Western Harbour Tunnel and Beaches Link in NSW and West Gate Tunnel and North East Link in Victoria and rail infrastructure projects including the Moorebank Intermodal Terminal and Botany Rail Duplication in NSW and the Suburban Rail Loop East in Victoria. These infrastructure projects have involved the development and researching of appropriate methodologies for the assessment of particulate exposures, with particular focus on community exposures and risks. The work has also considered detailed assessments related to other criteria pollutants that include ozone, nitrogen oxides, sulphur dioxide, particulate matter and other combustion products (such as polycyclic aromatic hydrocarbons and volatile organic compounds). Projects have involved detailed review of current literature in relation to the health effects and the identification and use of appropriate dose-response relationships relevant to the quantification of relevant health endpoints, with consultation conducted with stakeholders, including state health departments and the community. Work undertaken for the West Gate Tunnel and North East Link project included the panel inquiry (presentation and attendance at the inquiry).
- 2018-2019 – Detailed assessment of particulate risks associated with power station emissions, including detailed critical peer review of public commentary papers as well as published papers and the available research underlying current understanding of health impacts from changes to particulate matter in urban and rural air environments.
- 2010 to 2021 – Detailed assessment of health impacts associated noise, as generated from major road or rail infrastructure or from aircraft noise. These assessments require an understanding of various noise guidelines, as well as current literature on the health effects of noise on the community. Assessments have included qualitative, semi-quantitative as well as quantitative assessments of risk and population incidence utilising published exposure-response relationships.
- 2016 to 2018 – Detailed assessment of roadway and tunnel design features to ensure public health is protected. This has included assessment of exposures to nitrogen dioxide and the build-up of carbon dioxide (in-cabin) in long tunnels, design of long tunnels to ensure public safety from fatigue and monotony and design of roadways to ensure flicker effects do not adversely affect road users.
- 2015 to 2020 – conduct of detailed human health and ecological risk assessments for a range of sites (in particular airport and defence sites) where PFAS issues are

of potential concern both on the site and in relation to offsite migration, discharge and exposure. Work has involved detailed evaluations and the development of site-specific guidelines and management measures within the context of a moving regulatory environment.

- 2020 to 2022 – Detailed assessment of risks to human health and the environment in relation to the proposed reuse of materials in road infrastructure (considered a wide range of materials proposed for reuse, in a variety of use scenarios).
- 2008 to 2014 - Detailed evaluation of human health and environmental issues associated with a former chlor-alkali plant. The assessment involved detailed evaluation of mercury fate and transport with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered environmental issues associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment, as well as issues associated with mercury (elemental and inorganic) in soil and groundwater with respect to fate and transport, human health and environmental issues.
- 2010 to 2015 (with ongoing advice to 2022) – Conduct of a detailed Health Impact Assessment in relation to major rail infrastructure development proposal at Moorebank. The HIA involved consultation with stakeholders, in particular local councils, NSW Health and the community, with all aspects of the proposal being address in relation to health impacts, both positive and negative. The HIA was peer reviewed by the University of NSW and an international expert. Ongoing advice relates to construction and operational management of PFAS.
- 2016 to 2018 – Literature review and assessment of community health impacts associated with landfill gas emissions, and emissions from water to energy facilities.
- 2018 to 2022 – Conduct of a number of detailed human health risk assessment or health impact assessments in relation to the proposed development of waste-to-energy facilities in NSW, Victoria and Queensland. A number of the projects have been approved.
- 2011 – Quantitative assessment of risks to human health associated with the placement of remediated soil that contains residual levels of radiological contamination, beneath a proposed commercial/industrial development in South Australia.
- 2011 to 2016 – Detailed evaluation and development of chemical risk assessments for a range of products/compounds utilised during coal seam gas operations in NSW and Queensland.
- 2017 to 2018 – Panel member on the WA Government Technical Enquiry on hydraulic fracturing.
- 2011 – Development of a detailed scope of works for the assessment and remediation of an abandoned asbestos mine in NSW. The works required collaboration between key stakeholders including NSW Health and the NSW EPA with the focus of the works on the protection of off-site community health.
- 2011 to 2014 – Assessment of risk issues associated with the presence of friable and bonded asbestos materials on a range of sites, proposed to be used for residential or commercial/industrial purposes. The assessments include consideration of risk management measures required, monitoring requirements and establishing site specific criteria relevant for the protection of construction workers and off-site residents (as required).
- 2010 – Detailed assessment of risks (including detailed assessment of toxicity of individual compounds and mixtures) to human health associated with the presence of nitrate, nitrite and perchlorate contamination in drinking water (international project).
- 2009 to 2022 (and ongoing) – Expert support for contaminated land Auditors

located in New South Wales, Victoria, Queensland, South Australia and Western Australia. Expert support has included review of human health and ecological risk assessments for a range of projects and issues.

