ANNUAL SUMMARY REPORT

P76: The Use of Recycled Glass in Pavements – Year 2 (2019–20)

ARRB Project No.: 014959

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SUMMARY

In 2018, the Queensland Government sponsored a multi-year research project with the aim of increasing the use of recycled crushed glass (RCG) in pavement applications, including both unbound granular pavement and asphalt layers. The literature review undertaken during the first year of the project indicated that RCG may be incorporated into asphalt without detrimentally impacting performance.

This report presents the findings of the second year of the project that was primarily focused on investigating the performance of an asphalt mix containing up to 10% RCG by mass. Additionally, an evaluation on the variability of RCG sourced from suppliers throughout Queensland was undertaken to facilitate developing new specifications for RCG, and updating current, applicable specifications. The following are the key outcomes:

- Asphalt intermediate course layers may contain up to 10% RCG without detrimentally impacting performance.
- Recycled glass suppliers in Queensland can produce a consistent product appropriate for use in asphalt and unbound pavement applications.
- RCG contains low crystalline silica content and thus, there are likely no significant long-term adverse health risks (such as silicosis) associated with usage.
- A new specification for RCG was developed (MRTS36 *Recycled Glass Aggregate*) which specifies the requirements for RCG in asphalt and unbound granular applications. MRTS30 *Asphalt,* MRTS101 *Aggregates for Asphalt,* Technical Note 148 *Asphalt Mix Design Registration, MRTS04 General Earthworks and MRTS05 Unbound Pavements* were also updated to reference MRTS36.
- RCG meeting the proposed specification limits poses no increased risk to health and safety or the environment when used in asphalt (up to 10% by mass), unbound granular pavement materials (up to 20% by mass) or pipe-bedding materials (up to 100% by mass).

Recommendations for the third year of the project include:

- undertaking a demonstration project to assess the suitability of incorporating up to 5% RCG in an asphalt surfacing layer, which should evaluate the following parameters:
  - visual condition monitoring
  - skid resistance testing
  - assessing the level of reflectivity/glare from the surface
  - long-term performance
- identifying sites utilising RCG in wearing courses and conducting inspections on these sites
- disseminating findings through the development of a technical note on the performance of asphalt containing RCG, conducting knowledge transfer workshops/webinars and training for the industry and government staff.

ACKNOWLEDGEMENTS

The author would like to thank the recycled glass suppliers, asphalt industry and TMR for their contributions to this research through the supply of materials, data and relevant information.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 BACKGROUND

In 2018, the Queensland Government sponsored a multi-year project under the National Asset Centre of Excellence (NACoE) research program with the aim of increasing the use of recycled crushed glass (RCG) in pavement applications, including both unbound granular pavement layers and asphalt layers. The first year of the project, documented in *P76: Increasing the Use of Recycled Glass in Pavements – Year 1 (2018/2019)* (Latter & Coomer 2021) included a literature review of existing practice regarding the use of RCG in pavements, both locally and internationally, as well as preliminary laboratory testing on an asphalt mix incorporating RCG. The findings are summarised as follows:

- The literature indicated that 10-15% RCG at a nominal size of 4.75 mm can be used to replace traditional aggregates in asphalt without major detrimental effects on the performance of the mix. However, an anti-stripping agent may need to be included in the mixture to decrease moisture susceptibility and the risk of stripping.
- Limited studies suggested that asphalt surface courses incorporating 10% RCG by mass perform in-service as well as conventional asphalt mixes.
- The Queensland Department of Transport and Main Roads (TMR) requirements for RCG were generally in line with the other Australian state road agencies, however, no RCG was permitted in TMR- registered asphalt mixes. New South Wales permits the highest proportion of RCG by mass (10%) in dense graded asphalt (DGA) mixes that are not wearing courses, and up to 2.5% by mass RCG in DGA wearing courses.

It was recommended that Year 2 of the project undertake additional laboratory testing on mixes containing 0% and 10% RCG to characterise the engineering properties and performance of a typical TMR asphalt mix, which will also assist in the development of a TMR RCG specification.

1.2 OBJECTIVES AND APPROACH

This report outlines the second year of the multi-year project, building on the findings of the first-year report by Latter and Coomer (2021). The second-year project objectives and approach are summarised as follows (including the sections of the report where the results of the work are presented):

- undertaking a laboratory testing regime on an asphalt mix incorporating RCG at 0%, 5% and 10% to characterise the engineering properties, validate the design mixture and investigate the performance of the mix – Section 2
- development of an RCG specification for TMR, to be used for the Year 3 demonstration project as well as updating current TMR guidance and specifications – Section 3
- presenting the findings based on the project outcomes and recommending further investigation areas – Section 4
- determining the variability of RCG between recyclers in Queensland and whether it is suitable for usage in pavement applications – Appendix A
- establishing the risk of silicosis from RCG usage – Appendix B
- enRiskS *Recycled Glass Specification and Test Results: Technical Review* – Appendix C.

2 ASPHALT MIX LABORATORY TESTING

An exploratory laboratory testing regime on one asphalt mix incorporating RCG was undertaken to characterise the engineering properties, validate the design mixture and investigate the performance of the mix. The mix was designated as a medium duty dense graded asphalt with a nominal aggregate size of 20 mm using a conventional class 600 (C600) bitumen and varying percentages of RCG by mass (0%, 5% and 10%). Testing was undertaken on a supplier's asphalt mix design, with specimens manufactured from a production mix supplied to TMR's Materials Laboratory at Bulwer Island.

2.1 MIX DESIGN CONFORMANCE

The design mix volumetrics and particle size distribution (PSD) were tested to ensure conformance to the mix design requirements. PSD results for all three mix are shown in Figure 2.1, while the volumetric properties are presented in Table 2.1. This shows that the mix was compliant with the mix design requirements and all three mixes had a very similar grading.

Figure 2.1: PSD results

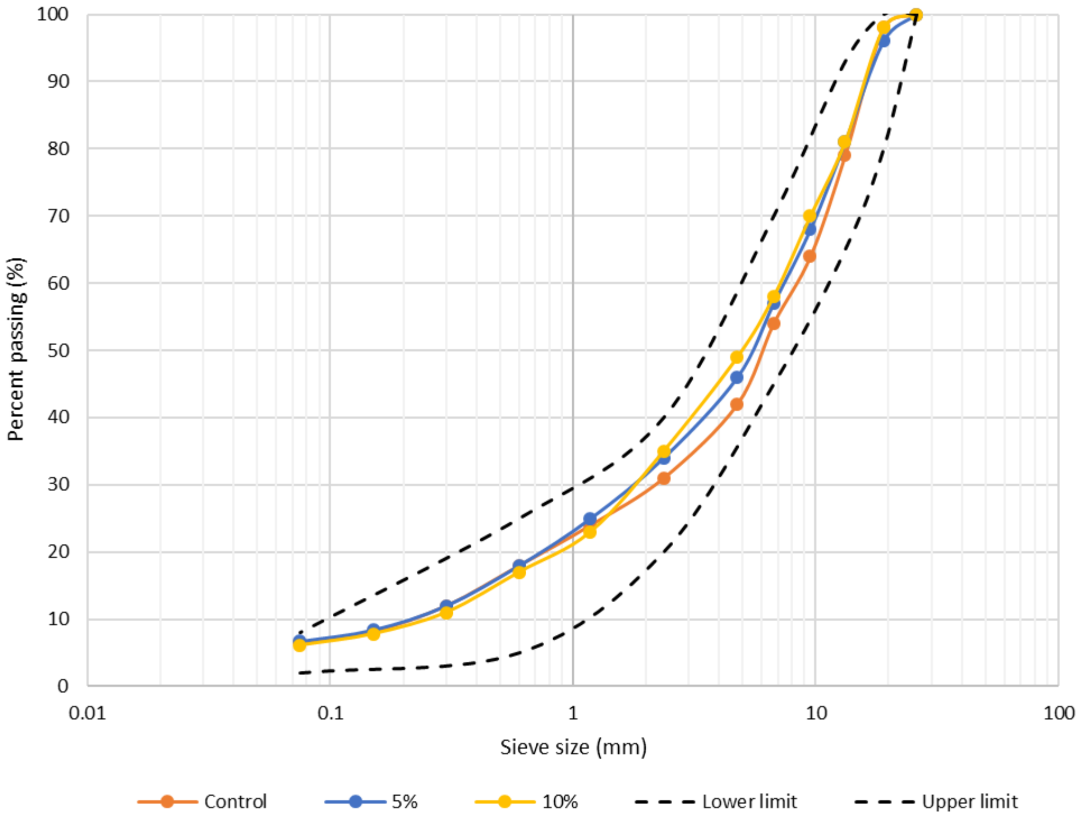


Table 2.1: Volumetric properties

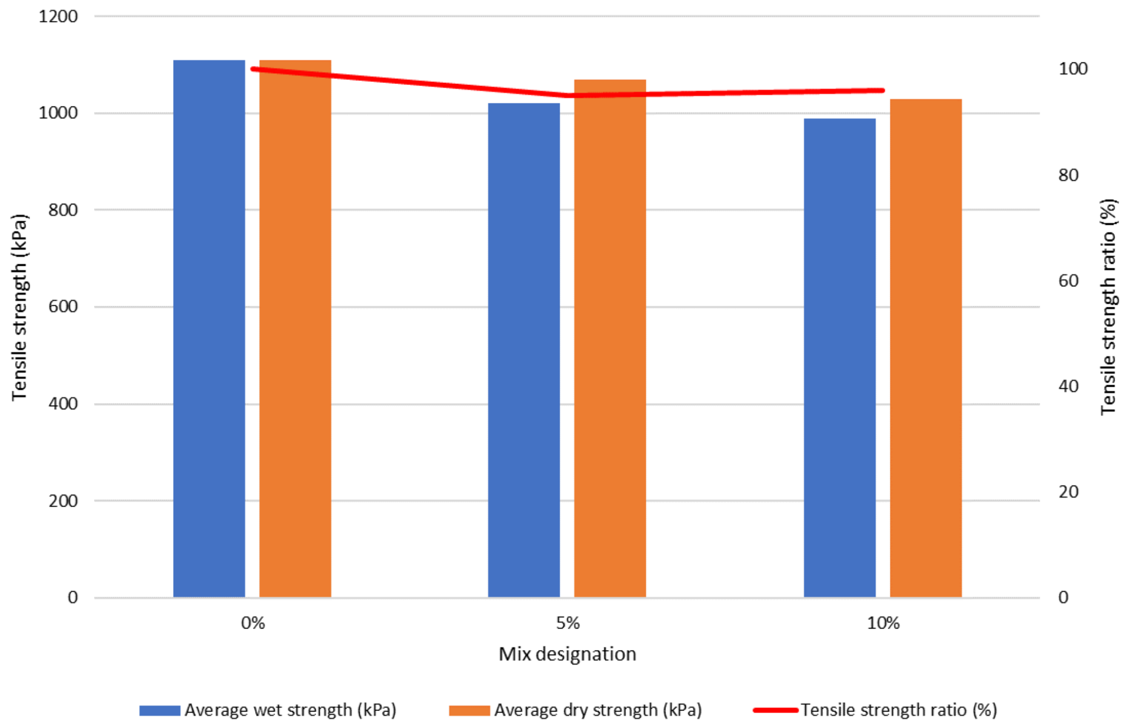
Property	0% glass	5% glass	10% glass	Lower limit	Upper limit
Bitumen content (%)	4.4	4.5	4.6	4.0	4.6
Maximum density (t/m^3)	2.666	2.649	2.616	2.615	2.685
Air voids (%)	2.9	3.9	3.4	3.0	6.0

2.2 MOISTURE SENSITIVITY

TMR performed the tensile strength ratio (TSR) testing to determine the stripping potential of the asphalt mixes in accordance with Test Method AGPT/T232 (Austroads 2007). The results are summarised in Figure 2.2. This shows that the control mix with no RCG added had the highest TSR result of 100%, followed by the 10% RCG mix with a TSR of 96% and the 5% CRG mix with a TSR of 95%. These results show compliance with the minimum TSR requirements outlined in MRTS30 *Asphalt* (TMR 2020a) where it is stated that DGA must have a TSR of at least 80% to ensure the asphalt mix has a satisfactory resistance to stripping. A decrease of 5% and 4% for the 5% CRG mix and 10% CRG mix respectively is relatively insignificant and may be attributed to laboratory variability.

As the TSR results for the mixes incorporating RCG comfortably met the TMR specification and did not show significant variance from the control mix it can be postulated (based on a limited amount of testing) that up to 10% RCG may be incorporated in an AC20M, C600 mix without compromising the moisture susceptibility of the asphalt.

Figure 2.2: TSR results



2.3 RUT RESISTANCE

2.3.1 DEFORMATION RESISTANCE OF ASPHALT BY WHEEL TRACKING

Wheel tracking testing was conducted in accordance with AGPT/T231 *Deformation Resistance of Asphalt Mixtures by the Wheel Tracking Test* (Austroads 2006) and the results are summarised in Table 2.2. This shows that the control mix reported the lowest mean final rut depth of 1.9 mm compared to a mean final rut depth of 2.4 mm and 2.2 mm for the 5% RCG and 10% RCG mixes, respectively. Notably, the mix that exhibited the highest mean rut depth was the 5% CRG mix rather than the 10% CRG mix although it is important to note that the mean air voids of the control mix were also the lowest, at 4.5%. This difference in air voids content may have contributed to the increased resistance to permanent deformation compared to the 5% CRG mix and the 10% CRG mix, as reducing air voids improves the deformation resistance of asphalt (Austroads 2014).

In accordance with the TMR requirements for the final rut depth of a heavy duty AC20, C600 mix, rutting must be less than or equal to 4.0 mm while production compliance is set at a maximum of 4.5 mm, in accordance with MRTS30. This shows that the results for each mix comfortably conform to TMR requirements although the mix tested is classified as medium duty. The key difference between a medium duty and heavy duty DGA mix according to TMR is the free flowing and high shear design traffic in the design lane in the year of opening (TMR 2020a), thus demonstrating the relatively high deformation resistance of each mix tested as part of this study.

The permanent deformation test results, in conjunction with the international literature cited and compliance with TMR requirements (for heavy duty DGA) indicate that that up to 10% RCG may be incorporated in an AC20M, C600 mix without compromising the permanent deformation resistance.

Table 2.2: Summary of wheel tracking test results

Mix	Mean air voids (%)	Mean deformation at 5000 cycles (10 000 passes) (mm)
0% glass	4.5	1.9
5% glass	5.0	2.4
10% glass	5.1	2.2

2.3.2 HAMBURG WHEEL TRACKER

Although the Hamburg wheel tracking device (HWTD) is not a performance requirement for asphalt mixes used by TMR, this testing was conducted to provide additional performance information to assist in evaluating the test mixes. This was conducted in accordance with TMR Test Method Q325 *Stability of Asphalt – Hamburg Wheel Tracking Device* (TMR 2020a). The device was designed to test an asphalt mix for susceptibility to moisture induced damage (including stripping) and resistance to rutting by tracking steel wheels over submerged samples at elevated temperatures (50–60 °C).

The testing was carried out by TMR and the results are summarised in Table 2.3. This shows that the control mix without any RCG had the lowest mean deformation of 4.0 mm, whereas the 5% RCG glass mix showed the greatest deformation of 4.9 mm and the 10% RCG mix had a deformation of 4.3 mm. Notably, the HWTD results show a similar trend to the standard wheel tracker test, where the least deformation and air voids are seen in the control mix and the highest deformation is observed in the 5% RCG mix. The difference in deformation results is not considered significant and supports the findings of the wheel tracking test in Section 2.3.1.

Table 2.3: Summary of HWTD test results

Mix	Mean air voids (%)	Mean deformation at 10 000 cycles (mm)
0% glass	6.3	4.0
5% glass	6.8	4.9
10% glass	7.4	4.3

2.4 RESILIENT MODULUS

A summary of the resilient modulus test results conducted in accordance with AS/NZS 2891.13.1:2013 *Methods of Sampling and Testing Asphalt: Determination of the Resilient Modulus of Asphalt – Indirect Tensile Method* is presented in Table 2.4 and depicted in Figure 2.3, Figure 2.4 and Figure 2.5 for the control mix, 5% RCG mix and 10% RCG mix, respectively. The resilient modulus of the control mix was 7073 MPa with an average bulk density of 2.54 t/m^3 and an average air voids content of 4.9%. The mean resilient modulus, average bulk density and air voids for the 5% mix was 6359 MPa, 2.51 t/m^3 and 5.1%, while the 10% mix was 6644 MPa, 2.48 t/m^3 and 5.1%, respectively.

The control mix had the highest average resilient modulus of the mixes tested at 7073 MPa, comparatively, the mix containing 5% CRG contents had the lowest average resilient modulus at 6359 MPa.

Notably, the coefficient of variance for the specimens containing 5% CRG contents was very low (2%) in comparison to the 10% CRG mix (7%) and the control mix (12%), which is evident looking at the resilient modulus variation of each sample depicted in Figure 2.3 to 2.5. However, these values are relatively insignificant and appear reasonable considering laboratory variability.