- 2000 to 2022 - Detailed evaluation of risks to human health and the environment associated with redevelopment of large a number of gasworks sites in New South Wales and Victoria. Projects have involved the evaluation of the vapour migration pathway, including the collection of relevant soil gas and vapour emissions data to quantify exposure consistent with the proposed developments. The process required liaison with relevant site auditors, Vic EPA, SA EPA, NSW EPA and NSW Department of Health as required.
- 1995 to 2022 - Detailed evaluation, modelling and risk assessment of a number of landfill and waste depots in Australia (in New South Wales, Australian Capital Territory, Queensland and Victoria). This includes proposed waste destruction technologies, proposed waste depots and landfills, operational landfills, composting operations and closed landfills with assessments considering workers, residents and recreational users of the site and surrounding areas. Assessments undertaken have considered issues associated with the presence of a wide range of chemicals, landfill gas emissions, leachate generation and leaks, stormwater management, bioaerosols and other pathogens and bacteria.
- 1995 to 2022 (ongoing process as vapour issues are relevant for many projects) - Evaluation of vapour migration (and vapour intrusion) from numerous sources including contaminated soils and groundwater (dissolved phase and free phase) for many different chemicals, and subsequent assessment of human health risks associated with the estimated vapour concentrations. In addition, Jackie has developed and managed various techniques for the direct measurement of vapour migration in residential, recreational and industrial settings as part of the risk assessment process.
- 2009 to 2022 - Detailed evaluation of public health issues associated with recreational exposures to arsenic, lead and/or PAHs in surface soil in primary/secondary schools, sporting areas and children’s playgrounds. Provision of technical advice along with appropriate general advice relevant for presentation to the public and responses to questions from the general public.
- 1995 to 2021 - Evaluation of human health risks associated with potential exposure to emissions from coal mining activities, including the assessment of potential risks and health effects associated with exposure to fine particulates.
- 1998 to 2009 - Evaluation of human health risks associated with the existence of and potential remediation of encapsulated scheduled waste materials located near residential and recreational areas. The assessment has involved ongoing monitoring, review of toxicity and exposures on an ongoing basis, review of remediation options and risks derived from the application of preferred remediation options. The encapsulation has now been remediated.
- 2007 to 2013 – Assessment of risks to human health and the environment associated with the re-use of water (including irrigation uses) from a groundwater treatment plant located in Sydney.
- 2000 to 2005 - Evaluation of human health risks associated with a number of contaminated sites located in Abu Dhabi, Spain and Azerbaijan. These risk assessments involved assessment of human health risks using USEPA guidance as well as WHO guidance.
- 2005 - Project management of large human health risk assessment associated with the redevelopment of explosives and munitions factories and firing ranges within various areas of NSW.
- 1995 to 1998 - Evaluation of human health risks associated with off-site accumulation of lead from historical deposition associated with a former operating lead paint site located within a residential area in Sydney. Project involved the

review of lead exposure and toxicity, identification and agreement to lead action levels relevant for residential properties located close to and further away from the former source.

- 1995 - Evaluation and coordination of a multi-pathway health risk analysis for a large contaminated site in Sydney involving the use of probabilistic risk assessment methodology.
- 2000 to 2005 - Conducting a feasibility assessment for a waste destruction facility in Sydney, using a probabilistic risk assessment methodology. Conduct of a detailed health risk assessment associated with the operation of the selected technology, including presentation to the Commission of Enquiry. Subsequent review of the process and exposures in relation to placing the facility within a rural area (as opposed to an urban area) and consideration of other multi-pathway exposures.
- 1993 - Assessment of risks to human health and the environment associated with sewage sludge incinerators at North Head and Malabar Sewage Treatment Plants.
- 1992 to 2022 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria.
- 1995 to 2022 (and ongoing) - Development of air sampling procedures and techniques to collect air data relevant to the further assessment of vapour migration pathways in a range of areas. This includes the collection of ambient air, soil gas data (active and passive and sub slab) and flux emissions.

Ecological Risk Assessment

- 1998 to 2022 (ongoing) - Derivation of risk-based criteria for a range of projects that are based on the protection of the aquatic environment. Evaluations have considered the potential for physical parameters (turbidity, pH, dissolved oxygen) and contaminants (principally metals, polycyclic aromatic hydrocarbons [PAHs], PFAS, petroleum compounds and chlorinated compounds). The evaluations include the potential for contaminants to leach from soil, migrate to groundwater and potentially discharge to a receiving environment (considered both marine and freshwater [including ephemeral] systems). Some of the assessments have required review and consideration of fate and transport modelling.
- 2009 to 2022 (ongoing) – Identification and derivation of investigation levels protective the terrestrial and aquatic environments associated with former clandestine drug laboratories in Australia. Ecological Tier 1 levels (based on available ecotoxicological data primarily from overseas studies) were identified and proposed for use in remediation guidelines with additional guidance provided in relation to sites where more detailed assessments of environmental risk issues needs to be conducted.
- 2010, 2011 and 2012 – Conduct (co-presenter) of lectures at the University of Sydney for the Risk Assessment (Human Health and Ecological) module for undergraduates, School of Geosciences. Ecological risk assessment lectures addressed basic principles and frameworks, stressors, fate and transport, bioaccumulation, uptake, derivation of ANZECC Guidelines, reviewing available ecotoxicological studies and conduct of statistical analysis using the CSIRO Burrlioz software for establishing water guidelines.
- 2010 to 2011 – Expert witness in relation to ecotoxicological impacts of initial works proposed for the Barangaroo site in NSW.
- 2010 - Assessment and derivation of water criteria for petroleum hydrocarbons relevant to the protection of the terrestrial and aquatic environments from the reuse of urban run-off for irrigation or a public park and associated runoff into a lake. Assessment required a detailed assessment of not only phytotoxicity, but levels at which grass growth would be affected to the extent by which grass cover on an important AFL playing field would be affected.

- 2009 to 2011 – Detailed review of screening level risk ecological assessment (supporting studies and outcomes) for the discharge of contaminated groundwater into a sensitive marine environment in South Australia. Review required detailed consideration of the local environment, consideration that appropriate ecological indicator species have been selected, consideration of the range of urbanisation stressors within the environmental and potential for groundwater discharges to result in adverse effects to the aquatic environment, over and above those from urbanisation.
- 2008 to 2010 - Detailed evaluation of environmental fate and transport issues associated with a former chlor-alkali plant. The assessment involved detailed evaluation of mercury fate and transport with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered ecotoxicological risks associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment.
- 1992 to 2022 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria. In relation to environmental risk issues, this has included the identification of appropriate and screening level criteria that are protective of fresh and marine environments and phytotoxic effects. Where necessary more detailed evaluations of ecotoxicological effects have been considered. This has included the design of suitable surveys and sampling programs (including microtox, microalgae, fish, crustacean, amphipod (sediments), plant and earthworm), interpretation of information and data from these studies, discussion of results with relevant regulatory parties, uncertainty analysis and reporting. These studies have been conducted for the assessment of petroleum hydrocarbon, cyanide, inorganics, ammonia, chloride, phosphorous and nitrate concentrations in soil and discharges from groundwater.
- 2000 to 2008 - Detailed evaluation of risks to human health and the environment (particularly aquatic species and sediments) associated with redevelopment of large a number of gasworks sites in New South Wales and Victoria. The project in NSW involved collaboration with sediment experts to determine the nature and extent of sediment contamination, potential for adverse ecotoxicological effects and requirements for remediation. The process required liaison with relevant site auditors and the DECCW (formerly NSW EPA) as required.
- 2007 - Assessment of risks to terrestrial and aquatic (marine water) environments associated with the re-use of water from a groundwater treatment plant located in Sydney. Water is proposed to be reused for a range of proposes that include industrial water (where it may be directly discarded to the marine environment) and irrigation where the water may affect terrestrial species and runoff may enter local water ways. The assessment considered available ecotoxicological data and guidelines available from Australian and International studies (where relevant to Australian species).

Contaminant Transport

- All of the projects listed above have involved the assessment of contaminant transport in at least one media. More specific examples are listed below:
- Vapour partitioning and transport assessed for petroleum compounds, including the development of a national database of petroleum vapour data, related to over 300 petroleum impacted sites, and detailed review of the database in conjunction with technical specialists from the USEPA. The database developed has been peer-reviewed by the USEPA and has been incorporated into the USEPA technical review of data from both the US and Australia for the purpose of determining screening distances;
- Vapour partitioning and transport assessed for chlorinated compounds at

numerous contaminated sites, including the assessment of vapour risk issues at the Orica Botany site from 1994 to 2018;

- Review and use of groundwater fate and transport modelling conducted in support of numerous detailed risk assessment outcomes. Reviews have been conducted for the purpose of ensuring these models adequately address the potential movement of contaminants from a source to a point of discharge, utilising appropriate inputs and site data;
- 2008 to 2014 - Detailed evaluation of mercury fate and transport in groundwater and air (mercury vapour) with use of specialised data collected and analysed by CSIRO and liaison with experts on mercury issues from the CSIRO. Assessment considered environmental issues associated with the presence of mercury in groundwater and discharge to an urban (highly modified) environment, as well as issues associated with mercury (elemental and inorganic) in soil and groundwater with respect to fate and transport, human health and environmental issues.