Table 2.4: Summary of resilient modulus testing

Mix	Mean bulk density (t/m^3)	Mean air voids (%)	Mean resilient modulus (MPa)	Coefficient of variance (%)
0% glass	2.54	4.9	7073	12
5% glass	2.52	5.1	6359	2
10% glass	2.48	5.1	6644	7

Figure 2.3: Resilient modulus control mix (0% glass)

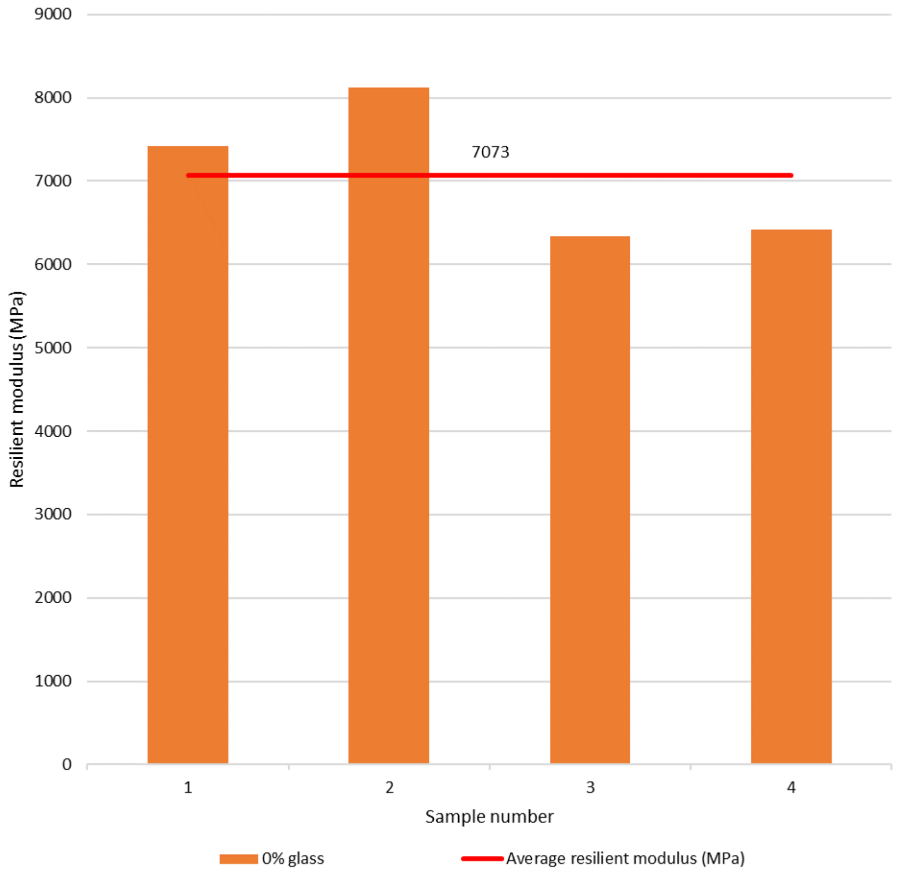


Figure 2.4: Resilient modulus control mix (5% glass)

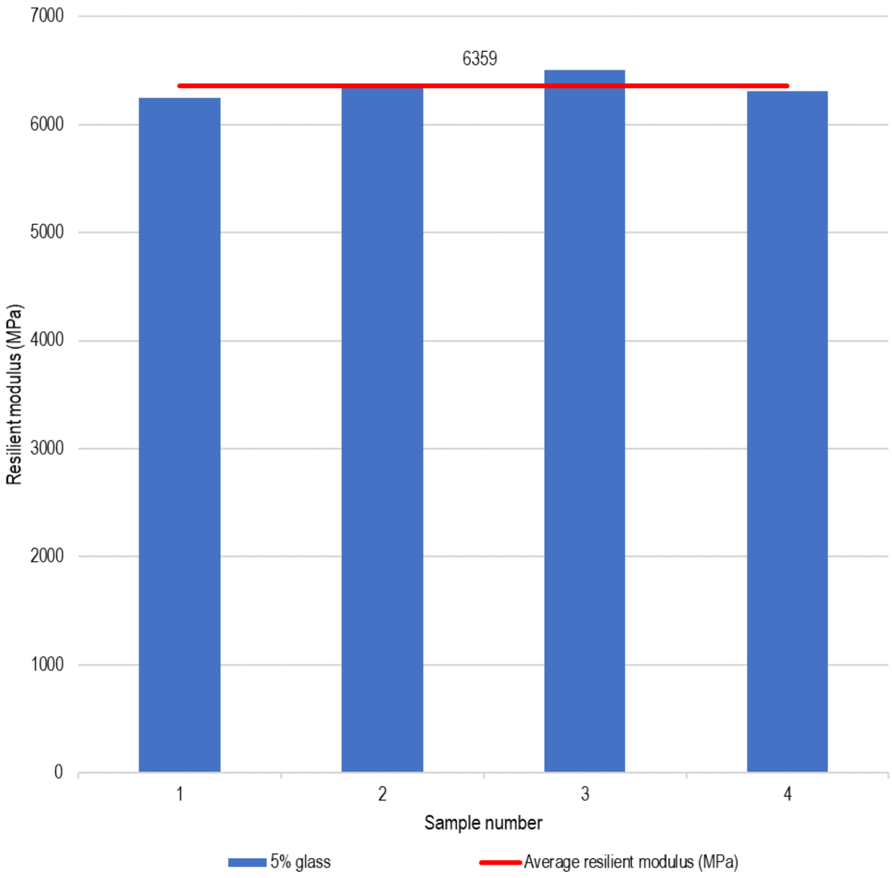
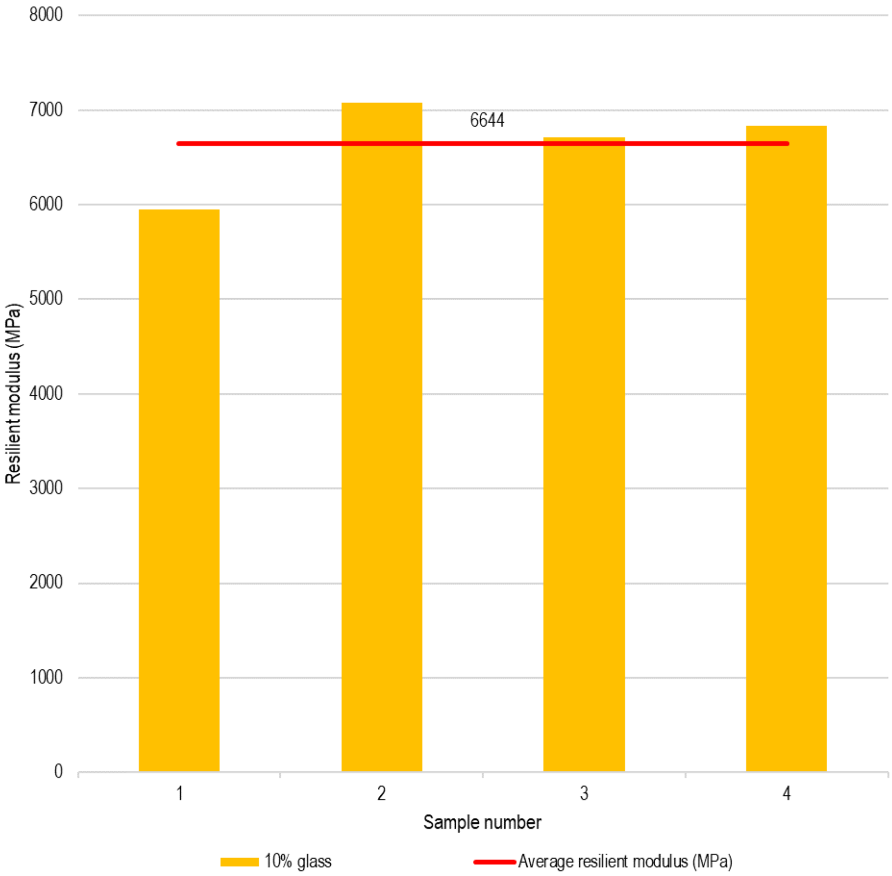


Figure 2.5: Resilient modulus control mix (10% glass)



2.5 FATIGUE RESISTANCE

Asphalt fatigue testing was performed at a load frequency of 10 Hz, in accordance with Test Method AGPT/T274 *Characterisation of Flexural Stiffness and Fatigue Performance of Bituminous Mixes* (Austroads 2016). The tests were performed at three strain levels (low, medium and high) and a temperature of 20 °C.

Figure 2.6 presents a comparison of the fatigue results where Nf_{50} represents the number of cycles to failure, with failure defined as a 50% reduction in the asphalt modulus. Furthermore, the fatigue resistance at 1 million cycles for each of the testing temperatures is presented in Table 2.5.

It is important to note that although AGPT/T274 recommends fatigue testing on a minimum of 18 beams tested at three different strain levels, a statistical analysis carried out as part of another NACoE project indicated it would be sufficient to test a minimum of 9 beams (Denneman & Bryant 2016).

The results show that the control mix and the 5% RCG mix have approximately the same fatigue resistance at 1 million cycles and the 10% RCG mix shows slight improvement. The coefficient of determination (R^2) value for each of the mixes is approximately 0.95, thus indicating the strength of the correlation. Although the 10% glass mix is noted to have performed the best, the performance improvement is only marginal and may be attributed to laboratory variability. These results indicate the addition of up to 10% CRG to asphalt will not have a detrimental effect on the fatigue performance of the asphalt mix tested.

Figure 2.6: Fatigue resistance results

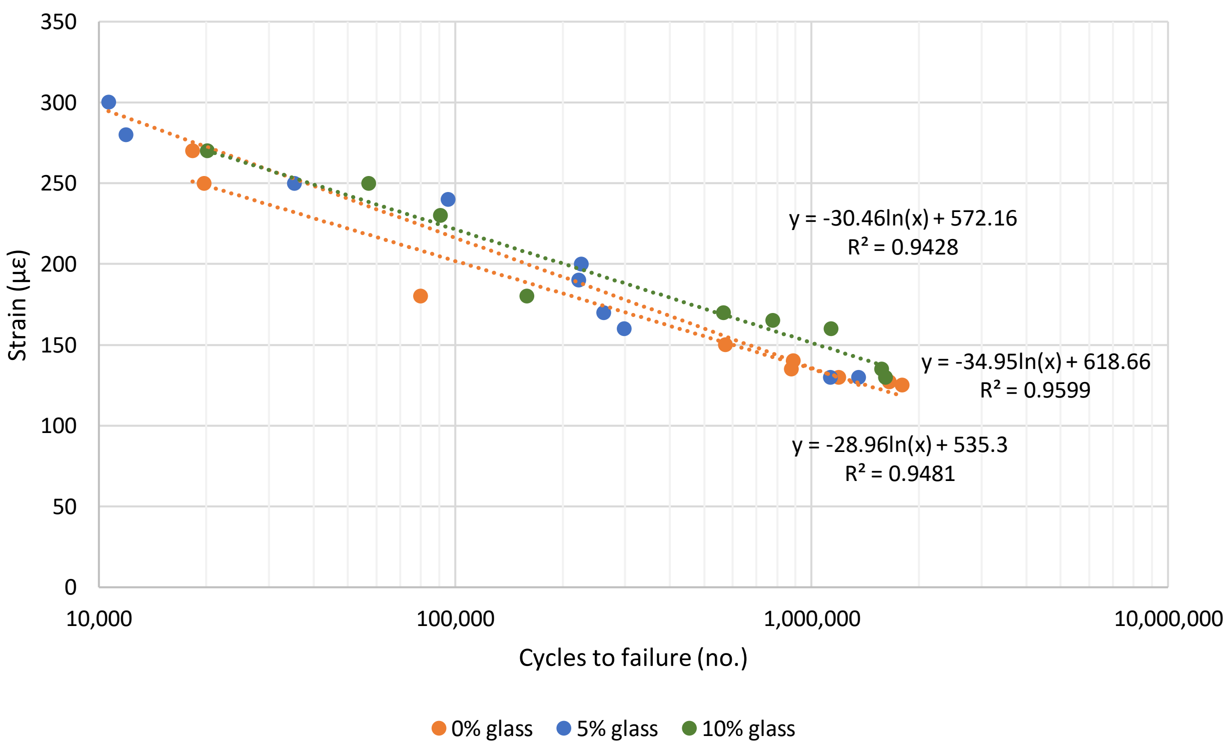


Table 2.5: Fatigue resistance results summary

Mix	Fatigue resistance at 10 Hz and 1 million cycles (με)
0% RCG (control)	135
5% RCG	136
10% RCG	151

2.6 LABORATORY TESTING SUMMARY

Laboratory testing was undertaken by the TMR Materials Laboratory on production samples in an attempt to characterise the performance of a standard AC20M asphalt mix containing up to 10% glass. The results of the performance tests conducted on the mix are summarised in Table 2.6. The results indicate that at RCG quantities of up to 10% by mass in the mix, there are no notable differences in performance compared to the control mix.

Additionally, the mixes tested comfortably achieved conformance with the TMR requirements outlined in MRTS30 (TMR 2020a.

Table 2.6: Summary of the laboratory testing

Property	Unit	Results		Limit
Air voids in laboratory compacted specimens	%	0% glass 5% glass 10% glass	2.9% 3.9% 3.4%	3.0% – 6.0%
Stripping potential of asphalt – tensile strength ratio	%	0% glass 5% glass 10% glass	100 95% 96%	≥ 80%
Wheel tracking at 60 °C and 5000 cycles (10 000 passes) rut depth	mm	0% glass 5% glass 10% glass	1.9 2.4 2.2	≤ 4.0*
Hamburg wheel tracking rut depth	mm	0% glass 5% glass 10% glass	4.0 4.9 4.3	–
Resilient modulus (ITT)	MPa	0% glass 5% glass 10% glass	7073 6359 6644	–
Fatigue resistance at 20 °C, 10 Hz and 1 million cycles	με	0% glass 5% glass 10% glass	135 136 151	–

** Production compliance limit for heavy duty AC20 mix.*

3 DEVELOPMENT AND UPDATES TO TMR DOCUMENTATION AND SPECIFICATIONS

3.1 MRTS36 RECYCLED GLASS AGGREGATE

3.1.1 DEVELOPMENT

For the development of MRTS36 *Recycled Glass Aggregate* (TMR 2020c), testing was undertaken to measure the variability of RCG produced in Queensland and to assess the risk of silicosis relative to the amorphous and crystalline silica content of the RCG being produced locally. This included testing nine RCG samples collected from five suppliers in Queensland over a six-month period from late-2019 to mid-2020. The results indicated that the crystalline silica content of the RCG tested did not typically exceed 1% and that natural sand contains significantly greater proportions of crystalline silica compared to the RCG, thus indicating there may be a reduced risk of exposure to respirable crystalline silica when working with RCG compared to natural sand. Additionally, this testing evaluated manufactured sand with similar findings, i.e., that the use of RCG may reduce potential worker exposure to respirable crystalline silica. Therefore, findings indicated that due to the low crystalline silica contents there are likely no significant long-term adverse health risks (such as silicosis) associated with RCG usage. It is important to note that appropriate health and safety controls should still be implemented when working with RCG, manufactured sand and natural sand dust. Detailed results and discussion are provided in Appendix A and Appendix B.

Additionally, to assess whether using the New South Wales Environmental Protection Agency (EPA) requirements (Table 3.1) for RCG in asphalt and unbound granular materials is suitable from an environmental perspective, ARRB engaged an experienced suitably qualified professional (SQP) with appropriate waste characterisation and contaminated land experience. The SQP was provided a supplier-anonymised copy of the RCG chemical analysis and PSD test results. A copy of the report prepared by the SQP is in Appendix C.

The review found that the proposed use of RCG in asphalt and pavement materials would have no issues of concern in relation to risk to human health or to the environment when the RCG meets the proposed NSW EPA specification adopted by TMR (Table 3.1). It is important to note that the review included proportions of up to 10% RCG by mass in asphalt and up to 20% RCG by mass in unbound granular pavement materials.

Furthermore, evaluating other uses for RCG such as pipe bedding or drainage found:

- The characteristics of the RCG tested are consistent with the characteristics expected for natural materials or clean fill, including gravel and sand commonly used in road applications.
- There are no issues of concern in relation to risks to human health, for any location where RCG is used in road/pavement materials or pipe bedding materials may be used.
- There are no issues of concern in relation to potential risks to the environment (terrestrial or aquatic) that may be adjacent to roadways and pavements where RCG is used in road and pavement materials, or pipe bedding materials.
- The limits adopted for the RCG in Table 3.1 should remain unchanged.

Based on the findings of the testing and evaluation indicating RCG is suitable to use in asphalt and pavement applications, the requirements of MRTS36 were developed based on the Transport for New South Wales (TfNSW) QA Specification 3151 *Granulated Glass Aggregate* (TfNSW 2020) and *The Recovered Glass Sand Order 2014* (NSW EPA 2014). These requirements were adapted to Queensland based on local testing and evaluation, outlined in the following sections.

3.1.2 MATERIALS

MRTS36 *Recycled Glass Aggregate* (TMR 2020c) sets out the requirements for RCG aggregate used in road pavements. The material requirements in MRTS36 can be summarised as follows:

- RCG aggregate shall be:
  - of nominal size 5 mm or less
  - produced from food and beverage containers
  - processed to a consistent gradation.
  - cubical in shape, not sharp edged or elongated
  - essentially free of contaminants such as ceramics, glass from other sources (such as cathode ray tubes, fluorescent light fittings and laboratory glassware), paper, cork, metals (including heavy metals), brick, plaster, plastic, rubber, wood, clay, paint and other deleterious materials
  - free from any putrid odour.
- Must not exceed the maximum allowable concentration limits for chemicals and other attributes, as summarised in Table 3.1.

Table 3.1: RCG aggregate maximum concentration limits for chemicals and other attributes

Chemicals and other attributes	Maximum average concentration for characterisation	Absolute maximum concentration
	Units in mg/kg 'dry weight' unless otherwise stated	
Mercury	0.5	1.0
Cadmium	0.5	1.5
Lead	50	100
Arsenic	10	20
Chromium (total)	20	40
Copper	40	120
Molybdenum	5	10
Nickel	10	20
Zinc	100	300
Total organic carbon	1.0%	2.0%
Electrical conductivity	1 dS/m or 1000 µS/cm	2 dS/m or 2000 µS/cm

Source: TMR (2020c).

3.1.3 SAMPLING AND TESTING

The contractor must, as a minimum, undertake testing for the following properties to demonstrate the recycled glass aggregate conforms with the requirements of Clause 6:

- PSD
- material finer than 75 µm
- chemicals and attributes listed in Table 3.1.

A composite sample consisting of five discrete sub-samples of equal size must be used to represent a lot of material. Recycled glass aggregate must be sampled and tested in accordance with the minimum frequencies listed in Table 3.2.

Table 3.2: RCG sampling and testing requirements summary

Number of historical test results for each property	Minimum frequency
< 5	1 per 500 tonnes
≥ 5	1 per 1000 tonnes

Source: TMR (2020c).

3.1.4 QUALITY SYSTEM REQUIREMENTS

Quality system requirements for the RCG aggregate production procedure should be in accordance with MRTS50 *Specific Quality System Requirements* (TMR 2020d) and must be submitted to the TMR administrator at least seven days prior to the commencement of aggregate production for the works. The submission must include the following details:

- target PSD
- source of the RCG
- production plant and methods of controlling the quality of the final product
- procedures for stockpile management and traceability as part of the lot control and as applicable, sub-lot control
- quality control procedures.

3.2 UPDATES TO CURRENT GUIDANCE

3.2.1 MTRS30 ASPHALT

MRTS30 *Asphalt* (TMR 2020a) describes the requirements for asphalt used in road pavements and includes medium duty DGA, heavy duty DGA, open graded asphalt (OGA) and stone mastic asphalt (SMA) mixes. The revisions in MRTS30 are contained within Clause 7.1.3 *Fine Aggregate*, adding the following requirements for the inclusion of RCG in asphalt mixes:

- The proportion of recycled glass fine aggregate shall not exceed the following limits:
  - 2.5% by mass of total mix in the wearing course
  - 10% by mass of total mix in other than the wearing course.
- Recycled glass fine aggregate shall not be used in open graded asphalt.

3.2.2 MRTS101 AGGREGATES FOR ASPHALT

The TMR specification MRTS101 *Aggregates for Asphalt* (TMR 2020e) sets out the requirements for coarse and fine aggregates that are used in asphalt. The changes proposed to existing clauses to permit the use of RCG are summarised in Table 3.3. Additionally, changes to minimum testing frequencies for source rock properties and fine aggregate properties are presented in Table 3.4 and Table 3.5, respectively.

Table 3.3: Revision register for MRTS101

Clause number	Description of revision
7.2 Fine aggregate	Added, 'recycled glass aggregate' to allowed fine aggregate materials.
	Added, 'In addition, recycled glass aggregate must also conform with the requirements of MRTS36'.
8.1 Submission of details of nominated aggregates to the Asphalt Mix Design Register	Added, 'Recycled glass aggregate production procedure (refer section 8.3) and aggregate test results from a production trial by the plant from which the aggregate will be produced'.
9 Material conformance	Added, 'For recycled glass aggregate sources, the conformance with this Technical Specification and MRTS36 Recycled Glass Aggregate shall be verified by sampling and testing and providing records of process control'.
9.3.1.3 Fine aggregate	Added, 'for recycled glass aggregate sources that are not registered and operated in accordance with the TMR QRS requirements, testing frequencies shall comply with the requirements of Table 9.3.1(a) (Table 3.4)'. Added, Table 9.3.1(b) outlining the minimum testing frequencies for test properties of recycled glass aggregate sources that are not TMR registered sources, as presented in Table 3.5.