Air Emissions and Vapour Assessment

- Jackie Wright is experienced in all aspects of determining air quality, including monitoring, assessing and modelling soil gas, vapour emissions and emissions from stacks and other fugitive sources. Projects include analysing dust emissions from a number of quarries and coal mines, motor vehicle emissions; modelling vapour emissions from motor vehicles and sources such as creeks, ponds and waste areas; and assessing odour emissions from sewage treatment plants.
- 2012 to 2013 – Development of petroleum vapour intrusion guidance for Australia in conjunction with CRC CARE. The project has involved the development of clear, prescriptive guidance that incorporates current science on the assessment of petroleum vapour intrusion. The guidelines being developed have been presented at a series of PVI training workshops (supported by ALGA and CRC CARE) run in Sydney, Melbourne and Perth.
- 2009 to 2022 (ongoing) - Development of a petroleum vapour database to assist in the interpretation and understanding of the behaviour of petroleum vapours in the subsurface environment. The database is unfunded and independent and has been interpreted by Jackie as well as industry experts in Australia and the US. The database has been peer-reviewed by the USEPA, and incorporated into the USEPA publication on the use of field data (from the US, Canada and Australia) to support and develop vertical exclusion/separation distances (refer to the following website for the USEPA review and access to the database developed: http://www.epa.gov/oust/cat/pvi/). This data is being used to support the development of screening distances that are being incorporated into guidance being developed in Australia and the US.
- 2005 to 2022 (ongoing) - Preparation of conceptual site models and completing screening level modelling (using published models such as Johnson & Ettinger) for the assessment of vapour migration and intrusion issues on a wide range of sites (over 200) affected by petroleum and chlorinated hydrocarbons.
- 2010 to 2022 – Detailed evaluation of community exposures and risks to PM10 and PM2.5 derived from urban (combustion – associated with road and rail infrastructure) sources as well as crustal (mining) sources. A number of urban projects have also considered community exposures and risks to other criteria pollutants that include ozone, nitrogen oxides and sulphur dioxide. Projects have involved detailed review of current literature in relation to the health effects and appropriate dose-response relationships relevant to the quantification of relevant health endpoints, with consultation conducted with stakeholders, including state health departments.
- 1995 to 2022 (ongoing) - Development of methods and approaches for the sampling and assessment of vapour (e.g. soil gas, flux emissions, indoor and

ambient air). Works conducted has involved the conduct of field activities for the purpose of collecting this data.

- 1995 to 2022 (ongoing) - Interpretation and assessment of vapour data for the purpose of characterising inhalation exposures in a range of scenarios. These include existing buildings and proposed developments.

Risk Communication

- 2000 to 2022 (ongoing) - Jackie Wright has experience in the preparation and presentation (communication) of risk outcomes from a number of key projects across Australia to a range of community groups. These groups include workers and unions, residents and community action groups. Successful communication with stakeholders and the community on controversial projects including infrastructure, coal seam gas and other mining projects has been required.

Air Quality Assessment

- 1990 to 1995 – Air dispersion modelling and air quality impact assessment conducted for various mining (coal mining and quarry activities) and transport (major roadways) in NSW and Victoria. Projects included the development of emissions inventories, setting up and running air dispersion models and reporting.
- 2011 to 2015 - Air dispersion modelling conducted for the assessment of exposures (and risks to human health) to crop, grain and timber fumigants. The assessment have been undertaken based on trial data, with scaling to address commercial application.
- 2010 to 2018 - Air dispersion modelling conducted for the assessment of exposures (and risks to human health) to grain fumigants, timber fumigants, hydrogen sulphide, chlorinated compounds, silica and dust (particulate) emissions from a range of facilities. Modelling has been conducted using Screening level and mode detailed Ausplume and Calpuff dispersion modelling packages.
- 2010 to 2021 - Review of air dispersion modelling undertaken for a range of projects. The reviews have been undertaken to determine if the assessments are adequate for the purpose of understanding and characterising community health impacts. In some cases the review has been undertaken as part of a larger assessment of public health impacts. Projects have included communication of the air quality assessment and health impact assessment to community groups.

Noise Impact assessment

- 2019 to 2022 - Systematic review of health impacts of transport noise for Waka Kotahi NZ Transport Agency in New Zealand. The work has involved a detailed systematic review of the evidence in published and grey literature in relation to the health effects of transport noise (road, rail and air) and whether the evidence is sufficient to support quantification of health impacts using exposure-response functions. The review has considered recent literature and the GRADE system of review to establish the robustness of the available publications and strength of evidence. This review considered the most recent reviews completed by the WHO and enHealth in 2018.
- 2014 to 2021 - Detailed Evaluation of Community Exposure and Risk to impacts associated with transport infrastructure projects for Transport for NSW and Transurban/Western Distributor Authority/ North East Link Authority in Victoria, Australia. Health impact assessments have included a detailed assessment of impacts from noise during construction and operation. This included a detailed review of current science in relation to health impacts of construction noise, as well as road transport noise sources. In some assessments quantitative risk assessment was required to be undertaken to address impacts on community

health. Projects have included: NorthConnex (road - NSW); WestConnex projects - M4 East, New M5, M4-M5 Link (road - NSW); F6 Stage 1 (road - NSW); Gateway project (road and rail – NSW); Western Harbour Tunnel and Beaches Link (road - NSW); West Gate Tunnel (road -Victoria); North East Link (road – Victoria).

- 2016 to 2017 - Brisbane Airport Corporation, Queensland, Australia. Conduct of a review of the health impacts of aircraft noise as these relate to the identification and use of exposure response relationships for assessing health impacts, particularly related to flight paths near major airports.