Table 3.4: Minimum testing frequencies for source rock test properties of natural sand and recycled glass aggregate sources that are not TMR registered sources

Property	Test method	Minimum frequency of testing
Petrographic analysis[1]	ASTM C295	1 per 6 months
Water absorption	AS 1141.5	1 per 5000 tonnes
Particle density dry basis	AS 1141.5	
Aggregate soundness (total weighted percent loss)[1]	AS 1141.11.1	

Note: 1. Testing of this property is not required for recycled glass.

Source: TMR (2020e).

Table 3.5: Minimum testing frequencies for fine aggregate and recycled glass aggregate product tests

Property	Test method	Minimum frequency of testing
Particle size distribution	AS 1141.11.1	1 per 1000 tonnes or 1 per 500 tonnes for recycled glass aggregate where there are less than 5 test results available for the product
Materials finer than 75 µm	AS 1141.12	

Source: TMR (2020e).

3.2.3 TECHNICAL NOTE 148 ASPHALT MIX DESIGN REGISTRATION

Technical Note (TN) 148 *Asphalt Design Registration* (TMR 2020f) contains guidance to assist prequalified asphalt contractors (PAC) with registering mix designs in accordance with TMR requirements. Relative to RCG, Table 3.6 summarises the changes proposed to existing clauses to permit the inclusion of RCG in asphalt mixes.

Table 3.6: Revision register for TN148

Clause number	Description of revision/addition
3.1.1.1 Asphalt mix design submission requirements	Added, 'recycled glass aggregate production procedure (where applicable)'.
3.4.3 Material sources	Added, 'recycled glass aggregate sources: the company name followed by the location in brackets, for example – Enviro Sand (Pinkenba)'.

4 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The objective of the second year of the multi-year project was to investigate the performance of an asphalt mix containing up to 10% RCG by mass, evaluate the variability of RCG sourced from suppliers throughout Queensland and facilitate the increased use of RCG by developing new, and updating current specifications. The following are the key outcomes:

- Up to 10% RCG may be incorporated into asphalt intermediate layers without detrimentally impacting performance.
- Testing of recycled glass suppliers in Queensland indicates suppliers can produce a consistent product appropriate for use in asphalt and unbound pavement layers.
- Due to the low crystalline silica contents, there are likely no significant long-term adverse health risks (such as silicosis) associated with RCG usage.
- There are no concerns in relation to environmental harm or human health and safety when RCG meeting the proposed environmental specification limits is used in asphalt (up to 10% by mass), unbound granular pavement materials (up to 20% by mass) or pipe bedding materials (up to 100% by mass).
- MRTS36 *Recycled Glass Aggregate* was compiled and specifies the requirements for the use of RCG in asphalt and unbound granular applications. MRTS30 *Asphalt,* MRTS101 *Aggregates for Asphalt,* Technical Note 148 *Asphalt Mix Design Registration, MRTS04 General Earthworks and MRTS05 Unbound Pavements* updates to allow RCG in accordance with MRTS36.

It is recommended that the third year of the project includes the following:

- undertaking a demonstration project to assess the suitability of incorporating up to 5% RCG in an asphalt surfacing layer, which may evaluate the following parameters:
  - visual condition
  - skid resistance testing
  - assessing the level of reflectivity/glare from the surface
  - long-term performance
- identifying sites utilising RCG in wearing courses and conduct of inspections on identified sites
- disseminating the findings through the development of a technical note on the performance of asphalt containing RCG, conducting knowledge transfer workshops as well as webinars and training for the industry and government staff.

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Transport for New South Wales 2020, *Granulated glass aggregate,* QA Specification 3151, TfNSW, Sydney, NSW.

Australian Standards

AS/NZS 2891.13.1, *Methods of sampling and testing asphalt: determination of the resilient modulus of asphalt – indirect tensile method.*

APPENDIX A TESTING AND EVALUATION OF GLASS PROPERTY VARIATION

A.1 VARIABILITY OF PROCESSED RCG BETWEEN SUPPLIERS

To measure the variability of RCG produced in Queensland, several suppliers throughout the state provided RCG samples. This included nine RCG samples collected from five suppliers geographically spread throughout Queensland. Samples were obtained over approximately a six-month period from late-2019 to mid-2020. A representative sample of RCG from the processed stockpile was requested.

The sampling was undertaken in three rounds, where the first round included nine samples from various suppliers. Testing included PSD, sugar testing, petrographic analysis, and chemical analysis. The second and third round of testing was conducted on samples of interest, selected from the results of the first round of testing.

A.1.1 PARTICLE SIZE DISTRIBUTION

The PSD for the first round of sampling is depicted in Figure A.1 while the second and third rounds of sampling PSD results are presented in Figure A.2. Additionally, supplementary RCG results from two suppliers for testing conducted separate to this project is presented in Figure A.3. The only particle size requirement for RCG in the current draft TMR specifications states that the RCG must be crushed to a nominal size of 5 mm, which is reflected in all the results included in this report.

Figure A.1 Round 1 PSD summary

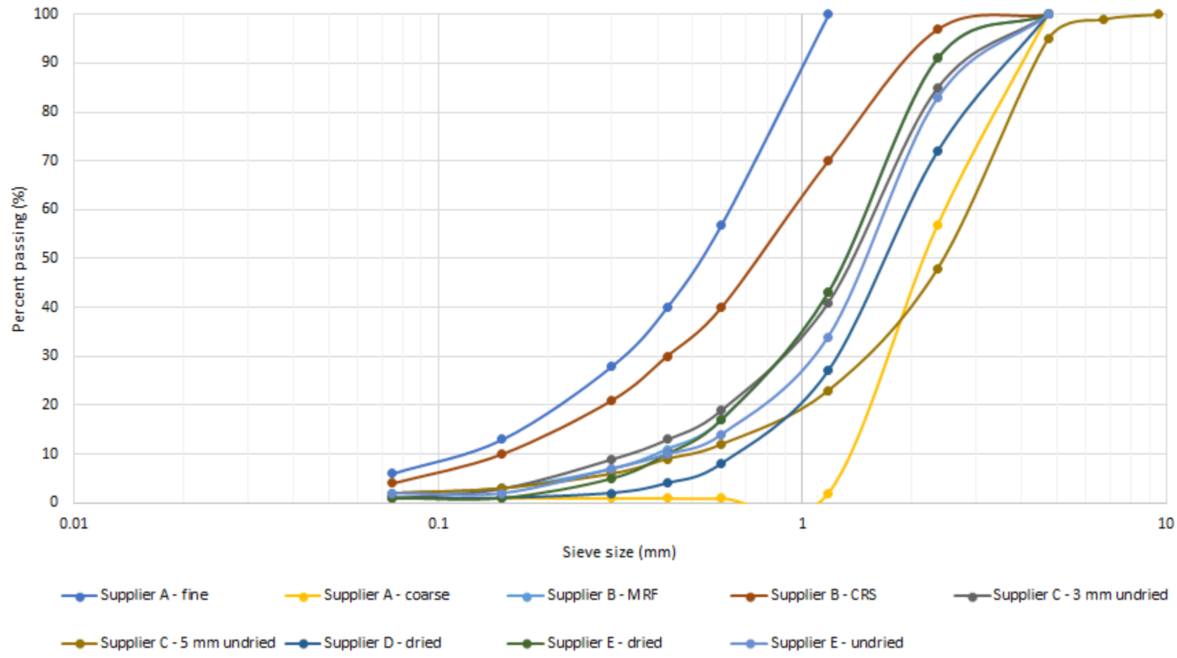


Figure A.2 Rounds 2 and 3 PSD summary

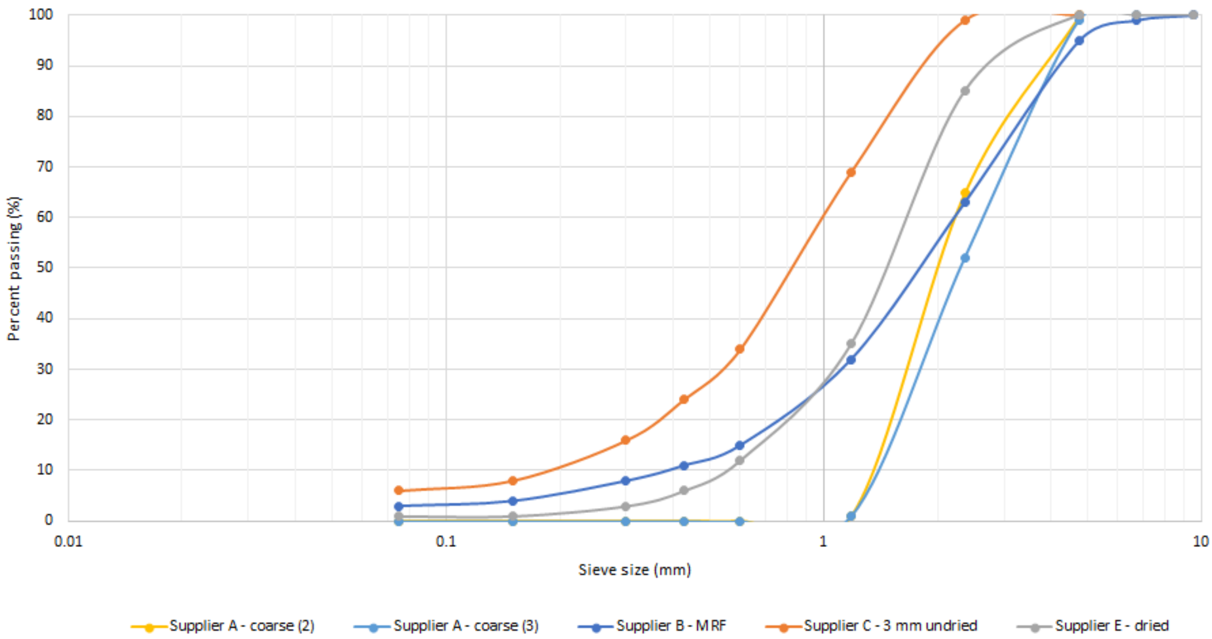
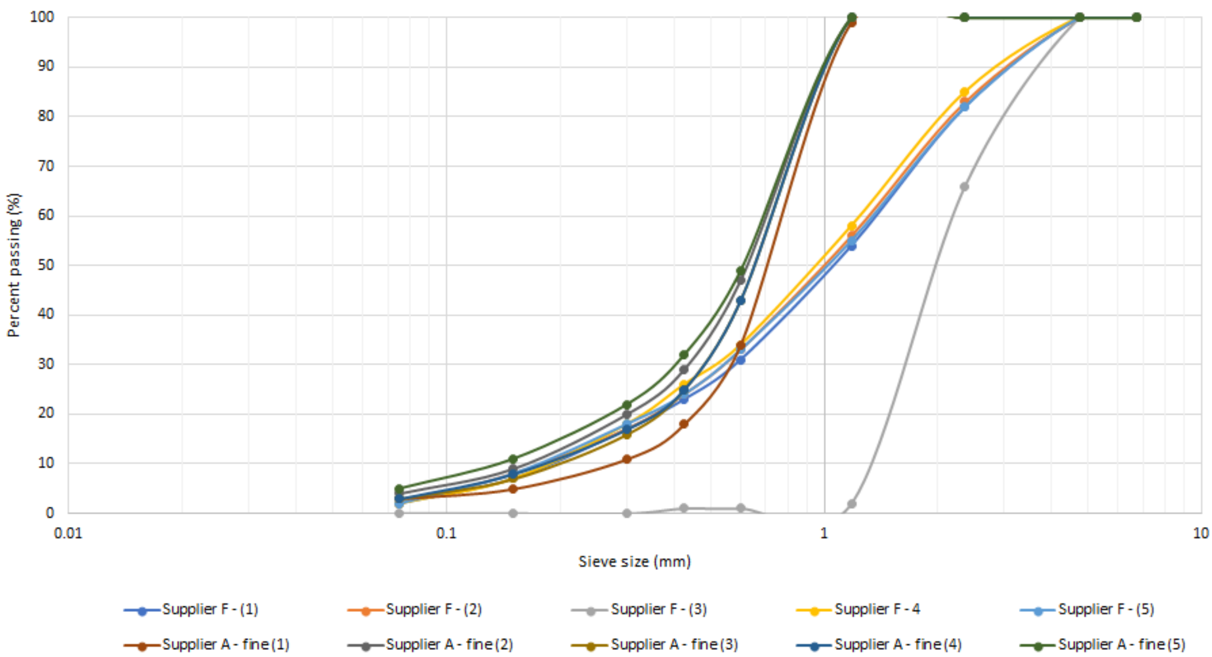


Figure A.3 Supplementary sample PSD summary



A.1.2 PETROGRAPHIC ANALYSIS

The petrographic analysis results of the first and second rounds of sampling are summarised in Table A.1 and Table A.2, respectively. This analysis was undertaken to measure the variability of RCG produced in Queensland relative to the amorphous and crystalline silica content. Following the second round of testing the results were evaluated and compared against both natural sand and manufactured sand and it was deemed that sufficient samples had been tested to ensure RCG did not pose an increased risk of exposure to respirable crystalline silica.

The petrographic results analysis is discussed further in the *Recycled Crushed Glass in the Road Industry – Risk of Silicosis* position paper, presented in Appendix B.

Table A.1: Round 1 RCG petrographic analysis

Description	Supplier A (fine)	Supplier A (coarse)	Supplier B (MRF)	Supplier B (CRS)	Supplier C – 3 mm (undried)	Supplier C – 5 mm (undried)	Supplier D (undried)	Supplier E (dried)	Supplier E (undried)
Primary minerals									
Manufactured glass fragments	99%	99%	97%	98%	88%	90%	95%	93%	77%
Quartz as single free, unstrained to mildly strained grains	<1%	Trace	1%	2%	<1%	<1%	<1%	<1%	3%
Feldspar	<1%	–	–	–	<1%	<1%	–	1%	1%
Carbonaceous plant matter	<1%	1%	1%	<1%	4%	4%	–	2%	3%
Carbonate fragments	<1%	–	1%	<1%	3%	1%	<1%	1%	–
Carbonate fragments	–	–	–	–	–	–	–	–	<1%
Carbonated cemented sandstone	–	–	–	–	–	1%	2%	–	–
Chloritized fragments	<1%	–	<1%	–	1%	–	2%	–	–
Clay cemented fragments	–	–	–	–	–	–	–	–	<1%
Clay cemented quartz	–	–	–	<1%	–	–	–	–	–
Clay cemented quartz fragments (<1% quartz)	<1%	–	–	–	<1%	<1%	–	–	–
Lithic clasts of basalt	–	–	–	–	–	3%	<1%	–	–
Lithic clasts of chert	–	–	–	–	–	–	–	–	<1%
Lithic clasts of chert (1% finely microcrystalline quartz)	–	–	–	–	–	–	–	1%	–
Lithic clasts of granite	–	–	–	–	<1%	1%	–	–	–
Lithic clasts of granite (3% quartz)	–	–	–	–	–	–	–	–	7%
Lithic clasts of granitoid rock	–	–	–	–	–	–	–	–	–
Lithic clasts of intermediate volcanics	–	–	–	–	–	–	–	–	2%

Description	Supplier A (fine)	Supplier A (coarse)	Supplier B (MRF)	Supplier B (CRS)	Supplier C – 3 mm (undried)	Supplier C – 5 mm (undried)	Supplier D (undried)	Supplier E (dried)	Supplier E (undried)
Lithic clasts of iron-stained limestone	–	–	–	–	–	–	<1%	–	–
Lithic clasts of limestone	–	–	–	–	3%	–	–	–	–
Lithic clasts of quartzite	–	–	–	–	<1%	–	–	–	2%
Lithic clasts of rhyolite	–	–	–	–	–	–	–	–	2%
Lithic clasts of silicified siltstone (<1% quartz)	<1%	–	<1%	–	<1%	<1%	1%	1%	–
Lithic clasts of silicified siltstone (1% finely microcrystalline quartz)	–	–	–	–	–	–	–	–	3%
Lithic clasts of unknown rock	–	Trace	–	–	–	–	–	–	–
Lithic clasts of acid volcanic/tuffaceous rock (<1% quartz)	–	–	–	–	–	–	–	1%	<1%
Mica	–	–	–	–	1%	<1%	–	–	–
Plastic fragments	–	–	–	–	–	–	–	–	Trace
Free silica content									
Amorphous silica	99%	99%	97%	98%	88%	90%	95%	93%	77%
Free silica content of the sand	<1%	<1%	1%	2%	<1%	<1%	<1%	1%	9%

Note: MRF = materials recovery facility, CRS = container refund scheme feed material.

Table A.2: Round 2 RCG petrographic analysis

Supplier	Supplier A (coarse)	Supplier B (CRS)	Supplier C – 3 mm (undried)
Primary minerals			
Manufactured glass fragments	91%	98%	32%
Quartz as single free, unstrained to mildly strained grains	Trace	<1%	<1%
Quartzite	2%	–	–
Feldspar	–	–	<1%
Carbonaceous plant matter	1%	1%	3%
Carbonate fragments	–	<1%	1%
Chloritized fragments	–	–	1%
Clay cemented quartz	–	1%	
Clay cemented quartz fragments (<1% quartz)	–	–	<1%
Lithic clasts biotite schist	3%	–	
Lithic clasts of granite	–	–	<1%
Lithic clasts of limestone	–	–	1%
Lithic clasts of quartzite	–	–	<1%
Lithic clasts of silcrete	3%	–	–
Lithic clasts of silicified siltstone (<1% quartz)	–	–	2%
Mica	–	–	<1%
Free silica content			
Amorphous silica	91%	92%	98%
Free silica content of the sample	5%	<1%	1%

Note: CRS = container refund scheme feed material.

A.1.3 CHEMICAL ANALYSIS

The chemical analysis results for round one are summarised in Table A.3, showing two non-conformances highlighted in red while the results for the second and third rounds of sampling are presented in Table A.4. It is important to note that the first round of testing only included testing against the NSW EPA criteria adopted by TMR (Table 3.1) as well as leachate testing on contaminants identified to be at comparatively high levels. The second and third rounds of testing were undertaken with an increased scope to include hydrocarbons and phenols which may adversely affect the surrounding environment if present in the RCG and used in road construction.

These test results were used to inform the suitability of RCG for use in asphalt and unbound granular materials, as discussed in Appendix A.2.