Expert Witness

- Long Term Containment Facility at Nowingi, case presented in VCAT. The proponent was Major Projects Victoria, approvals application WA58772.
- Lend Lease (Millers Point) Pty Ltd and Orsats Australians for Sustainable Development Inc., Land and Environment Court Proceedings, 40965 of 2010 (NSW).
- Seppanen&Seppanen v Ipswich City Council, Minister for Economic Development Queensland and Queensland Urban Utilities (2016).
- Westgate Tunnel Project, Expert Witness, Inquiry and Advisory Committee (IAC) hearings (Victoria, August-September 2017).
- Child care centre project, Provision of advice as expert witness for ACT Government Solicitor (2017).
- Caltex Petroleum Pty Ltd v Campbelltown City Council Environment, Resources and Development Court Proceedings No 258 of 2015 (2017 to 2019) (SA).
- North East Link Expert Witness, Inquiry and Advisory Committee (IAC) hearings, Expert Witness (Victoria, 2019).
- Clermont Quarries Pty Ltd v Isaac Regional Council, ECL Dalby Pty Ltd, Chief Executive, Department of State Development, Manufacturing, Infrastructure and Planning and Environment Court (Qld), Expert witness (2019 - 2020).

Teaching

- 2010 to 2012 – Conduct of lectures at the University of Sydney for the Risk Assessment (Human Health and Ecological) module for undergraduates, School of Geosciences.
- 2009, 2010, 2012, 2013 to 2021 – Conduct of lectures at the University of Technology Sydney as part of the Contaminated Site Assessment and Management (CSARM) Professional Development Short Course, Risk Based Site Assessment.
- 2020 and 2022 – Toxicological Risk Assessment lecture to UNSW School of Business.
- 2017 – ALGA Risk Assessment Training Course: New Zealand
- 2014 – ACLCA (Qld) Training Course on Vapour Intrusion and Landfill Gas Assessment (organising and teaching) – May 2014
- 2014 and 2015 – ACLCA (SA and VIC) Training Course on Vapour Intrusion (teaching) – June 2014.
- 2013 and 2015 – ALGA Training Course on Vapour Intrusion (teaching).
- 2013 and 2015 – Vapour Intrusion Short Course. Training Course conducted at CleanUp 2013 and 2015, CRC CARE (teaching).
- 2016 – Clandestine laboratories – risk assessment (teaching) ALGA and ACTRA (separate workshops)
- 2014-2018 – Short courses/branch forums for ALGA – various issues regarding PFAS assessment, vapour intrusion, bioaccessibility methods, clandestine laboratories

- 2016 and 2018 – Short course for WasteMINZ – bioaccessibility methods
- 2010-2011 – Basic and Advanced Risk Assessment Course for Queensland Branch of the Australian Contaminated Land Consultants Association

Work History

Principal/Director/ Owner	Environmental Risk Sciences Pty Ltd	2008 (current)
Adjunct Lecturer	Flinders University	2016 (current)
Principal Environmental Scientist	URS Australia, North Sydney, NSW (formerly Woodward-Clyde)	1992 to 2008
Project Engineer	Sydney Water, Sydney, NSW	1991-1992
Environmental Scientist	Nigel Holmes & Associates, Sydney NSW	1990-1992
Assistant	Dames & Moore, Crows Nest, NSW	1988-1990

Education

BE (Hons)	University of Sydney, Bachelor of Engineering (Hons)	1989
PhD	Public Health, Health and Environment, Flinders University	2016

Professional Accreditation

Fellow of the Australasian College of Toxicology and Risk Assessment (ACTRA)

Professional Development

American College of Toxicology - Virtual Advanced Comprehensive Toxicology Online training course (25 modules) (2021)

Invited member of task force - WA EPA scientific inquiry into fracking in WA (2018)

Clandestine laboratory safety and investigator training and synthesis run by the Clandestine Laboratory Investigators Association (8-hour course, 2011)

Ecological Risk Assessment Course run through AEHS and credited by University of Massachusetts Boston (2010)

Mid-America Toxicology Course (35 hours, 2010)

Dose-Response Boot Camp run by Toxicology Excellence for Risk Assessment (TERA) (5 day course, 35 hours, 2008)

Vapor Intrusion Assessment and Mitigation Short Course run by Air & Waste Management Association (4 hours, 2006)

USEPA Human Health Risk Assessment Short Course (24 hours, 1995)

Affiliations

Member (former committee member, remains co-opted committee member), Australasian College of Toxicology and Risk Assessment (since 2007).

Member, Australian Land and Groundwater Association (since 2010).

Clean Air Society of Australia and New Zealand (re-joined 2015)

Member, Environmental Health Australia (since 2011).

Member, SETAC (Asia Pacific) (since 2011).

Member, Air & Waste Management Association (since 2006).

Member, Society for Risk Analysis (since 1997).

Member, Association for Environmental Health and Sciences Foundation (since 1997).