Table A.3: Round 1 chemical results summary

Property	Absolute max.	Supplier A (fine)	Supplier A (coarse)	Supplier B (MRF)	Supplier B (CRS)	Supplier C – 3 mm (undried)	Supplier C – 5 mm (undried)	Supplier D (undried)	Supplier E (dried)	Supplier E (undried)
Conductivity, uS/cm	2000	220	37	160	150	330	460	260	530	520
Total organic carbon, %	2	0.3	<0.1	0.3	0.2	0.6	0.7	1	0.7	1.6
Moisture, %	–	<1	<1	<1	<1	1.6	1.1	<1	<1	1.3
Heavy metals										
Arsenic, mg/kg	20	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cadmium, mg/kg	1.5	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Chromium, mg/kg	40	<5	<5	<5	<5	<5	5.3	11	<5	<5
Copper, mg/kg	120	33	<5	<5	<5	11	5.3	5.3	41	7.9
Lead, mg/kg	100	26	<5	<5	<5	120	97	19	32	2000
Mercury, mg/kg	1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum, mg/kg	10	<5	<5	<5	<5	<5	<5	9.4	<5	<5
Nickel, mg/kg	20	<5	<5	<5	<5	<5	<5	<5	<5	<5
Zinc, mg/kg	300	43	<5	31	96	98	250	57	41	87
Leachate pH 5.0										
Chromium, mg/L	–	–	–	–	–	–	<0.01	<0.01	–	–
Copper, mg/L	–	0.2	–	–	–	0.06	0.02	0.02	0.03	0.04
Lead, mg/L	–	0.75	–	–	–	0.22	0.12	0.41	0.34	9.3
Molybdenum, mg/L	–	–	–	–	–	–	–	<0.01	–	–
Zinc, mg/L	–	1.8	–	1.3	3.6	1.9	1.7	2.2	1.3	1.8
Leachate pH 9.2										
Chromium, mg/L	–	–	–	–	–	–	<0.01	<0.01	–	–
Copper, mg/L	–	0.13	–	–	–	0.05	0.03	0.03	0.03	0.06
Lead, mg/L	–	0.03	–	–	–	0.03	0.04	0.08	0.09	0.69
Molybdenum, mg/L	–	–	–	–	–	–	–	<0.05	–	–
Zinc, mg/L	–	0.09	–	0.04	0.01	0.1	0.07	0.05	0.07	0.07
Foreign materials – Type I										
Metal, %	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Glass, %	–	100	100	100	100	100	100	100	100	100

Property	Absolute max.	Supplier A (fine)	Supplier A (coarse)	Supplier B (MRF)	Supplier B (CRS)	Supplier C – 3 mm (undried)	Supplier C – 5 mm (undried)	Supplier D (undried)	Supplier E (dried)	Supplier E (undried)
Asphalt, %	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Stone, %	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ceramic and slag (other than blast furnace slag), %	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Foreign materials – Type II										
Plaster, %	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Clay lumps and other friable material, %	0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Foreign materials – Type III										
Rubber, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Plastic, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Bitumen, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Paper, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.26
Cloth, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Paint, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Wood, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Vegetable matter, %	0.5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.16

Table A.4: Round 2 and round 3 chemical results summary

Property	Absolute max.	Supplier A (coarse)	Supplier B (MRF)	Supplier C (undried)	Supplier A (coarse)	Supplier E (dried)
Conductivity, uS/cm	2000	56	370	180	45	390
Total organic carbon, %	2	<0.1	0.5	–	0.2	0.9
Moisture, %	–	<1	2	1.5	<1	<1
Total recoverable hydrocarbons – 1999 NEPM fractions						
TRH C6-C9	–	<20	<20	<20	<20	<20
TRH C10-C14	–	<20	<20	<20	<20	51
TRH C15-C28	–	<50	<50	<50	<50	670
TRH C29-C36	–	<50	<50	<50	<50	160
TRH C10-C36 (Total)	–	<50	<50	<50	<50	881
BTEX						
Benzene	–	<0.1	<0.1	<0.1	<0.1	<0.1
Toluene	–	<0.1	<0.1	<0.1	<0.1	<0.1
Ethylbenzene	–	<0.1	<0.1	<0.1	<0.1	<0.1
m&p-Xylenes	–	<0.2	<0.2	<0.2	<0.2	<0.2
o-Xylene	–	<0.1	<0.1	<0.1	<0.1	<0.1
Xylenes (Total)	–	<0.3	<0.3	<0.3	<0.3	<0.3
4-Bromofluorobenzene (surr.)	–	57	97	112	39	23
Total recoverable hydrocarbons – 2013 NEPM fractions						
Naphthalene (N02)	–	<0.5	<0.5	<0.5	<0.5	<0.5
TRH C6-C10	–	<20	<20	<20	<20	<20
TRH C6-C10 less BTEX (F1) (N04)	–	<20	<20	<20	<20	<20
TRH >C10-C16	–	<50	<50	<50	<50	59
TRH >C10-C16 less naphthalene (F2) (N01)	–	<50	<50	<50	<50	59
TRH >C16-C34	–	<100	<100	<100	<100	750
TRH >C34-C40	–	<100	<100	<100	<100	140
TRH >C10-C40 (total)*	–	<100	<100	<100	<100	949
Polycyclic aromatic hydrocarbons						
Benzo(a)pyrene TEQ (lower bound)*	–	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)pyrene TEQ (medium bound)*	–	0.6	0.6	0.6	0.6	0.6
Benzo(a)pyrene TEQ (upper bound)*	–	1.2	1.2	1.2	1.2	1.2

Property	Absolute max.	Supplier A (coarse)	Supplier B (MRF)	Supplier C (undried)	Supplier A (coarse)	Supplier E (dried)
Acenaphthene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthylene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Benz(a)anthracene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)pyrene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b&j)fluoranthene (N07)	–	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(g.h.i)perylene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(k)fluoranthene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Dibenz(a.h)anthracene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3-cd)pyrene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Naphthalene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene	–	<0.5	<0.5	<0.5	<0.5	<0.5
Total PAH*	–	<0.5	<0.5	<0.5	<0.5	<0.5
2-Fluorobiphenyl (surr.)	–	82	85	89	109	122
p-Terphenyl-d14 (surr.)	–	69	80	80	111	123
Phenols (halogenated)						
2-Chlorophenol	–	<0.5	<0.5	<0.5	<0.5	<0.5
2.4-Dichlorophenol	–	<0.5	<0.5	<0.5	<0.5	<0.5
2.4.5-Trichlorophenol	–	<1	<1	<1	<1	<1
2.4.6-Trichlorophenol	–	<1	<1	<1	<1	<1
2.6-Dicholorophenol	–	<0.5	<0.5	<0.5	<0.5	<0.5
4-Chloro-3-methylphenol	–	<1	<1	<1	<1	<1
Pentachlorophenol	–	<1	<1	<1	<1	<1
Tetrachlorophenols – total	–	<10	<10	<10	<10	<10
Total halogenated phenol*	–	<1	<1	<1	<1	<1
Phenols (non-halogenated)						
2-Cyclohexyl-4.6-dinitrophenol	–	<20	<20	<20	<20	<20
2-Methyl-4.6-dinitrophenol	–	<5	<5	<5	<5	<5
2-Methylphenol (o-Cresol)	–	<0.2	<0.2	<0.2	<0.2	<0.2

Property	Absolute max.	Supplier A (coarse)	Supplier B (MRF)	Supplier C (undried)	Supplier A (coarse)	Supplier E (dried)
2-Nitrophenol	–	<1	<1	<1	<1	<1
2.4-Dimethylphenol	–	<0.5	<0.5	<0.5	<0.5	<0.5
2.4-Dinitrophenol	–	<5	<5	<5	<5	<5
3&4-Methylphenol (m&p-Cresol)	–	<0.4	<0.4	<0.4	<0.4	<0.4
4-Nitrophenol	–	<5	<5	<5	<5	<5
Dinoseb	–	<20	<20	<20	<20	<20
Phenol	–	<0.5	<0.5	<0.5	<0.5	<0.5
Total non-halogenated phenol*	–	<20	<20	<20	<20	<20
Phenol-d6 (surr.)	–	40	68	74	84	88
Heavy metals						
Arsenic	20	<2	<2	<2	<2	<2
Beryllium	–	<2	<2	<2	<5	<5
Boron	–	<20	<20	<20	<10	39
Cadmium	1.5	<0.4	<0.4	<0.4	<0.5	<0.5
Chromium	40	–	–	–	<5	<5
Chromium (hexavalent)	–	<1	<1	<1	<1	<1
Cobalt	–	<5	<5	<5	<5	<5
Copper	120	<5	<5	<5	<5	<5
Lead	100	<5	11	<5	<5	20
Manganese	–	<5	22	<5	<5	17
Mercury	1	<0.1	<0.1	<0.1	<0.1	<0.1
Molybdenum	10	–	–	–	<10	<10
Nickel	20	<5	<5	<5	<5	<5
Selenium		<2	<2	<2	<2	<2
Zinc	300	37	43	58	<5	38
Foreign materials – Type I						
Metal	0.5	<0.1	<0.1	<0.1	<0.1	<0.1
Glass	–	100	72	<0.1	100	100
Asphalt	0.5	<0.1	<0.1	<0.1	<0.1	<0.1
Stone	0.5	<0.1	<0.1	<0.1	<0.1	<0.1
Ceramic and slag (other than BFS)	0.5	<0.1	<0.1	<0.1	<0.1	<0.1
Foreign materials – Type II						
Plaster	0.5	<0.1	<0.1	<0.1	<0.1	<0.1

Property	Absolute max.	Supplier A (coarse)	Supplier B (MRF)	Supplier C (undried)	Supplier A (coarse)	Supplier E (dried)
Clay lumps and other friable material	0.5	<0.1	28	100	<0.1	<0.1
Foreign materials – Type III						
Rubber	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Plastic	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Bitumen	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Paper	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Cloth	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Paint	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Wood	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Vegetable matter	0.5	<0.05	<0.05	<0.05	<0.05	<0.05
Leachate pH 5.0						
Boron	–	–	–	–	–	0.68
Lead	–	–	–	–	–	0.49
Zinc	–	–	–	–	–	2.5
Leachate pH 9.2						
Boron	–	–	–	–	–	N/A
Lead	–	–	–	–	–	0.03
Zinc	–	–	–	–	–	0.05
Leachate reagent water						
Boron	–	–	–	–	–	0.22
Lead	–	–	–	–	–	0.01
Zinc	–	–	–	–	–	0.04

A.2 SUITABILITY OF USAGE

To assess whether using the NSW EPA requirements (Table 3.1) for RCG in asphalt and unbound granular materials is suitable from an environmental perspective, ARRB and TMR engaged an experienced suitably qualified professional (SQP) with appropriate waste characterisation and contaminated land experience. The SQP was provided a supplier-anonymised copy of the RCG chemical analysis and PSD test results.

The advice sought was provided in three main areas:

1. Whether or not aligning TMR's requirements for the use of RCG in asphalt and unbound granular materials with those from the NSW EPA will cause environmental harm if conforming RCG materials are used in up to 10% by mass for asphalt and up to 20% by mass for unbound granular pavement materials.
2. Are the NSW EPA criteria suitable to prevent environmental harm, nuisance, and community health impacts when 100% RCG is used as a drainage or bedding material or in concrete?
3. Are there more optimal criteria that could be adopted or additional requirements that should be included for other applications (e.g. leachate testing)? If so, what are these and how should testing be done (methods, frequencies, limits)?

Relative to the first advice area, the NSW EPA limits adopted by TMR summarised in Table 3.1 were reviewed to ascertain:

- whether these limits had the potential to cause harm to human health where the material may be used in roads and pavements within a residential area
- if these characteristics of RCG had potential to cause harm to the environmental where the material may be used in roads and pavements in any location, which may include locations that are adjacent to an open space, residential or sensitive environment.

The review found that the proposed use of RCG in asphalt and pavement materials would have no issues of concern in relation to risk to human health or to the environment when the RCG meets the proposed NSW EPA specification adopted by TMR (Table 3.1). It is important to note that the review included proportions of up to 10% RCG by mass in asphalt and up to 20% RCG by mass in unbound granular pavement materials.

The findings from the second and third advice areas, evaluating other uses such as pipe bedding or drainage are:

- The characteristics of RCG are consistent with the characteristics expected for natural materials or clean fill, including gravel and sand commonly used in road applications.
- There are no issues of concern in relation to risks to human health, for any location where RCG is used in road/pavement materials or pipe bedding materials may be used.
- There are no issues of concern in relation to potential risks to the environment (terrestrial or aquatic) that may be adjacent to roadways and pavements where RCG is used in road and pavement materials, or pipe bedding materials.
- It is not recommended that the limits adopted for the RCG be modified or refined.

However, if other applications of RCG are proposed that include the use of 100% RCG in unbound materials (i.e. not bound in concrete or asphalt) or beneath sealed surfaces, over large areas (areas greater than 1000 m^2) that may be close to an aquatic environment, further consideration of potential leaching of metals to groundwater or surface water would need to be undertaken. This should include a site-specific assessment.

It was also recommended that the sampling of RCG should continue to include analysis for leaching potential, using an Australian Standard Leachate Potential (ASLP) method (which uses neutral water), for metals such as copper, nickel and zinc so that material-specific soil-water partition coefficients (Kd) can be determined and used in future assessments (where required).

The full environmental assessment report for recycled glass is contained in Appendix C.

APPENDIX B SILICOSIS POSITION PAPER

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Position Paper

P76: Recycled Crushed Glass in the Road Industry – Risk of Silicosis

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Prepared for:	Queensland Department of Transport and Main Roads

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AN INITIATIVE BY:

arrb Queensland Government

SUMMARY

The use of recycled crushed glass (RCG) has been increasing in the road industry due to its economic and environmental benefits. However, there are some health and safety concerns for the general public and workers regarding the increasing use of RCG as aggregate replacement. These concerns include respirable crystalline silica dust causing negative biological effects as a result of inhalation (silicosis), irritation to the skin and eyes as well as the potential for cuts and abrasions from handling the RCG particles.

This study addressed the risk of silicosis associated with RCG through reviewing the available literature relative to the physical and chemical properties of RCG its various applications in the road industry and identifying its hazardous chemical components and the potential risk of exposure to these components. Additionally, a limited laboratory testing evaluation was undertaken to establish the mineral composition of RCG compared to natural sand.

Based on the review, the findings related to the risk of silicosis are as follows:

1. Silicosis is the result of long-term inhalation of respirable crystalline silica particles (less than 10 µm). Respirable crystalline silica is derived from materials containing greater than 1% crystalline silica.
2. Glass manufacturing involves breaking down crystalline silica into the inert amorphous silica. Concentrations of less than 1% crystalline silica are present in glass particles.
3. There is limited research into the long-term exposure of dust generated from the production and application of RCG aggregates. However, it is postulated that due to the low crystalline silica contents there are likely no significant long-term adverse health risks (such as silicosis) associated with RCG usage.
4. The Australian worker exposure limit for respirable crystalline silica dust is 0.05 mg/m^3. This may be measured through determining the percent crystalline silica in the dust over an 8-hour time-weighted average (TWA) using AS 2985 and infrared spectroscopy or XRD analysis.
5. The crystalline silica content of RCG does not typically exceed 1%. Samples tested exceeding 1% crystalline silica are postulated to have been contaminated by foreign materials such as natural sand.
6. Natural sand contains significantly greater proportions of crystalline silica than RCG indicating there may be a reduced risk of exposure to respirable crystalline silica when working with RCG compared to natural sand. However, workplace health and safety controls should still be implemented when working with both RCG and natural sand dust.
7. Manufactured sand may contain greater proportions of crystalline silica than RCG, thus the use of RCG rather than manufactured sand may reduce the potential worker exposure to respirable crystalline silica.

Therefore, based on these conclusions, it is recommended that the use of RCG in pavement applications is permitted, ensuring the appropriate OHS controls are implemented to manage the risks of dust inhalation and manual handling.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

The use of recycled crushed glass (RCG) in the road industry has been increasing due to the economic and environmental benefits of using this product (Leek & Huband 2010). However, there are some possible health and safety concerns regarding the use of RCG in roads. These concerns include the negative biological effects of glass dust as a result of inhalation (known as silicosis), ingestion, contact with skin and eyes, as well as the potential for cuts and abrasions from handling the RCG particles.

The literature indicates that when RCG aggregates are crushed to 4.75 mm or less, it pose no significant increase in the risk of injury to construction personnel or the public (Su & Chen 2002). However, perceived health and safety concerns include the risk of silicosis from glass dust inhalation as a result of crushing the RCG particles to below 4.75 mm for both the public and construction personnel.

This paper presents a brief review, focussing on the risks of silicosis as a result of glass dust inhalation, relative to the following:

1. Is there an occupational health and safety (OHS) risk of silicosis when using RCG as a replacement for natural aggregate in road construction?
2. How can any related health risks be minimised and controlled?
3. What is the mineral composition of RCG compared to natural sand?

2 THE APPLICATION OF RCG IN THE ROAD INDUSTRY

Approximately 850 000 tonnes of glass are consumed in Australia each year, with 350 000 tonnes recovered for recycling (Austroads 2009). In November 2018, the Queensland Government introduced a container refund scheme (CRS), increasing the amount of glass available for recycling. The reuse of glass in road infrastructure (Figure 2.1) has been identified as one of several possible high value uses for these materials (Mohajerani et al. 2017).

Figure 2.1: Recycled crushed glass aggregates

Source: ABC (2017).

Several road jurisdictions in Australia and internationally already allow for limited amounts of RCG in road infrastructure, as well as the structural and surfacing layers of roads. Road infrastructure applications that could use RCG as a partial or complete virgin material replacement include (Nash et al. 1995):

1. embankments (up to 20% by mass)
2. flexible pavement base materials (up to 20% by mass)
3. asphalt pavement layer materials (up to 5% by mass)
4. pipe bedding (up to 100% by mass)
5. backfill for structures, roadbeds and retaining walls (up to 20% for structural support and 100% for non-structural applications).

Despite the high capacity and benefit of using RCG as a virgin aggregate replacement (by specific percentage) in road infrastructure, there are some concerns about the possible silicosis OHS risks to the public and construction personnel during RCG production and application. This study assesses the possible risk of using RCG by reviewing the relevant publications and highlighting measures to manage the possible risks.

3 HEALTH RISKS OF UTILISING RCG IN ROAD MATERIALS

To assess the OHS risk of silicosis when using RCG, a review has been done on the type, size, and chemical components of this recycled product, identifying the possible risks to human health. The risk of generating hazardous material in each stage, from RCG production to road construction, has also been assessed by reviewing the hazards in similar fields such as mining, glass and asphalt production.

3.1 RECYCLED CRUSHED GLASS TYPE AND SIZE

Recycled glass is produced primarily from container glass and glass pieces collected through municipal and industrial waste steams which is then crushed into small particles that may show geotechnical properties resembling natural gravels and sand (Disfani 2011). This crushed glass typically requires colour sorting and contaminant cleaning to meet applicable standards for recycling back into container glass or fibre glass manufacture, thus increasing the cost of recycling (Ali 2012), while the smaller-size mixed coloured glass and plate glass are commonly sent to landfill as a wasted resource (Sicoe & Leek 2011). However, RCG used in pavement construction would not require sorting by colour and could be crushed immediately, thus decreasing the cost of RCG (Ali 2012).

To minimise the risk of skin cuts, abrasions and tyre punctures, RCG is typically crushed to a maximum particle size of 4.75 mm (AASHTO 2015; Huang et al. 2007). The RCG aggregates passing the 4.75 mm sieve have the potential to be an adequate virgin aggregate replacement in base and subbase applications (to 30% by mass), as well as in asphalt applications (up to 10–15%) (Mohajerani et al. 2017).