Awards

2020: Winner of Best Case Study (principal author), Australia New Zealand Policing Advisory Agency and National Institute of Forensic Science

2017: Winner of Best Case Study (principal author), Australia New Zealand Policing Advisory Agency and National Institute of Forensic Science

2017: Winner of ALGA Outstanding Leadership by a Woman in the Contaminated Land & Groundwater Industry

2017: Finalist of ALGA Outstanding Individual in the Contaminated Land & Groundwater Industry

Publications

Peer-reviewed journal articles:

Kuhn, E.J., Walker, G.S., Whiley, H. Wright, J. and Ross, K.E., 2021. Overview of Current Practices in the Methamphetamine Testing and Decontamination Industry: An Australian Case Study. International Journal of Environmental Research and Public Health 18, 8917.

Wright, J., B. Symons, J. Angell, K. E. Ross and S. Walker, 2021. Current practices underestimate environmental exposures to methamphetamine: inhalation exposures are important. Journal of Exposure Science & Environmental Epidemiology 31: 45-54.

Kuhn, E.J., Walker, G.S., Wright, J., Whiley, H. and Ross, K.E., 2021. Public health challenges facing Environmental Health Officers during COVID-19: methamphetamine contamination of properties. Australian and New Zealand Journal of Public Health, 45: 9-12.

Wright, J., M. Kenneally, K. Ross and S. Walker, 2020. Environmental Methamphetamine Exposures and Health Effects in 25 Case Studies. Toxics 8 (3): 61.

Wright, J., G. S. Walker and K. E. Ross, 2019. Contamination of Homes with Methamphetamine: Is Wipe Sampling Adequate to Determine Risk? International Journal of Environmental Research and Public Health 16 (19): 3568.

Kuhn, E. J., G. S. Walker, H. Whiley, J. Wright and K. E. Ross, 2019. Household Contamination with Methamphetamine: Knowledge and Uncertainties. International Journal of Environmental Research and Public Health 16(23): 4676.

Capon, A. and J. Wright, 2019. An Australian incremental guideline for particulate matter ($PM_{2.5}$) to assist in development and planning decisions. Public Health Research & Practice 29 (4).

Wright, J., Kenneally, M. E., Edwards, J.W. and Walker, S., 2017. Adverse Health Effects Associated with Living in a Former Methamphetamine Drug Laboratory — Victoria, Australia, 2015. Morbidity and Mortality Weekly Report (MMWR) January 6, Vol.65, No. 52, p1470-1473

Wright, J., Edwards, J. and Walker, S., 2016. Exposures associated with clandestine methamphetamine drug laboratories in Australia. Reviews on Environmental Health.

Lahvis, M.A., Hers I., Davis, R.V., Wright, J. and DeVaull G.E., 2013. Vapor Intrusion Screening at Petroleum UST Sites. Groundwater Monitoring & Remediation.

Wright J. and Howell M., 2003. "Volatile Air Emissions from Soil or Groundwater – Are They as Significant as Model Say They Are?". In Contaminated Soils, Volume 8, Edited by Edward J. Calabrese, Paul T. Kostecki and James Dragun, p375-393.

Gorman J., Mival K., Wright J. and Howell M., 2003, Developing Risk-Based Screening Guidelines for Dioxin Management at a Melbourne Sewage Treatment Plant. Water, Science and Technology, Vol 47 No 10, pp 1-7.

Wright J., and Howell M., 1995, "Health Risk Assessment - Practical Applications Related to Air Quality Issues". Clean Air, Volume 29, No. 2, May 1995.

Government and industry publications:

Environmental Health Australia, 2019. Australian Voluntary Code of Practice, Assessment, remediation and validation: Former clandestine drug laboratories and other methamphetamine contaminated properties. Principal author.

CRC CARE, 2018. Weathered Petroleum Hydrocarbons (Silica Gel Clean-up), CRC CARE Technical Report no. 40, CRC for Contamination Assessment and Remediation of the Environment, Newcastle, Australia. Principal author.

CRC CARE, 2013. Petroleum Vapour Intrusion (PVI) Guidance. CRC Care Technical Report No 23, CRC for Contamination Assessment and remediation of the Environment, Adelaide, Australia. Principal author.

NEPM 2013 Revision (released in 2013), Schedule B4 (Guideline on Site-Specific Health Risk Assessment Methodology) and Schedule B7 (Guideline on Derivation of Health-Based Investigation Levels). Primary author of toxicological evaluations and derivation of health investigation levels and contributing author to the Schedules (conducting full revision/rework of both Schedules, including responding to public comments and comments from state health agencies).

Australian Government, 2011. Guidelines for Environmental Investigations, Remediation and Validation of former Clandestine Drug Laboratory Sites [Guidelines], April 2011. Primary author of toxicological evaluations and derivation of remeidation guidelines using risk based approach and listed contributor to main document.

Davis G.B., Wright J. and Patterson B.M., 2009. Field Assessment of Vapours, CRC CARE Technical Report no. 13, CRC for Contamination Assessment and remediation of the Environment, Adelaide, Australia.