3.2 CHEMICAL COMPONENTS OF RCG

RCGs can have different chemical components depending on its origin and application. Ordinary glazing and container glass constitute the primary source of RCG and is normally formed from a specific type called soda-lime glass, composed of approximately 75% silicon dioxide (SiO_2), sodium oxide (Na_2O) from sodium carbonate (Na_2CO^3), calcium oxide (CaO), also called lime, and several other minor additives (El Khiati et al. 2000). This indicates that silicon dioxide (silica) forms by far the highest percentage of the RCG aggregates.

The physical and toxicological properties of silica depend on the molecular structure of the chemical components, most commonly occurring in the following forms:

- Crystalline silica – silicon dioxide molecules are arranged in a repetitive pattern that has unique spacing, lattice structure and angular relationships. In nature, quartz is the crystalline form most commonly encountered and is so abundant that the term quartz is often used in place of crystalline silica. Quartz is present in most rocks, soils and sand (Key-Schwartz et al. 2003). The chemical components of crystalline silica include quartz, cristobalite and tridymite (US OSHA 2019).
- Amorphous silica-silicon dioxide molecules are randomly arranged. Naturally occurring amorphous silica is present in flint and opal. Amorphous silica may also be produced synthetically by breaking down the crystalline structure of quartz sand through chemical or thermal treatments producing an extremely fine material comprised of amorphous silicon dioxide (Graf 2018).

Based on sufficient evidence of carcinogenicity from studies in humans, the toxic form of silica in its respirable form is crystalline silica, which in 1991 was first associated with elevating the rate of lung cancer in humans (National Toxicology Program 2016). Respirable particles are those that can penetrate the airways of the respiratory system with a particle size less than 10 µm and when inhaled, lung tissue reacts by developing fibrous tissue around the silica particles which over prolonged exposure reduces the ability of oxygen to be absorbed into the body (Winder 2011). This effect is known as silicosis and is irreversible (Department of Justice and Attorney General, Workplace Health and Safety Queensland 2013). Silicosis may be present as three types, varying with the exposure and time (Madl et al. 2010):

- Acute – may develop within weeks to years of very heavy exposure to silica. The lungs are filled with a fluid containing a lot of protein, which causes severe breathlessness.
- Chronic – the most common form of silicosis, forming slowly after 10 years or more of low to moderate silica exposure.
- Accelerated – can develop after exposures of 5–10 years from moderate to high levels of silica dust and causes inflammation, protein in the lung and scarring of the lung.

Dust from materials containing greater than 1% crystalline silica is classified as toxic, such as silica sand or quartz sand (Shin & Sonntag 1994). It is important to note that human cancer risks are associated with exposure to crystalline silica but not to amorphous silica (National Toxicology Program 2016).

Glass is the product of molten crystalline silica (as well as other ingredients) which has been bound into the glass matrix without any regular crystal structure, in a form of amorphous silica (Winder 2011). Bulk sample testing of glass dust samples showed that crystalline silica was present in concentrations of less than 1%, placing glass dust in the nuisance category according to the US federal regulations (Shin & Sonntag 1994; US National Library of Medicine n.d.).

3.3 POSSIBLE SHORT- AND LONG-TERM HEALTH IMPACTS OF EXPOSURE TO RCG

In general, there are two possible hazards associated with handling and processing various types of aggregate, including RCG:

1. Risk of cuts or abrasions – studies show that working with RCG has a risk of cuts or abrasions. However, RCG aggregates smaller than 19 mm present no greater risk in terms of cuts or abrasions than conventional aggregates of the same size (AASHTO 2015; Huang et al. 2007). It is acknowledged that simple methods can minimise these minor hazards including the use of personal protective equipment (PPE) (GHD 2008).
2. Risk of biological effects (respiratory disease symptoms and eye and skin dermatoses) as a result of inhalation or ingestion of crystalline silica dust (Figure 3.1). Crystalline silica may be found in stone, rock, gravel and clay, as well as bricks, tiles, concrete, glass and some plastic materials (Department of Justice and Attorney General, Workplace Health and Safety Queensland 2013). When these materials are worked on (cutting, grinding or drilling these materials on a construction site), crystalline silica is released as a fine, respirable dust. Prolonged exposure to respirable crystalline silica can increase the risk of developing lung cancer, respiratory disease symptoms (such as silicosis) as well as eye and skin dermatoses (Ugbogu et al. 2009).

Figure 3.1: Silica dust particles close-up (left) and airborne particles during mining operations (right)

Source: HealthTimes (2017) (left) and Matta (2017) (right).

3.3.1 SHORT-TERM EXPOSURE

The glass crushing process required to produce RCG aggregates of suitable size will generate dust, although only as a small proportion of the total particulates. Furthermore, this dust will comprise an amorphous silica structure (> 99%) rather than crystalline (< 1%) and the concentration of respirable crystalline silica dust will be undetectable and, as such, eliminating construction personnel exposure to crystalline silica (Winder 2011). The density of RCG particles (2.2–2.5 g/cm^3) is greater than that of sand (1.8 g/cm^3), meaning they are proportionally heavier and will fall out of the air quicker than sand particles, further limiting exposure.

In a trial conducted by the NSW Department of Environment and Climate Change (DECC) in 2007 where 100% RCG was used as a pipe-bedding material, construction workers experienced no issues with odour, skin contact or dust and found it to have similar characteristics to natural sand (DECC 2007). Fulton (2008) documented similar responses from construction crews regarding the use of granular materials incorporating 5% RCG in New Zealand.

It is shown in the two practical applications with exposure to RCG, the workers experienced no issues in the short-term with this material. However, the long-term health effects and the short-term effects in specific projects, where this material must be heated (such as an asphalt plant) or must mix with lime or cement (used in stabilisation process), remained unanswered.

3.3.2 LONG-TERM EXPOSURE

There is limited research into the long-term effects of exposure to dust generated from the production and application of RCG aggregates in road infrastructure. However, it is postulated that due to the low crystalline silica content there are no significant long-term adverse health risks compared to the risks of silicosis associated with exposure to respirable crystalline silica.

The Safe Work Australia Workplace Exposure Standard for worker exposure to respirable crystalline silica is currently 0.05 mg/m^3 as an 8-hour time-weighted average (TWA) (Safe Work Australia 2019). This limit is recommended to protect workers from fibrosis and silicosis, thus minimising the risk of lung cancer. Engineering and work practice controls can ensure construction personnel exposure is maintained below this limit.

In general, this review shows that there are minimal risks of silicosis associated with the use of RCG aggregates due to crystalline silica dust exposure based on the molecular structure and chemical composition of glass. However, increasing the use of RCG in road infrastructure, especially in unsealed and asphalt roads may necessitate undertaking additional OHS testing to determine the health risk for the public and workers in the following roadwork procedures (especially for the procedure involved heating, milling and stabilising the material which involves dust and fume generation):

- RCG production and stockpiling
- asphalt production
- asphalt paving
- in-place milling and recycling
- in-service – especially for unsealed roads which generate dust during traffic.

It is important to note that due to the percentages used and the breakdown rate of aggregates during asphalt production, paving, milling and in-service there is likely a negligible OHS risk. Additionally, the melting point of glass is above 1000 °C and, as such, fume generation due to heating will also likely be negligible.

4 MEASURES TO CONTROL THE RISKS OF USING RCG

4.1 MEASURING THE EXPOSURE LIMIT

Lung cancer, silicosis and chronic obstructive pulmonary disease can result from exposure to respirable crystalline silica dust. Section 49 of the WHS Regulation (Queensland) specifies that air monitoring must be conducted to determine whether there is a risk to a worker's health, or if there is any uncertainty that the exposure standard is being exceeded.

The process for collecting an air sample to measure airborne silica in accordance with AS 2985 *Workplace Atmospheres – Method of Sampling and Gravimetric Determination of Respirable Dust* (Standards Australia international 2009) is as follows:

- A worker will wear a device called a vertical cyclone elutriator on the shirt lapel for a period of 6–8 hours during the work shift, within the workers breathing zone (300 mm of the nose or mouth).
- Air is drawn through the sampling device by a small, portable, battery-powered pump in which the vertical elutriator separates out the respirable fraction of the dust which corresponds to that fraction of a dust cloud that will penetrate to the alveolar oxygen exchange part of a human lung.
- Sampled dust may then be assessed for its respirable dust concentration and respirable crystalline silica concentration by infrared spectroscopy or X-ray diffraction (XRD) analysis.

By performing this procedure, it is possible to identify and monitor the risk to health for construction personnel. If the exposure limit is exceeded, additional engineering controls and work practices will need to be implemented to reduce exposure to respirable crystalline silica as low as is reasonably practicable.

4.2 OHS CONTROLS

The Safe Work Australia Code of Practice *Managing Risks of Hazardous Chemicals in the Workplace* (Safe Work Australia 2018) details the hierarchy of controls. Those of most importance to workplaces with potential respirable crystalline silica exposure are, in order:

- elimination
- substitution – using silica replacements, changing from dry to wet processes, vacuuming rather than sweeping
- engineering controls – such as isolating the areas of risk, enclosing the dust, wetting down the dust at the point of generation and installing dust collection system onto machines
- administrative controls – such as improving work practices to increase awareness about operations that can leads to respirable crystalline silica exposure, restricting time of exposure and rotating of staff away from dusty areas
- respiratory protection – including the use PPE such as respirators and masks for short-term applications and when higher-order controls have been applied but cannot fully control the risk.

5 LABORATORY EVALUATION

The mineralogical and chemical characteristics of rocks can be investigated using petrographic analysis. Petrographic analysis can be used both qualitatively and quantitatively in mineralogical analysis to identify the mineral composition in a rock mixture, establish the presence of defects such as cleavage and twinned zones and determine the mineral's physical properties such as optical characteristics and colour (Edwards 2013).

To measure the variability of RCG produced in Queensland relative to the amorphous and crystalline silica content, several suppliers through the state provided RCG samples. This included nine RCG samples collected from five suppliers in Queensland, one in Brisbane, Cairns, Mackay, Rockhampton and Townsville. Samples were obtained over approximately a six-month period from late-2019 to mid-2020. A representative sample of RCG from the processed stockpile was requested for testing using petrographic analysis in two rounds, where the first round included nine samples from various suppliers. The second round of testing was conducted on samples of interest, selected from the first-round results. These results were compared to petrographic analysis conducted on natural sands.

The approximate average composition of the tested samples is summarised in Table 5.1, Table 5.2, Table 5.3 and Table 5.4 for the RCG Round 1, RCG Round 2 and natural sand samples, respectively.

The Round 1 results (Table 5.1) show that with the exception of Supplier B (container refund scheme feed material (CRS)) (2%) and Supplier E undried (9%), the RCG samples did not contain greater than 1% free silica content. The free silica content (or total quartz plus chert content) of the sand, comprises quartz as free grains or locked within lithic clasts. It is postulated that both samples exceeding the 1% free silica expected value were caused by the presence of foreign particles such as natural sand. This is supported by the quartz as a single free, unstrained to mildly strained grain content of 2% for Suppler B CRS and 3% for Supplier E undried which does not exceed 1% in any of the other Round 1 samples. Additionally, Supplier E undried also contains a number of other minerals not present in other samples, including 7% lithic clasts of granite, 2% lithic clasts of volcanics, 2% lithic clasts of quartzite, 2% lithic clasts of rhyolite and 3% lithic clasts of silicified sandstone.

The results of the Round 2 RCG petrographic analysis, summarised in Table 5.2 showed that only Supplier A (coarse) exceeds the 1% expected free silica content. However, similar to the Round 1 RCG results it is postulated that the exceedance is caused by foreign materials in the RCG sample. This is supported by the presence of 2% quartzite, 3% lithic clasts of silcrete and 3% lithic clasts biotite schist present in Supplier A (coarse) and not present in the other Round 2 samples.

The petrographic analysis results from the natural sand samples summarised in Table 5.3 show the relatively large proportions of free silica content present in natural sand, ranging from 36% to 98%. This shows that the free silica content (crystalline silica) is significantly higher in natural sand than RCG, indicating there may be a reduced risk of exposure to respirable crystalline silica when working with RCG compared to natural sand. However, workplace OHS controls, such as those summarised in Section 4.2 should still be implemented when working with both RCG and natural sand dust.

Additionally, Table 5.4 presents the petrographic analysis results from two manufactured sand suppliers in Queensland. Compared to the RCG this shows that the sample from Supplier 1 has less than 1% crystalline silica, similar to RCG while the sample from Supplier 2 has approximately 5% crystalline silica. This indicates, although based on limited samples, that the use of RCG may reduce the potential worker exposure to respirable crystalline silica.

Table 5.1: Round 1 RCG petrographic analysis

Description	A (fine)	A (coarse)	B (MRF)	B (CRS)	C – 3 mm (undried)	C – 5 mm (undried)	D (undried)	E (dried)	E (undried)
Primary minerals									
Manufactured glass fragments	99%	99%	97%	98%	88%	90%	95%	93%	77%
Quartz as single free, unstrained to mildly strained grains	<1%	Trace	1%	2%	<1%	<1%	<1%	<1%	3%
Feldspar	<1%	–	–	–	<1%	<1%	–	1%	1%
Carbonaceous plant matter	<1%	1%	1%	<1%	4%	4%	–	2%	3%
Carbonate fragments	<1%	–	1%	<1%	3%	1%	<1%	1%	–
Carbonate fragments	–	–	–	–	–	–	–	–	<1%
Carbonated cemented sandstone	–	–	–	–	–	1%	2%	–	–
Chloritized fragments	<1%	–	<1%	–	1%	–	2%	–	–
Clay cemented fragments	–	–	–	–	–	–	–	–	<1%
Clay cemented quartz	–	–	–	<1%	–	–	–	–	–
Clay cemented quartz fragments (<1% quartz)	<1%	–	–	–	<1%	<1%	–	–	–
Lithic clasts of basalt	–	–	–	–	–	3%	<1%	–	–
Lithic clasts of chert	–	–	–	–	–	–	–	–	<1%
Lithic clasts of chert (1% finely microcrystalline quartz)	–	–	–	–	–	–	–	1%	–
Lithic clasts of granite	–	–	–	–	<1%	1%	–	–	–
Lithic clasts of granite (3% quartz)	–	–	–	–	–	–	–	–	7%
Lithic clasts of granitoid rock	–	–	–	–	–	–	–	–	–
Lithic clasts of intermediate volcanics	–	–	–	–	–	–	–	–	2%

Description	A (fine)	A (coarse)	B (MRF)	B (CRS)	C – 3 mm (undried)	C – 5 mm (undried)	D (undried)	E (dried)	E (undried)
Lithic clasts of iron stained limestone	–	–	–	–	–	–	<1%	–	–
Lithic clasts of limestone	–	–	–	–	3%	–	–	–	–
Lithic clasts of quartzite	–	–	–	–	<1%	–	–	–	2%
Lithic clasts of rhyolite	–	–	–	–	–	–	–	–	2%
Lithic clasts of silicified siltstone (<1% quartz)	<1%	–	<1%	–	<1%	<1%	1%	1%	–
Lithic clasts of silicified siltstone (1% finely microcrystalline quartz)	–	–	–	–	–	–	–	–	3%
Lithic clasts of unknown rock	–	Trace	–	–	–	–	–	–	–
Lithic lasts of acid volcanic/tuffaceous rock (<1% quartz)	–	–	–	–	–	–	–	1%	<1%
Mica	–	–	–	–	1%	<1%	–	–	–
Plastic fragments	–	–	–	–	–	–	–	–	Trace
Free silica content									
Amorphous silica	99%	99%	97%	98%	88%	90%	95%	93%	77%
Free silica content of the sand	<1%	<1%	1%	2%	<1%	<1%	<1%	1%	9%

Note: MRF = materials recovery facility, CRS = container refund scheme feed material.

Table 5.2: Round 2 RCG petrographic analysis

Supplier	A (coarse)	B (CRS)	C – 3 mm (undried)
Primary minerals			
Manufactured glass fragments	91%	98%	32%
Quartz as single free, unstrained to mildly strained grains	Trace	<1%	<1%
Quartzite	2%	–	–
Feldspar	–	–	<1%
Carbonaceous plant matter	1%	1%	3%
Carbonate fragments	–	<1%	1%
Chloritized fragments	–	–	1%
Clay cemented quartz	–	1%	
Clay cemented quartz fragments (<1% quartz)	–	–	<1%
Lithic clasts biotite schist	3%	–	
Lithic clasts of granite	–	–	<1%
Lithic clasts of limestone	–	–	1%
Lithic clasts of quartzite	–	–	<1%
Lithic clasts of silcrete	3%	–	–
Lithic clasts of silicified siltstone (<1% quartz)	–	–	2%
Mica	–	–	<1%
Free silica content			
Amorphous silica	91%	92%	98%
Free silica content of the sample	5%	<1%	1%

Note: CRS = container refund scheme feed material.

Table 5.3: Natural sand petrographic analysis

Description	1	2	3	4	5	6	7	8	9	10
Primary minerals										
Quartz as single free, unstrained to mildly strained grains	77%	50%	42%	23%	20%	37%	33%	87%	64%	81%
Quartz, moderately strained	23%	14%	17%	6%	8%	13%	36%		13%	11%
Accessory minerals (hornblende, epidote, hematite and opaque oxides)	–	–	–	<1%	–	–	–	–	–	–
Argillized clast	–	–	–	1%	–	2%	–	–	–	–
Biotite	–	–	–	–	–		3%	–	–	–
Chert	–	–	–	–	–	<1%		–	–	–
Chloritized fragments	–	–	–	–	–	–	–	–	–	Trace
Clay/sericite	–	–	9%	–	–	–	–	–	–	3%
Crystalline composite epidote and quartz fragments	–	–	–	–	5%	–	–	–	–	–
Epidote	–	–	–	–	–	–	3%	–	–	Trace
Epidotized fragments	–	–	–	–	–	–	–		1%	–
Feldspar		17%	9%	10%	32%	6%	13%	1%	6%	1%
Feldspar (few grains are complete kaolinized)	<1%	–	–	–	–	–	–	–	–	1%
Ferruginized fragments	–	–	–	–	1%	–	–	–	<1%	–
Free mica and biotite	–	–	–	<1%	–	–	–	–	–	–
Free mineral grains	–	–	–	–	–	4%	–	–	–	–
Geothite	<1%	–	–	–	–	–	–	–	–	–
Heavily altered basalt/diorite	–	–	–	4%	–	–	–	–	–	–
Hornblende grains	–	–	–	–	2%	–	–	Minor	–	Minor
Iron oxide/hydroxides	–	8%	8%	–	–	–	4%	2%	–	Minor

Description	1	2	3	4	5	6	7	8	9	10
Lithic clasts of acid volcanics	–	–	–	–	1%	5%	–	–	1%	–
Lithic clasts of epidotized rock	–	–	–	3%	–	–	–	–	–	–
Lithic clasts of granite	–	–	–	–	–	–	–	–	4%	–
Lithic clasts of granitoid rock	–	–	–	45%	18%	–	–	–	–	–
Lithic clasts of hornfels	–	–	–		2%	–	–	–	–	–
Lithic clasts of intermediate volcanics	–	–	–	1%	4%	2%	–	–	1%	–
Lithic clasts of iron-stained limestone	–	–	–	–	–	–	–	–	1%	–
Lithic clasts of meta-pelite	–	–	–	–	–	1%	–	–	–	–
Lithic clasts of rhyolite	–	–	–	–	–	–	–	8%	–	–
Lithic clasts of sandstone (<1% quartz)	–	–	–	2%	–	–	–	–	–	–
Lithic clasts of siltstone	–	–	–	–	–	–	–	–	1%	–
Lithic clats of diorite	–	–	–	–	2%	–	–	–	–	–
Lithic clasts of acid volcanic/tuffaceous rock (<1% quartz)	–	–	–	<1%	–	–	–	–	–	–
Meta-arenite (7% quartz (5% moderately strained), 4% feldspar, 6% calcite)	–	–	–	–	–	19%	–	–	–	–
Mica	–	–	7%	–	–	–	–	–	–	Trace
Muscovite	–	–	–	–	–	–	–	Trace	–	Minor
Organic matter	–	–	–	–	–	1%	–	Trace	–	Minor
Other (hornblende, staurolite)	–	–	1%	–	–	–	–	–	–	–
Other free mineral grains (biotite, muscovite, opaque oxide, epidote, sphene)	–	–	–		3%	–	–	–	–	–
Other mineral grains (hornblende, zircon, pyroxene)	–	9%	–	–	–	–	–	–	–	–

Description	1	2	3	4	5	6	7	8	9	10
Other mineral grains (leucoxene, limonite, rutile, zircon and tourmaline)	<1%	–	–	–	–	–	–	–	–	–
Plagioclase	–	–	–	–	–	–	–	–	–	1%
Pyrite	–	–	1%	–	–	–	–	–	–	–
Quartzite	–	–	–	1%	–	9%	–	–	8%	–
Rutile	–	–	–	–	–	–	–	Trace	–	–
Secondary iron oxide as partial grain coatings	–	–	–	–	2%	–	–	–	–	–
Sericitized clasts	–	–	–	2%	–	–	–	–	–	–
Serictite	–	–	–	–	–	–	7%	Trace	–	–
Shells	–	2%	–	–	–	–	–	1%	–	–
Tourmaline	–	–	–	–	–	–	–	Trace	–	–
Vein quartz (heavily strained)	–	–	–	2%	–	1%	–	–	–	–
Zircon	–	–	4%	–	–		1%	Trace	–	–
Free silica content										
Free silica content of sand	98%	64%	59%	51%	36%	68%	69%	90%	86%	85%

Table 5.4: Manufactured sand petrographic analysis

Source	1	2
Primary minerals		
Quartz as single free, unstrained to mildly strained grains	<1%	5%
Actinolite/tremolite	–	21%
Calcite	–	3%
Clinopyroxene	–	5%
Epidote	–	29%
Feldspar	–	32%
Groundmass feldspar	41%	–
Leucoxene	–	<1%
Opaque oxide	<1%	<1%
Plagioclase phenocrysts	30%	–
Prehnite	–	<1%
Pyroxene phenocrysts	7%	–
Secondary minerals		
Calcite	1%	–
Chlorite/chlorite-smectite	12%	4%
Epidote	5%	–
Hematite	2%	–
Pyrite	<1%	<1%
Quartz	<1%	–
Sericite	–	1%
Zeolite	2%	–
Free silica content		
Amorphous silica	–	–
Free silica content	<1%	5%

6 CONCLUSIONS AND RECOMMENDATIONS

The main aim of the study was to define the health risks of using RCG in road applications. The findings are as follows:

1. Silicosis is the result of exposure to high concentrations of respirable crystalline silica particles (less than 10 µm). Respirable crystalline silica is derived from materials containing greater than 1% crystalline silica.
2. RCG contains high percentages of silica, typically comprising as much as 75% of the chemical components. Silica is most commonly structured as crystalline or amorphous silica.
3. Glass manufacturing involves breaking down crystalline silica into the inert amorphous silica. Concentrations of less than 1% crystalline silica are present in glass particles.
4. Based on two studies on the use of RCG as aggregate replacement in road applications, there were no noted issues with cuts and abrasions, odours, skin contact or dust as RCG was found to have similar characteristics to natural sand. However, these studies only assessed the short-term effects of using RCG for applications that did not involve heating or mixing with any stabiliser.
5. There is limited research into the long-term exposure of dust generated from the production and application of RCG aggregates. However, it is postulated that due to the low crystalline silica contents there are no significant long-term adverse health risks (such as silicosis) associated with RCG usage.
6. The Australian worker exposure limit for respirable crystalline silica dust is 0.05 mg/m^3. This may be measured through determining the percent crystalline silica in the dust over an 8-hour TWA using AS 2985 and infrared spectroscopy or XRD analysis.
7. Increasing the use of RCG in road infrastructure, especially in unsealed and asphalt roads may necessitate undertaking additional personal exposure monitoring to determine the health risk for the public and workers in pavements involved in heating, milling and stabilising the material which involves dust and fume generation. However, these risks are likely to be negligible.
8. The crystalline silica content of RCG does not typically exceed 1%. Samples tested exceeding 1% crystalline silica are postulated to have been contaminated by foreign materials such as natural sand.
9. Natural sand contains significantly greater proportions of crystalline silica than RCG indicating there may be a reduced risk of exposure to respirable crystalline silica when working with RCG compared to natural sand. However, workplace OHS controls should still be implemented when working with both RCG and natural sand dust.
10. Manufactured sand may contain greater proportions of crystalline silica than RCG, thus the use of RCG rather than manufactured sand RCG may reduce the potential worker exposure to respirable crystalline silica.

Therefore, based on these conclusions, it is recommended that the use of RCG in pavement applications is permitted, ensuring the appropriate OHS controls are implemented to manage the risks of dust inhalation and manual handling.

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APPENDIX C ENRISKS REPORT

Recycled Glass Specification and Test Results: Technical Review

Prepared for: Australian Road Research Board (ARRB) and Queensland Department of Transport and Main Roads

9 October 2020

EnRiskS

Document History and Status

Report Reference	AT/20/RGR001
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Limitations

Environmental Risk Sciences has prepared this report for the use of the Australian Road Research Board (ARRB) 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 between June and October 2020. 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.

Table of Contents

Appendices:

Glossary of Terms

BGL	Below Ground Level
COPC	Chemical of Potential Concern
CRC CARE	CRC for Contamination Assessment and Remediation of the Environment
CSM	Conceptual Site Model
HHRA	Human Health Risk Assessment
HSL	Health Screening Level
IMW	Intrusive Maintenance Worker
LNAPL	Light Non-aqueous Phase Liquid
LOR	Limit of Reporting
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organisation

Executive Summary

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by the Australian Road Research Board (ARRB), on behalf of the Queensland Department of Transport and Main Roads (TMR) to undertake a technical review and provide advice in relation to the use of recycled crushed glass (RCG).

TMR has prepared a Technical Specification for the use of RCG in road pavements (TMR 2020), which includes sealed asphalt and unbound granular pavements (which may or may not be sealed). TMR proposes to allow RCG up to the following limits:

- 10% by mass for asphalt
- 20% by mass for unbound granular pavement materials.

In addition, this review has also considered the proposed use of 100% RCG as a drainage or bedding material (such as pipe bedding, service backfill etc) or in concrete.

This review has been undertaken to provide advice on whether the proposed use of RCG, which complies with the TMR (2020) Technical Specification, will cause harm to human health and the environment.

RCG is being used for these purposes in NSW and Victoria and has been subject to assessments of suitability for these uses within these jurisdictions. In NSW, contaminant limits were established for RCG, which were adopted within the TMR Specification (2020).

Data was provided on the concentrations of metals, inorganics and organics detected in RCG as provided by a number if suppliers proposed to be used within Queensland. This data showed that RCG could meet the contaminant limits provided in the TMR Specification. This data also included information on the leaching of some metals from the RCG.

The review undertaken has evaluated the concentration limits proposed for RCG to determine if these would be protective of human health and the environment where used as proposed. The assessment has considered the RCG specifications assuming that RCG comprises 100% of the materials used in the proposed applications, as the characteristics of the other materials to be used is not defined.

An important aspect of the review has involved consideration of whether the characteristics of the RCG differ from the characteristics of natural materials or clean fill (which is uncontaminated) and would be applicable to many of the materials (such as sand and gravel) to which RCG may be mixed with or substituted for.

Based on the available information and reviews undertaken, the following has been concluded in relation to the proposed use of RCG in accordance with the Technical Specification from TMR (2020):

- The characteristics of RCG are consistent with the characteristics expected for natural materials or clean fill, including gravel and sand commonly used in road applications.
- There are no issues of concern in relation to risks to human health, for any location where RCG is used in road/pavement materials or pipe bedding materials may be used.

- There are no issues of concern in relation to potential risks to the environment (terrestrial or aquatic) where RCG may be used in road and pavement materials, or pipe bedding materials.

Section 1. Introduction

1.1 Background

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by the Australian Road Research Board (ARRB), on behalf of the Queensland Department of Transport and Main Roads (TMR) to undertake a technical review and provide advice in relation to the use of recycled crushed glass (RCG).

TMR has prepared a Technical Specification for the use of RCG in road pavements (TMR 2020), which includes sealed asphalt and unbound granular pavements (which may or may not be sealed). TMR proposes to allow RCG up to the following limits:

- 10% by mass for asphalt
- 20% by mass for unbound granular pavement materials.

The Technical Specification has largely followed guidelines for the characteristics of RCG proposed to be used from the NSW Environment Protection Authority (EPA) "the recovered glass sand order 2014" (EPA 2014).

This review has been undertaken to provide advice on whether the proposed use of RCG, which complies with the TMR (2020) Technical Specification and NSW EPA, will cause harm to human health and the environment.

1.2 Objectives and scope of works

The objectives of the review undertaken and presented in this report are to determine if the proposed use of RCG:

- will cause environmental harm in these applications if conforming RCG is used
- will cause environmental nuisance in these applications if conforming RCG is used
- will cause community health impacts in these applications if conforming RCG is used, or
- there any further issues for consideration.

This review has not provided an assessment of the engineering requirements or specifications relevant to the use of RCG as proposed. The focus of this review relates to the potential for harm to human health and the environment.

More specifically the review has involved the following:

Task 1 – Initial advice

This task involved the provision of initial advice about whether or not aligning TMR's requirements for the use of RCG in asphalt and unbound granular (gravel) materials with those of the NSW Environment Protection Authority (EPA) will cause environmental harm if conforming materials are used. This initial advice was provided in a letter dated 10 June 2020. This report provides further detail and justification of the advice provided in relation to these materials.

Tasks 2 and 3 – Additional advice

This involves the provision of additional advice in relation to the following:

1. Are the NSW EPA criteria suitable (as they are) to prevent environmental harm, nuisance, and community health impacts when 100% RCG is used as a drainage or bedding material (such as pipe bedding, service backfill and so on) or in concrete.
2. Are there more optimal criteria that could be adopted or additional requirements that should be included for other applications (e.g. leachate testing) – if so, what are these and how should testing be done (methods, frequencies, limits).

These additional questions have been addressed in this report.

1.3 Methodology

This review has been undertaken in accordance with the following legislation and guidance (and associated references as relevant):

- *Environmental Protection Act 1994* and *Environmental Protection Regulation 2019*
- *Waste Reduction and Recycling Act 2011*
- National Environmental Protection Measure (NEPM) (NEPC 1999 amended 2013a, 1999 amended 2013b, 1999 amended 2013c, 1999 amended 2013d)
- enHealth, 2012. Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012);
- NSW EPA Resource Recovery Order under Part 9, Clause 93 of the Protection of the Environment Operations (Waste) regulation 2014, The recovered glass sand order 2014;
- NSW DECCW 2010, Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage.

1.4 Qualification of author/SQP

This report has been prepared 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. **Appendix D** presents the required statutory declarations relevant to this assessment.

Section 2. Summary of the proposal

2.1 Overview

The proposal relates to a Technical Specification for the use of RCG as an alternative to quarry or natural sand or aggregate in the following applications:

- Recycled materials blends for pavements – with RCG comprising 20% by mass for unbound materials
- Aggregates for asphalt – with RCG comprising 10% by mass.

In addition, this review has also considered the proposed use of 100% RCG as a drainage or bedding material (such as pipe bedding, service backfill etc) or in concrete. For this review it is assumed that the RCG proposed to be used for this purpose meets the RCG specification.

The above are consistent with the uses of RCG that is the subject of the NSW EPA Resource Recovery Order under Part 9, Clause 93 of the *Protection of the Environment Operations (Waste) Regulation 2014*, The recovered glass sand order 2014. This order imposes requirements that must be met by suppliers of recovered glass sand for the purpose of "*pipe bedding, drainage or for road making activities*".

2.2 RCG specification

The TMR (2020) Technical Specification for RCG is included in **Appendix B**. This specification has a number of key criteria for the use of RCG as defined by the NSW EPA, along with relevant Australian Standards. The standard addresses:

- Standard test methods
- Quality system requirements
- Material requirements, which includes maximum concentration limits
- Compliance testing.

Definitions

In relation to recycled glass aggregate or RCG proposed to be used as outlined in the Technical Specification, the following definitions apply:

Recycled glass - Glass sourced from the collection of domestic or commercial waste. This includes glass collected from domestic commingled recycling collections

Recycled glass aggregate shall be

a) of nominal size of 5 mm or less
b) produced from food and beverage container glass
c) processed to a consistent gradation
d) cubical in shape, not sharp edged or elongated
e) essentially free of contaminants such as ceramics, glass from other sources (such as cathode ray tubes, fluorescent light fittings and laboratory glassware), paper, cork, metals (including heavy metals), brick, plaster, plastic, rubber, wood, clay, paint, and other deleterious materials, and
f) free from any putrid odour.

Compliance requirements

Table 1 presents the specifications relevant to RCG as defined in the TMR (2020) Technical Specification. In addition, the material is required to demonstrate compliance with requirements in relation particle size distribution. Testing required to demonstrate compliance is outlined in the TRM (2020) Technical Specification.

Table 1: RCG specification

Column 1	Column 2	Column 3
Chemicals and other attributes	**Maximum average concentration[1] (mg/kg dry weight unless otherwise specified)**	**Absolute maximum concentration (mg/kg dry weight unless otherwise specified)**
Mercury	0.5	1
Cadmium	0.5	1.5
Lead	50	100
Arsenic	10	20
Chromium (total)	20	40
Copper	40	120
Molybdenum	5	10
Nickel	10	20
Zinc	100	300
Total Organic Carbon (TOC)	1%	2%
Electrical Conductivity	1 dS/m or 1000 µS/cm	2 dS/m or 2000 µS/cm

Notes

1 = The average shall be based on the five most recent test results

Section 3. Assessment of the proposal

3.1 Use of RCG in other jurisdictions

The proposal relates to the use of RCG for specific purposes in Queensland, namely in road base (asphalt), paving materials and as pipe bedding/drainage.

RCG is being used for these purposes in NSW and Victoria as noted below:

- NSW, where the use of RCG for the same purposes is permitted, where it complies with the NSW EPA Resource Recovery Order under Part 9, Clause 93 of the *Protection of the Environment Operations (Waste) Regulation 2014*. This is the key reference for the TMR (2020) Technical Specification. This provides a comprehensive specification that includes contaminant limits for the materials to be used for these purposes.
- VicRoads (Technical Note 107, September 2019) relates to the use of recycled materials in road pavements. The note includes the use of crushed glass, where it is noted that since 2011, glass fines have been permitted to be used as a replacement for sand in intermediate and base course asphalt mixes, and in 2018 the use of glass fines in general concrete paving was introduced. Crushed glass is also permitted as a supplementary material in many crushed rock mixes as a granular filter materials for subsurface drains. The suitability of glass fins and crushed glass in these materials has been considered in research projects undertaken at Swinburne University[1].

Other states and territories do not appear to have developed specifications for the inclusion of RCG in these products, and typically only discuss the inclusion of glass as foreign material in asphalt and paving materials. It is noted that some individual local councils have allowed for the inclusion of 5% RCG in asphalt (City of Canning in Western Australia), or undertaken demonstration projects utilising 100% RCG for pipe bedding, 5% RCG in asphalt and 40% RCG in pavements and concrete (Clarence City Council in Tasmania) (GHD 2011).

Internationally, the use of RCG has been incorporated in specifications for pavement materials in New Zealand (5% in various pavements), the United States (variable specifications) and the UK (up to 15% in aggregate mixes) (GHD 2011).

Much of the focus of specifications, including the assessments completed by Swinburne University focus on the engineering or geotechnical aspects of the RCG and RCG as added to various pavement products, including pH, particle size, plasticity, shrinkage, compaction and strength. Few provide specifications on the chemical characteristics of the RCG. The including of the chemical characteristics in the NSW EPA specification, and the TMR (2020) Technical Specification allows for the assessment of potential risks to human health and the environment where RCG is proposed to be used.

[1] https://www.sustainability.vic.gov.au/Government/Waste-and-resource-recovery/Recycled-materials-in-pavement

3.2 RCG as waste

The focus of this review relates to assessing the use of RCG where it meets the specifications outlined in the TMR (2020) Technical Specification.

The limits are below the Queensland guidelines relevant to the classification of regulated waste (DES 2019), as shown in **Table 2**. Hence the RCG material would not be considered regulated waste.

Table 2: Comparison of limits for RCG against regulated waste guidelines

Chemicals and other attributes	Maximum average concentration (mg/kg dry weight unless otherwise specified)	Absolute maximum concentration (mg/kg dry weight unless otherwise specified)	Waste guidelines in QLD – Not regulated (mg/kg)
Mercury	0.5	1	<80
Cadmium	0.5	1.5	<90
Lead	50	100	<300
Arsenic	10	20	<300
Chromium (total)	20	40	<300 (Cr VI)
Copper	40	120	<220
Molybdenum	5	10	<117
Nickel	10	20	<1200
Zinc	100	300	<400
Total Organic Carbon (TOC)	1%	2%	NA
Electrical Conductivity	1 dS/m	2 dS/m	<1.2

3.3 Available assessments and data

The characteristics of RCG has been evaluated by the NSW EPA in a trial for the use of RCG as pipe bedding and drainage (DECC 2007); by researchers from Swinburne University in relation to two samples of RCG produced in Victoria (Disfani et al. 2012); and data collected from potential RCG suppliers in Queensland. These data are further summarised as follows:

Trial of RCG as pipe bedding

This trial (DECC 2007) was conducted with Sydney Water and considered the use of RCG as pipe bedding. The RCG was derived from one supplier in Sydney and the proportions of RCG in bedding included 25%, 50% and 100% (with the remainder being sand). Chemical testing was undertaken to evaluate the potential for these materials to be of concern to human health or the environment. The testing included bulk analysis of the material along with leach testing. The results were directly compared against NSW Waste Guidelines for inert waste, NEPM Health Investigation Levels for the protection of ecological and human health, groundwater criteria based on protection of aquatic ecosystems and drinking water as well as freshwater aquatic guidelines.

The testing found that chemical and physical contaminants were either not detected or were present at background or trace levels and concluded no unacceptable human health and/or environmental impacts when RCG is used as a sand substitute in these situations. This conclusion was principally based on the characteristics of the material being consistent with background and compliance with human health guidelines.