Invited lectures

Wright, J. 2020 to 2022. Toxicological risk assessment. Guest lecture to University of New South Wales School of Business.

Wright, J., 2013. Petroleum Vapour Intrusion Guidance in Australia. AEHS 23rd Annual International Conference on Soil, Water, Energy, and Air and AEHS Foundation Annual Meeting, March 18-21, 2013, Mission Valley Marriott, San Diego, California. Invited lecture

Wright, J., 2012. Evaluation of the Australia Hydrocarbon VI Data Base: Exclusion Criteria. AEHS 22nd Annual International Conference on Soil, Water, Energy, and Air and AEHS Foundation Annual Meeting, March 19-22, 2012, Mission Valley Marriott, San Diego, California. Invited lecture.

Conference Proceedings (Oral Presentations):

Wright, J. (2021) Weathered Petroleum – Assessing the toxicity of polar metabolites vs petroleum hydrocarbons. ACTRA Annual Scientific Meeting, Sydney 26-27 August 2021

Wright, J. (2021) Risk Assessment and CSMs? Presentation to ACLCA – Western Australian branch meeting

Wright, J. (2020) Clan labs and meth contaminated properties - Risks and issues. Environmental Health Australia, Professional Development Workshop

Wright, J. and Manning, T. (2020) Basements, Really, you thought THAT was a good idea !!!!. ALGA Ecoforum 2020

Wright, J. (2020) Attenuation Factors and VI. ACLCA Webinar, 29 April 2020

Wright, J. and Manning, T. (2020) Chlorinated Hydrocarbons - Myths and Realities. ACTRA webinar (industry training) 27 February 2020

Wright J. and Stratford, M. (2020) Methamphetamine Risk Management Industry Voluntary Code of Practice. ACTRA webinar (industry training) 20 February 2020

Wright, J. and Manning, T. (2018) Perplexing guidelines: What it means for measurement, RACI PFAS Symposium, November 2018

Wright, J. (2018) Contrasting current contamination issues: Inside the home – methamphetamine, ALGA Regional Conference, Townsville October 2018

Wright, J. (2018) Contrasting current contamination issues: Outside the home – PFAS, ALGA Regional Conference, Townsville October 2018

Capon, A. and Wright, J. (2018) An Australian incremental guideline for particulate matter less than or equal or 2.5 micrometres (PM2.5). ACTRA Conference, October 2018

Manning, T. and Wright, J. (2018) Contaminated Land Risk Assessment and the Building Code of Australia, Ecoforum October 2018

Jarman, R., Wright, J., Manning, T. and Pendergast, D. (2016). Using oral bioaccessibility testing to refine exposure assessment for carcinogenic PAHs in soil. EcoForum, October 2016.

Manning, T., Wright, J., Jarman, R. and Bowles, K. (2016) Per and poly fluorinated alkyl substances – where are we, ecologically speaking? SETAC AU October 2016.

Jarman, R., Manning, T., and Wright J. (2016). Setting toxicity reference values for PFAS – what can we learn from TOXCAST and TOX21. ACTRA Annual Scientific Meeting, September 2016.

Manning, T., Wright, J., Jarman, R. and Bowles, K. (2016) Per and poly fluorinated alkyl substances – the Australian Story. EmCon 2016 September 2016.

Manning, T. and Wright, J. (2016). Particulate Risk Assessments – Issues and Challenges. EcoForum, October 2016.

Manning, T. and Wright, J. (2015). Review of Ecological Investigation Levels for Total Petroleum Hydrocarbons. 6th International Contaminated Site Remediation Conference (Cleanup 2015), September 2015.

Manning, T. and Wright, J. (2015). Particulate Risk Assessments – Issues and Challenges. 22nd Clean Air and Environment Conference, September 2015.

Wright, J. and Manning, T. (2015). Bioavailability/Bioaccessibility – Practical Considerations. ALGA Workshop, Use of Bioavailability and Bioaccessibility Techniques to Refine Assessment of Human Health Risk, November 2015.

Wright, J. and Manning, T. (2015). PAHs and Bioaccessibility. ALGA Workshop, Use of Bioavailability and Bioaccessibility Techniques to Refine Assessment of Human Health Risk, November 2015.

Manning, T. and Wright, J. (2014). Contaminated Land – How do environmental guidelines get used? SETAC-AU Conference Adelaide September 2014.

Manning, T. and Wright, J. (2014). Use of Health Impact Assessment in Environmental Impact Statements. Ecoforum Conference Gold Coast October 2014.

Wright J., 2014. Particulate Risk Assessments – Issues and Challenges. ACTRA Annual Scientific Meeting, Sydney October 9-10 2014.

Wright J. and Manning T., 2014. Health Impact Assessment – Role in EIS. Keynote presentation. Ecoforum, 29-31 October 2014, Gold Coast.