Swinburne University (Disfani et al. 2012)

This research paper notes previous studies relating to the suitability of using RCG in concrete mixtures, asphalt and road pavements, as well as free-draining material in filters and drainage blankets and the replacement of natural backfill materials in trenches and pipe bedding materials. Most studies focus on geotechnical evaluations of these materials with few focusing on environmental concerns. One study (CWC 1998) included bulk analysis of the RCG, and some limited leach testing, and concluded all chemical concentrations were within acceptable ranges.

The study conducted by Disfani et al (2012) included analysis of two different samples of RCG from suppliers in Victoria. The study included assessment of geotechnical properties relevant to the use of the materials in road pavements, as well as analysis of chemical concentrations in the bulk material and leaching. The data was compared with EPA Victoria criteria in fill material and solid inert waste, concluding that environmental risks of using RCG in road applications are negligible. This outcome is consistent with the additional study from the same university (Imteaz, Ali & Arulrajah 2012) where samples of RCG from a stockpile in Melbourne were analysed.

In these studies, where the materials were consistent with characteristics of clean fill, no human health or environmental risk issues were identified. In addition, the studies referenced EPA Victoria guidelines that where a material is deemed suitable to be used as fill, there is no need to conduct leaching tests (ASLP) on the materials.

Leach data from these studies were evaluated against guidelines relevant to the determination of solid or inert waste (considered to be representative of a negligible impact on the environment) and hazardous waste (adopting a USEPA definition of ASLP < 100 x drinking water guidelines).

Data from RCG suppliers in QLD

RCG is expected to be sourced by TMR from a number of different suppliers in Queensland. Data has been provided on the analysis of chemicals (organic and inorganic) from RCG samples from these suppliers. The analysis also included the % foreign materials present and leach testing for metals.

These analyses have not detected concentrations benzene, toluene, ethylbenzene, xylenes, polycyclic aromatic hydrocarbons (PAHs) or phenols. The only compounds detected are metals and total recoverable hydrocarbons (TRH). Its is noted that the reporting of TRH (noted to be detected in one sample only) is a general measure of a range of different compounds that may be present in a specific group or band of outputs from the GC analysis. It includes petroleum hydrocarbons as well as a number of other non-petroleum hydrocarbons and compounds (including acids, aldehydes, ketones etc) that are also present. The key chemicals detected in analysis relate to metals/inorganics.

Table 3 presents a summary of the metals detected in RCG from these various suppliers, with comparison against the TMR limits. The table lists the range reported from 6 suppliers (which may include a single or multiple locations) for a range of different RCG materials described as fine, coarse, dried, undried or different size fractions.

Review of **Table 3** indicates that for the chemicals listed in the Technical Specification, the RCG from most suppliers complies with the limits provided. The exception is an elevated concentration of lead in one sample from Supplier E. This batch of RCG would not meet the required specification and not be suitable for the proposed use.

Some leach test data is available from Queensland suppliers. Some of the samples analysed for composition were also analysed for leaching, with the leaching of only some metals reported (i.e. not the full suite of metals listed in the specification). In relation to this data, leachable concentrations of boron, copper, lead and zinc were detected, as summarised in **Table 4**. The table includes the data relevant to leaching at pH 5, which is more relevant to environmental conditions (compared with leach data from pH 9). Chromium and molybdenum were not detected in leachate. This indicates that some metals can leach from the RCG material as supplied.

It is noted that where the leach data is considered in conjunction with the concentration reported for the RCG samples analysed, the ratio of the solid concentration:leachate is calculated to be approximately 10 fold lower than the published values of Kd (the soil-water partition coefficient). This means that the available data suggests that the leaching of metals from RCG is approximately 10 times lower than from soil (with the equivalent concentration).

Table 3: Summary of chemical data related to RCG from Queensland suppliers

Chemicals and other attributes	Range of concentrations reported in samples analysed from various suppliers (mg/kg dry weight unless otherwise specified)						Technical Specification RCG maximum concentration limits (mg/kg dry weight unless otherwise specified)	
	A	B	C	D	E	F	Maximum average concentration for characterisation	Absolute maximum concentration
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.5	1
Cadmium	0.7	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	1.5
Lead	5.4 - 26	11	97 - 120	19	20 - 2000	7 - 16	50	100
Arsenic	<2	<2	<2	<2	<2	<2	10	20
Chromium (total)	<1	<1	5.3	11	<1	<1	20	40
Copper	6.7 - 33	<5	5.3 - 11	5.3	7.9 - 41	5.7 - 73	40	120
Molybdenum	<10	<10	<10	9.4	<10	<10	5	10
Nickel	<5	<5	<5	<5	<5	<5	10	20
Zinc	15 - 50	31 - 96	58 - 250	57	38 - 87	60 - 180	100	300
Total Organic Carbon (TOC)	0.2 – 0.6%	0.2 – 0.5%	0.6 – 0.7%	1%	0.7 – 1.6%	0.1 – 0.4%	1%	2%
Electrical Conductivity	0.037 – 0.22 dS/m	0.15 – 0.37 dS/m	0.18 – 0.46 dS/m	0.26 dS/m	0.39 – 0.53 dS/m	0.052 – 0.3 dS/m	1 dS/m	2 dS/m
Other chemicals detected								
Boron	<10	<10	<10	<10	39	<10	--	--
TRH >C10-C16 (F2)	<50	<50	<50	<50	59	<50	--	--
TRH >C16-C34 (F3)	<100	<100	<100	<100	750	<100	--	--
TRH >C34-C40 (F4)	<100	<100	<100	<100	140	<100	--	--

Table 4: Summary of chemical leaching test data related to RCG from Queensland suppliers

Chemicals reported	Range of concentrations reported in leach test results at pH 5 from various suppliers (mg/L)					
	A	B	C	D	E	F
Boron	--	--	--	--	0.68	--
Chromium (total)	--	--	<0.01	<0.01	--	--
Copper	0.02 – 0.2	--	0.02 – 0.06	0.02	0.03 – 0.04	0.03 – 0.23
Lead	0.15 – 1.4	--	0.12 – 0.22	0.41	0.34 – 9.3	0.1 – 0.3
Molybdenum	--	--	--	<0.01	--	--
Zinc	0.95 - 2	1.3 – 3.6	1.7 – 1.9	2.2	1.3 – 2.5	2.8 – 5.6

Notes

Not all RCG samples analysed for chemical composition were tested for leaching. Not all tests reported the metals listed above.

-- No data reported

Section 4. Assessment of risks to human health and the environment

4.1 Potential for exposure

The TMR (2020) Technical Specification requires RCG to be tested by the supplier to demonstrate compliance with the limits. Hence the focus of this review relates to RCG that may have chemical characteristics equal to the limits outlined in the Technical Specification. As shown in **Table 3**, it is likely that actual concentrations would be lower than the limits, however it is important to demonstrate that the limits are protective of human health and environmental risks. In addition to the technical limits, this review has also considered the potential presence of other chemicals detected in RCG from Queensland suppliers, namely boron and TRH.

The focus of this review relates to consideration of potential risks to human health and the environment in relation to the use of RCG in pavement materials (including concrete), asphalt for roadways as well as in pipe bedding or drainage materials.

In relation to the potential for exposure, the **Figures 1 and 2** provide diagrammatic conceptual site models relevant to the proposed use of RCG. The figures include the mechanisms for contaminants to migrate from the materials where used and the potential for exposure where human health and ecological risks may require further consideration.

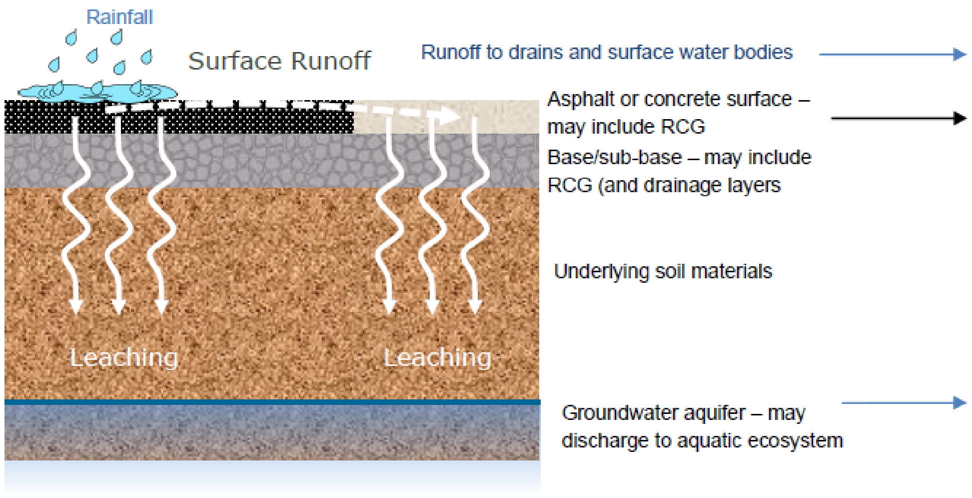
Where RCG is used by TMR in asphalt (10% by mass) and unbound granular pavement materials (20% by mass), the RCG will be mixed with other road and pavement materials. These other materials will have their own unique properties which may, or may not, have concentrations lower than presented in **Table 1**. Hence the mixing of RCG in asphalt and pavement materials may or may not result in lower concentrations being present where the materials are used.

For the purpose of this assessment the characteristics of RCG as presented in **Tables 1 and 3** have been considered.

In the review undertaken the RCG limits relating to total organic carbon is not of concern in relation to environmental harm.

The limits for electrical conductivity relates to salinity, and the potential for RCG to result in saline soil conditions. The limits listed in **Table 1** and proposed use in pavement, asphalt, drainage and pipe bedding materials will not adversely affect soil salinity. Hence electrical conductivity has not been further assessed.

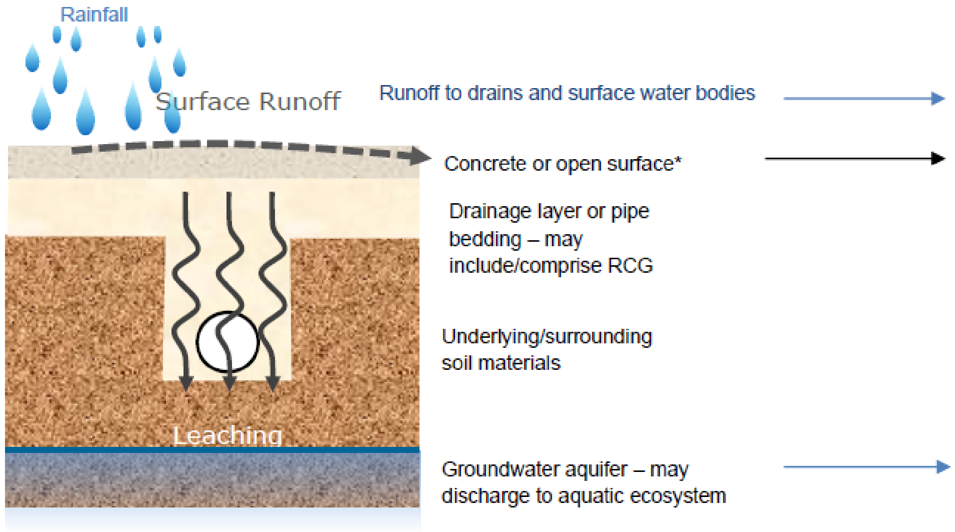
The focus of the review relating to human health and ecological harm relates to the chemical composition of RCG.



Human health	Ecological
Direct contact* with surface water - Drinking water or recreational	Aquatic environments in surface water
Direct contact* with materials	Terrestrial environments
Groundwater extraction and use Direct contact* with water Drinking water or recreational	Aquatic environments where groundwater discharges

* Direct contact includes ingestion and dermal absorption

Figure 1: Conceptual model – use of RCG in pavement and asphalt



Human health	Ecological
Direct contact* with surface water - Drinking water or recreational	Aquatic environments in surface water
Direct contact* with materials	Terrestrial environments
Groundwater extraction and use Direct contact* with water Drinking water or recreational	Aquatic environments where groundwater discharges

* Direct contact includes ingestion and dermal absorption

* May include landscape areas

Figure 2: Conceptual model – use of RCG in drainage or pipe bedding

4.2 Assessment of human health issues

4.2.1 Potential for exposure

In relation to potential risks to human health the pathways of exposure relevant to the use of RCG as proposed involve the following:

- Direct contact with RCG materials in roadways or pavements, where these materials are in an area accessible to workers and residents who may live directly adjacent to the locations where these materials may be used. This exposure relates to direct contact with chemicals that may be present in surface materials. Where materials are bound in asphalt or concrete, used at depth, placed beneath sealed surfaces or as pipe bedding sand there is no potential for direct contact with the materials to occur.
- Direct contact with chemicals that may have leached from the RCG used in roadways, pavement or as bedding materials and may directly runoff to surface water, where this water may be accessed for recreational uses or extracted for drinking water (refer to **Section 4.4**).
- Direct contact with chemicals that may have leached from the RCG as used, migrate to groundwater and groundwater is extracted and used for drinking water. Groundwater may also discharge to surface water where exposures via recreational use or drinking water may occur (refer to **Section 4.4**).

4.2.2 Direct contact with RCG materials

To assess the potential for the above exposures to be of concern, the maximum limits for RCG have been directly compared with guidelines that are based on the protection of human health for exposures by commercial/industrial workers and residents. These guidelines are available from the ASC NEPM (NEPC 1999 amended 2013a) and are protective of the following exposures, which are highly conservative in relation to likely exposures that may occur in areas where RCG is proposed to be used:

- Commercial/industrial workers – ingestion of soil and dust, dermal absorption of chemicals from contact with soil and dust and inhalation of dust, 8 hours per day for 240 days of the year for 30 years.
- Residents – ingestion of soil and dust, dermal absorption of chemicals from contact with soil and dust, inhalation of dust, ingestion of homegrown fruit and vegetables grown in soil (10% of intakes are from home produce).

Where guidelines are not available from the NEPM, they have been derived from CRC CARE (CRC CARE 2011) in relation to direct contact exposures with TRH, and the USEPA Regional Screening Levels (RSLs) for residential and industrial soil – which are derived on a similar basis as the NEPM guidelines.

Table 5 presents a comparison of the TMR limits against these health based guidelines. The table also includes the additional chemicals detected in analysis of RCG from Queensland suppliers.

Table 5: Review of limits and concentrations for RCG – Human health

Chemicals and other attributes	Limits for RCG (mg/kg dry weight unless otherwise specified)		Guidelines protective of human health (mg/kg)	
	Maximum average concentration	Absolute maximum concentration	Commercial/ industrial workers N (HIL-D)	Residents N (HIL-A)
Mercury	0.5	1	730	40
Cadmium	0.5	1.5	900	20
Lead	50	100	1500	300
Arsenic	10	20	3000	100
Chromium (total)	20	40	3600 (Cr VI)	100 (Cr VI)
Copper	40	120	240000	6000
Molybdenum	5	10	5800 U	390 U
Nickel	10	20	6000	400
Zinc	100	300	400000	7400
Other chemicals detected in RCG				
Chemicals	**Maximum detected in Queensland supplied materials (mg/kg)**		Commercial/ industrial workers N (HIL-D)	Residents N (HIL-A)
Boron	39		300000	4500
TRH >C10-C16 (F2)*	59		62000 C	3300 C
TRH >C16-C34 (F3)	750		85000 C	4500 C
TRH >C34-C40 (F4)	140		120000 C	6300 C

* It is noted that TRH F2 is also considered to be volatile where there may be the potential for the inhalation of volatile TRH in air. For the proposed use of the RCG these would only be in outdoor areas where the NEPM (NEPC 1999 amended 2013a) indicates that the guideline protective of inhalation exposures in outdoor air is not limiting – this means that the saturated vapour concentration is lower than the vapour concentration that would result in unacceptable risks. Hence there are no vapour inhalation risk issues of concern, and the guidelines adopted relate to direct contact exposures only.

N = Health based guidelines as listed in the NEPM (NEPC 1999 amended 2013a), unless noted otherwise

C = CRC CARE guidelines (CRC CARE 2011) based on the protection of human health for direct contact exposures

U = USEPA RSLs (USEPA 2020) for industrial or residential soil – protective of human health

Review of **Table 5** indicates the following:

- All limits are below conservative health based guidelines that are protective of direct contact exposures by workers and residents.
- For the chemicals not listed in the limits but detected in the RCG, the reported concentrations are well below the health based guidelines and do not warrant further consideration.

Hence the evaluation undertaken, based on the TMR (2020) limits for RCG in materials to be used for pavements, asphalt, pipe bedding and concrete has not identified any risk issues of concern in relation to human health.

It is noted that the assessment presented relates to the use of 100% RCG in these areas, and for the use in drainage or pipe bedding. Where mixed as expected in pavement materials (20% RCG) and asphalt (10% RCG), the potential human health risks may be lower than presented in this assessment, depending on the characteristics of the material into which RCG is mixed.

Further review of potential risks related to the leaching of metals from RCG is presented in **Section 4.4**.

4.3 Assessment of ecological issues

4.3.1 Potential for exposure

In relation to the potential for ecological impacts related to the proposed use of RCG the following issues are of relevance:

- Terrestrial ecosystems - Asphalt and pavement materials are used for roads where the growth of plants is not desired. In the case of asphalt, this material would preclude the growth of plants, regardless of the inclusion of RCG in this material. Where RCS is used in subsurface drainage or pipe bedding, plant growth and terrestrial ecosystems are not relevant. Hence the focus of this review relates to the potential for harm in areas located adjacent to the pavement or roadway.
- Aquatic ecosystems – This is of relevance where chemicals present in RCG leach and may impact on surface water quality and/or groundwater quality, and groundwater discharges to an aquatic environment (refer to **Section 4.4**).

4.3.2 Terrestrial ecosystems

In relation to potential impacts on adjacent terrestrial ecosystems, this would only relate to the presence of the materials that may have spilled or extend beyond the road or pavement. Where the RCS is bound in asphalt or concrete, then there is no potential for ecological exposures and therefore no risk.

To assess the potential for RCG to be of concern to terrestrial ecosystems, the TMR (2020) limits have been compared with published ecological investigation levels (EILs), as presented in **Table 6**. The level of protection relevant to terrestrial ecosystems adjacent to roadways or paved areas is consistent with that adopted in the NEPM for open space and residential use. This relates to 80% species protection and is expected to be conservative for areas where RCG may be present (unbound) in soil.

Soil EILs from the NEPM (NEPC 1999 amended 2013a) have been adopted in this assessment. Where EILs are not available, guidelines available from CCME or RIVM, protective of agricultural or residential soil have been adopted. The NEPM EILs have been derived to also consider potential leaching and impacts on groundwater and aquatic ecosystems.