Wright J. and Manning T., 2014. Addressing Risk Perceptions through Risk Assessment. Ecoforum, 29-31 October 2014, Gold Coast.

Wright J. and Manning T., 2014. Vapour Assessment for TCE. Ecoforum, 29-31 October 2014, Gold Coast.

Wright J., Howell J. and Newell P., 2014. Assessment and Remediation of Illegal Drug Laboratories. Ecoforum, 29-31 October 2014, Gold Coast.

Wright, J., 2014. Clandestine Drug Laboratories – Understanding Exposures and Public Health. The Second International Conference on Law Enforcement and Public Health, Amsterdam 5-8 October 2014.

Wright, J. 2014. ASC NEPM – Implementation. AEBN (Australian Environment Business Network) Conference on Managing Contaminated Land, September 2014.

Wright, J. 2014. Managing Vapours – The Issues to Consider for Developers and Councils. AEBN (Australian Environment Business Network) Conference on Managing Contaminated Land, September 2014.

Wright, J., 2012. Exposure and Risk Issues associated with Clandestine Drug Laboratories – development of guidelines. British Occupational Hygiene Society (BOHS), Occupational Hygiene 2012 Conference, 24-26 April 2012, Mercure Holland House Hotel, Cardiff.

Wright, J., 2012. Risks of Not remediating Clandestine Drug Laboratories. 66th Annual Western Australian Environmental Health Australia (WA) State Conference Environmental Health: Imagine Life Without Us, 28-30 March 2012.

Wright, J, 2011. Establishing exclusion criteria from empirical data for assessing petroleum hydrocarbon vapour intrusion. CleanUp 2011: Proceedings of the 4th International Contaminated Site Remediation Conference, 11-15 September, Adelaide, Australia.

Wright, J., 2010. Review of Petroleum Vapour Data from Australia. Abstract presented at Ecoforum 2010, 3rd ALGA Annual Conference 23-24 February 2010.

Wright, J., 2010. Interpretation and Use of Soil Gas and other Vapour Data. Abstract presented at Ecoforum 2010, 3rd ALGA Annual Conference 23-24 February 2010.

Weaver T., Hassell T., Wright J., Stening J. and Apte S., 2009. Speciation and Geochemical Modelling as a Tool to Refine a Risk Assessment for Mercury in Groundwater. Presented at EcoForum, Sydney 28-30 April 2009.

Wright J. and Robinson C., 2009. The Reality of Sampling and Assessing Vapour Intrusion on Petroleum Sites. Presented at Air &Waste Management Association's Vapor Intrusion 2009, January 27-29 2009, San Diego CA.

Wright J., Lee A. and Howell M., 2008. Role of Risk-Based Concentrations in Assessment and remediation of Contaminated Sites. Presented at EcoForum, Gold Coast, 27-29 February 2008.

Wright J., Howell M. and Barnes J., 2006. Risk Assessment – Important Tool for Managing Issues on Contaminated Sites or Just a Task. Presented at Enviro06, Melbourne 2006.

Hall, A, Wright J. and Calabrese N, 2006. Ray Street Landfill – Audit Acceptance Levels for CO_2 in Redeemed Soils. Presented at Enviro06, Melbourne 2006.

Wright J. and Howell M., 2004. "Evaluation of Vapour Migration Modelling in Quantifying Exposure". Presented at Enviro04, Sydney March 2004.

Lee A., Howell M., and Wright J. 2004. "TPH – Analysis, Guidelines and Risk Assessment" Presented at Enviro04, Sydney March 2004.

Pershke D., van Merwyk T., Graham-Taylor S., Wright J., Mitchell T., and Elliot P., 2004. "Health Risk Assessment: Broadening the Horizons of the Traditional Health and Safety Approach", Presented at Enviro04, Sydney March 2004.

Wright J., Buchanan V., and Howell M., "Health Risk Assessment using Probability Density Functions". Presented at the AWWA Waste and Wastewater Conference, Brisbane 1998.

Wright J. and Buchanan V., 1996, "Uptake of Organics and Inorganics into Edible Fruit and Vegetable Crops". Presented at Intersect-96 International Symposium on Environmental

Chemistry and Toxicology, Royal Australian Chemical Institute and the Australian Society for Ecotoxicology, 14-16 July 1996.

Wright J. and Howell M., 1995, "Risk Based Approach to Assessment and Management of Air Quality Issues Associated with Contaminated Sites and Hazardous Waste". Presented at Waste Management Institute (New Zealand) Inc., 7th Annual Conference and Exhibition, 31 October - 3 November, 1995.

Harrington J F, Clark L T and Wright J, 1994, "The Incineration of Sludge and its Effect on Ambient Air Quality in the Evaluation of Risk Factors for Primary School Children". Presented at Australia and New Zealand Clean Air Conference, Perth 1994.

Royston D, Clark L T and Wright J, 1993, "Chlorinated Dioxins and Furans from Combustion Sources: A review". Poster presented at the Sixth Conference of Asia Pacific Confederation of Chemical Engineering, Melbourne, 1993.