Table 6: Review of limits and concentrations for RCG – Terrestrial ecosystems

Chemicals and other attributes	Limits for RCG (mg/kg dry weight unless otherwise specified)		Guidelines protective of ecological health (mg/kg)
	Maximum average concentration	Absolute maximum concentration	
Mercury	0.5	1	12 [C]
Cadmium	0.5	1.5	3.8 [CA]
Lead	50	100	275 [ERF]
Arsenic	10	20	50 [ERF]
Chromium (total)	20	40	130 [ARF]
Copper	40	120	65 [ARF]
Molybdenum	5	10	5 [CA]
Nickel	10	20	30 [AFR]
Zinc	100	300	120 [ARF]
Other chemicals detected in RCG			
Chemicals	**Maximum detected in Queensland supplied materials (mg/kg)**		**Guidelines protective of ecological health (mg/kg)**
Boron	39		3100 [R]
TRH >C10-C16 (F2)*	59		120 [ES]
TRH >C16-C34 (F3)	750		300 - 1300 [ES]
TRH >C34-C40 (F4)	140		2800 - 5600 [ES]

NEPM ecological guidelines
E = EIL
A = Added contaminant level (ACL) with the EIL based on background from QLD (low traffic volumes) + ACL calculated for CEC = 5 cmolc/kg, pH = 6, iron content = 5%, clay content = 1%
F = Fresh contamination guideline (relevance to RCG)
ES = Ecological Screening Level for petroleum hydrocarbons
C = CCME guideline protective of agricultural and residential soil (ecological)
CA = CCME guideline protective of agricultural soil (ecological) (more conservative than residential guideline or no residential guideline available)
R = RIVM intervention screening level for soil

Review of **Table 6** indicates the following:

- All limits as maximum average concentrations are below the adopted ecological guidelines.
- Where the absolute maximum concentration is considered, the limits for copper, molybdenum and zinc exceed the adopted ecological guidelines. It is noted that the guidelines are not specifically applicable to the maximum, with the average more representative of concentrations that may be relevant to terrestrial ecosystems, and there are no exceedances where the average is considered. In addition the adopted ecological guidelines are highly conservative as it is assumes that all the soil in large areas used for open space or recreational purposes is at the guideline levels – which would not be the case as the RCG would only be used in bound products or pavement/bedding materials with limited potential for large areas adjacent to these uses to include RCG. Where commercial/industrial guidelines are considered, the maximum concentrations in the TMR limits are below these values.
- The concentrations reported for boron and TRH are generally below the adopted ecological guidelines. The concentration of TRH F3 is within the range relevant to fine and coarse soil, and it is noted to be below the ecological guidelines for commercial/industrial areas. It should also be noted that the guidelines adopted for TRH relate to the TRH being petroleum hydrocarbons. The guidelines are overly conservative for the assessment of TRH that

comprises other, non-petroleum, compounds which is likely for RCG. On this basis the TRH detected is not considered to of concern to terrestrial ecosystems.

4.3.3 Aquatic ecosystems

It is noted that the EILs and ESLs have been derived to also consider potential leaching and migration to groundwater (and protection of aquatic ecosystems). The potential for leaching to be of concern to any aquatic environment has been further reviewed in **Section 4.4**.

4.4 Further review of potential risk issues

Where any material is used for paving (including concrete and asphalt), or materials are used for pipe bedding, there is the potential for metals (and other contaminants if present) to leach and migrate to groundwater or surface water (where humans and aquatic ecosystems may be exposed).

This transport mechanism is not considered to be of concern where the characteristics of the materials used are consistent with what is considered to be clean fill or natural (or uncontaminated) materials. This is particularly relevant as metals (and inorganics) are naturally occurring within soil and rock, and hence there are concentrations that would be expected in materials such as soil, gravel, sand and crushed rock that are commonly used for paving and bedding materials that are considered to be representative of naturally occurring materials. It is noted that the concept of naturally occurring requires consideration as there are numerous areas where mineralised rock/soil is present that may pose a risk to health and the environment. Hence some Australian jurisdictions have specifically defined the concentrations that are considered to be to be naturally occurring or clean fill, which typically excluded naturally mineralised areas.

Where the RCG comprises characteristics consistent with clean fill or natural materials, the material is considered to be consistent with the characteristics of existing materials commonly used in roads and pavements, and of no concern to human health or the environment.

The clearest definitions of clean fill or natural materials are from Victoria, NSW and South Australia.

- EPA Victoria (EPA Victoria 2010) provides a definition of fill materials, commonly referred to as clean fill criteria. This provides concentrations of contaminants, below which are considered to not be contaminated and therefore not of concern to human health or the environment. The guidance also provides for review of the history of the material to determine if concentrations of metals above these criteria are derived from natural origins (where the material would not be considered contaminated). EPA does not regulate fill materials and the criteria for fill materials only relate to concentrations (EPA Victoria 2009). There is no requirement to test for leaching in relation to these materials.
- The NSW EPA provides criteria used to define excavated natural material (ENM) (NSW EPA 2014). This order provides the requirements that must be met by suppliers of excavated natural materials for use in fill or earthworks. The order provides characteristics of the material as a maximum average and absolute maximum concentrations. These criteria are considered to define clean fill in NSW and the material that complies with the ENM criteria is not considered to be contaminated and does not pose a risk to human health or the environment. Leach testing is not required for these materials.
- South Australia provides a standard for waste derived fill (SA EPA 2013). This standard provides the maximum concentrations of chemical substances that would meet the waste fill

criteria. Concentrations in excess of the waste fill criteria require further assessment including consideration of leaching to the environment (noting that the standard also provides Intermediate Waste Criteria). The waste fill criteria relate to concentration of chemicals only. There is no requirement for leach testing of these materials.

It is acknowledged that the criteria established, as noted above, relate to soil (being clay, silt and/or sand), gravel and rock of naturally occurring materials. The South Australian standard allows for the inclusion of other inert mineralogical matter. These criteria are appropriate for determining if the characteristics of RCG (which is an inert material) are consistent with the characteristics of other natural materials commonly used in road applications, and if the characteristics of RCG has the potential to be of concern to the human health or the environment, when used in the same way as these other materials.

Queensland does not have a guideline on concentrations that comprise clean fill or natural (uncontaminated) materials. Schedule 19 of the *Environmental Protection Regulation 2019* defines "*clean earth*" as "*any natural substance found in the earth that is not contaminated with waste or a hazardous contaminant*". There are no criteria established in Queensland as to the concentrations of metals in these materials that is considered to be natural or uncontaminated. As noted in **Section 3.2** the RCG is not considered to be regulated waste in Queensland.

Further assessment of soil (and rock) concentrations in Queensland that would be considered to be representative of natural background materials (precluding naturally mineralised areas) has been undertaken by Easterly Point Environmental (Salmon 2017). This review has considered the available data on background or natural soil concentrations in Queensland, along with guidance provided in the NEPM (NEPC 1999 amended 2013d, 1999 amended 2013a) to determine residual soil levels, which would be considered suitable for any use and are not considered to be of concern to human health or the environment.

Table 7 provides a review of the RCG criteria against the available guidance from Victoria, NSW and SA in relation to the characteristics of natural materials or clean fill (i.e. uncontaminated material). The proposed residual soil levels for Queensland are also presented.

Review of **Table 7** indicates that the RCG Specification provides concentration limits for metals that are consistent with (and in some cases lower than) the criteria relevant to materials that would be considered naturally occurring or clean fill. These are the same criteria that would be applicable to the use of gravels or sand materials in pavements and bedding materials, to which RCG is proposed to be added (or substituted). RCG remains an inert material which would not be different to the natural materials to which the criteria apply. In fact, as noted in **Section 3.3**, the leaching of metals from RCG is noted to be lower than expected from natural materials at the same concentration. The potential for leaching is even lower where RCG is bound in asphalt or concrete materials or used beneath sealed surfaces where infiltration of rainfall is very low. Further review of potential risks related to leaching from RCG is presented in **Appendix** C, which supports the outcomes presented in this review.

On this basis the RCG, where it meets the Specifications, is no different to the materials to which RCG is added to or substituted for and would not be considered to be of concern to human health or the environment. This includes the potential for metals to leach from these materials and impact on groundwater or surface water quality.

Table 7: Review of RCG Specification against criteria for natural materials or clean fill

Metals	**Technical Specification RCG maximum concentration limits** (mg/kg dry weight unless otherwise specified)		**Criteria available for defining clean fil or natural materials** (not considered contaminated and not of concern to health or the environment) (mg/kg)				
	Maximum average concentration for characterisation	**Absolute maximum concentration**	**EPA Victoria – Clean fill**	**NSW EPA – Excavated Natural Material (ENM)**		**SA EPA – Waste derived fill**	**Queensland – suggested residual soil levels**
				Maximum average	**Absolute maximum**		
Mercury	0.5	1	1	0.5	1	1	3
Cadmium	0.5	1.5	3	0.5	1	3	4
Lead	50	100	300	50	100	300	60
Arsenic	10	20	20	20	40	20	50
Chromium (total)	20	40	1 for Cr VI[1]	75	150	400 Cr III and 1 Cr VI[1]	50
Copper	40	120	100	100	200	60	200
Molybdenum	5	10	40	NA	NA	NA	NA
Nickel	10	20	60	30	60	60	60
Zinc	100	300	200	150	300	200	400

Notes

1 – Chromium VI is not the predominant form of chromium present in the environment and is typically present as a result of industrial processes. Organic matter in soil is expected to convert chromium VI to insoluble chromium III oxide. Chromium is most commonly present as chromium III.

4.5 Overview of human health and ecological risks

The evaluation undertaken, based on the TMR (2020) limits for RCG in materials to be used for pavements, asphalt, pipe bedding and concrete has not identified any risk issues of concern in relation to human health, ecological health, terrestrial or aquatic.

The assessment undertaken for RCS (direct contact and leaching) does not take into account the mixing of RCG with other materials as proposed for asphalt and paving. As such the assessment presented relates to the use of 100% RCG in these areas, and for the use in drainage or pipe bedding. Where mixed as expected in pavement materials (20% RCG) and asphalt (10% RCG), the potential human health and ecological risks may be lower than presented in this assessment, depending on the characteristics of the material into which RCG is mixed.

Section 5. Advice and conclusions

This proposal relates to the proposed use of RCG in road pavements (including asphalt and concrete), as well as other uses such as pipe bedding or drainage, where the RCG meets the Technical Specifications prepared by TMR (2020). The Technical Specifications are largely consistent with the NSW Environment Protection Authority (EPA) "the recovered glass sand order 2014" (EPA 2014). This assessment has specifically evaluated the potential for the use of RCG, that meets these specifications, to cause environmental harm.

Based on the available information and the proposed use of RCG, the following can be concluded:

- The characteristics of RCG are consistent with the characteristics expected for natural materials or clean fill, including gravel and sand commonly used in road applications.
- There are no issues of concern in relation to risks to human health, for any location where RCG is used in road/pavement materials or pipe bedding materials may be used.
- There are no issues of concern in relation to potential risks to the environment (terrestrial or aquatic) where RCG may be used in road and pavement materials, or pipe bedding materials.

These conclusions are consistent with those presented in reviews conducted on the use of up to 100% RCG in pipe bedding materials (DECC 2007) and on the use of RCG in pavements in Victoria (Disfani et al. 2012; Imteaz, Ali & Arulrajah 2012).

The assessment undertaken has considered the use of 100% RCG in these applications. This is conservative for the proposed use in pavement materials (20% RCG proposed) and asphalt (10% RCG proposed) but is consistent with the potential use of 100% RCG in pipe bedding materials. Hence, should a higher percentage of RCG be used in pavement materials and asphalt, the assessment presented in this report does not change. Where RCG is mixed in pavement materials and asphalt, the potential human health and ecological risks may be lower than presented in this assessment, depending on the characteristics of the material into which RCG is mixed.

It is not recommended that the limits adopted for the RCG be modified or refined.

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Appendix 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 25 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, 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
- Health Impact Assessment
- Environmental Chemistry, Fate and Transport
- Vapour Intrusion
- Indoor Air
- Risk Communication
- Air Dispersion Modelling

Professional Accomplishments

Toxicology and Risk Assessment

- 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.
- 2005 to 2018 (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.
- 2006 to 2018 (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 2018 (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 2018 (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 2018 – 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 in NSW and West Gate Tunnel in Victoria and rail infrastructure projects including the Moorebank Intermodal Terminal. 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 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 2018 – 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 2018 – 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.
- 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 2018) – 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.
- 2016 to 2018 – Literature review and assessment of community health impacts associated with landfill gas emissions, and emissions from water to energy facilities.
- 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 2018 (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 2016 - 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 2018 - 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, bioaerosols and other pathogens and bacteria.
- 1995 to 2018 (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 2018 - 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 2010 - 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 2018 (and ongoing) - Determination of preliminary remediation goals for numerous contaminated sites based on risk criteria.
- 1995 to 2018 (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 2018 (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 2018 (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 2018 (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.
- 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.

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 2018 (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 2018 (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 2018 – 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 2018 (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 2018 (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 2018 (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 2012 – Air dispersion modelling undertaken to evaluate community exposures to hydrogen sulfide (from accidental releases), chlorinated hydrocarbons (from remediation plant) and silica and dust (particulate) emissions from a range of facilities. Modelling has been conducted using Screening level and more detailed Ausplume and Calpuff dispersion modelling packages.
- 2010 to 2018 - 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.

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
- Seppanen&Seppanen v Ipswich City Council, Minister for Economic Development Queensland and Queensland Urban Utilities.
- Westgate Tunnel Project, Expert Witness, Inquiry and Advisory Committee (IAC) hearings (August-September 2017)
- Child care centre project, Provision of advice as expert witness for ACT Government Solicitor (2017)
- Caltex v Campbelltown City Council (SA) (Current)

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 2018 – 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.
- 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

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

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

Journal Articles:

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:

Wright J., 2013. Petroleum Vapour Intrusion (PVI) Guidance. CRC Care Technical Report No 23, CRC for Contamination Assessment and remediation of the Environment, Adelaide, Australia (in publication).

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., 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. 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.

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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.

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

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Appendix B TMR Technical Specification

Technical Specification

Transport and Main Roads Specifications
MRTS36 Recycled Glass Aggregate

July 2020

Queensland Government

Translating and interpreting assistance

The Queensland Government is committed to providing accessible services to Queenslanders from all cultural and linguistic backgrounds. If you have difficulty understanding this publication and need a translator, please call the Translating and Interpreting Service (TIS National) on 13 14 50 and ask them to telephone the Queensland Department of Transport and Main Roads on 13 74 68.

Feedback

Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

Transport and Main Roads Specifications, July 2020

Contents

1 Introduction

This Technical Specification sets out the requirements for recycled glass aggregate used in asphalt and unbound granular road pavements. Recycled glass aggregate used in other applications is not covered by the Technical Specification unless referenced elsewhere.

Recycled glass aggregate may be considered as an alternative to a quarry or natural sand material for the applications listed in Table 1.

The requirements of the parent Technical Specification shall apply to recycled glass aggregate unless those requirements are specifically excluded or amended by this Technical Specification.

Table 1 – Parent technical specifications

Parent Technical Specification	Application
MRTS05	*Unbound Pavements*
MRTS101	*Aggregates for Asphalt*

This Technical Specification shall be read in conjunction with MRTS01 *Introduction to Technical Specifications*, MRTS50 *Specific Quality System Requirements* and other Technical Specifications as appropriate.

This Technical Specification forms part of the Transport and Main Roads Specifications Manual.

2 Definition of terms

The terms used in this Technical Specification are as defined in Clause 2 of MRTS01 *Introduction to Technical Specifications*, and Table 2 of this Technical Specification.

Table 2 – Definition of terms

Term	Definition
Composite sample	A sample that combines five discrete sub-samples of equal size into a single sample for the purpose of analysis.
Recycled glass	Glass sourced from the collection of domestic or commercial waste. This includes glass collected from domestic commingled recycling collections.

3 Referenced documents

Table 3 lists the documents referenced in this Technical Specification.

Table 3 – Referenced documents

Reference	Title
MRTS01	*Introduction to Technical Specifications*
MRTS05	*Unbound Pavements*
MRTS50	*Specific Quality System Requirements*
MRTS101	*Aggregates for Asphalt*

4 Standard test methods

The standard test methods listed in Table 4 shall be used in this Technical Specification.

Further details of test numbers and test descriptions are given in Clause 4 of MRTS01 *Introduction to Technical Specifications*.

Table 4 – Standard test methods

Property to be Tested	Method No.
Sampling of aggregates	AS 1141.3.1
Particle size distribution	AS 1141.11.1
Material finer than 75 µm	AS 1141.12
Chemicals – sample preparation	USEPA SW-846 Method 3051A Microwave assisted acid digestion of sediments, sludges, soils, and oils.
Chemicals – analysis	USEPA SW-846 Method 6010C Inductively coupled plasma - atomic emission spectrometry, or an equivalent analytical method with a detection limit < 10% of the stated absolute maximum concentration in Table 6.2, Column 3.
Mercury concentration	USEPA SW-846 Method 7471B Mercury in solid or semisolid waste (manual cold vapour technique), or an equivalent analytical method with a detection limit < 20% of the stated absolute maximum concentration in Table 6.2, Column 3.
Total organic carbon content	Method 105 (Organic Carbon) and using a 2 gram sample in Schedule B (3): Guideline on Laboratory Analysis of Potentially Contaminated Soils, National Environment Protection (other published or validated classical chemistry technique or instrumentation technique).[1]
Electrical conductivity	Method 104 (Electrical Conductivity) in Schedule B (3): Guideline on Laboratory Analysis of Potentially Contaminated Soils, National Environment Protection (Assessment of Site Contamination) Measure 1999 or APHA 2510-B. (other published or validated classical chemistry technique or instrumentation technique)[1]

Notes

[1] Where an equivalent analytical method is used, the detection limit must be equal to or less than that nominated for the methods in Table 4. Instrumentation techniques may include Ion Chromatography / Inductively Coupled Plasma / Discrete Analyser and so on. NATA endorsed test results are evidence of a validated technique.

5 Quality system requirements

5.1 Hold Points, Witness Points and Milestones

General requirements for Hold Points, Witness Points and Milestones are specified in Clause 5.2 of MRTS01 *Introduction to Technical Specifications*.

The Hold Points, Witness Points and Milestones applicable to this Technical Specification are summarised in Table 5.1.

There are no Witness Points defined.

Table 5.1 – Hold Points, Witness Points and Milestones

Clause	Hold Point	Witness Point	Milestone
5.2	1. Acceptance of production procedure		Submit recycled glass aggregate production procedure

5.2 Recycled glass aggregate production procedure

For each source of recycled glass aggregate to be used in the Works, the Contractor shall prepare a procedure for aggregate production in accordance with Clause 6 of MRTS50 *Specific Quality System Requirements* and detail the following for the nominated material:

a) target particle size distribution

b) source(s) of recycled glass

c) production plant and methods of controlling the quality of the final product

d) procedures for stockpile management and traceability as part of the lot control and as applicable, sub-lot control, and

e) quality control procedures.

The recycled glass aggregate production procedure shall be submitted to the Administrator at least seven days prior to the commencement of aggregate production for the Works. **Milestone**

The use of recycled glass aggregate shall not commence until all relevant production procedures have been accepted by the Administrator. **Hold Point 1**

6 Material requirements

6.1 General

Recycled glass aggregate shall be:

a) of nominal size of 5 mm or less

b) produced from food and beverage container glass

c) processed to a consistent gradation

d) cubical in shape, not sharp edged or elongated

e) essentially free of contaminants such as ceramics, glass from other sources (such as cathode ray tubes, fluorescent light fittings and laboratory glassware), paper, cork, metals (including heavy metals), brick, plaster, plastic, rubber, wood, clay, paint, and other deleterious materials, and

f) free from any putrid odour.

6.2 Chemical and other attributes

Recycled glass aggregate shall comply with the maximum concentration limits for chemicals and other attributes given in Table 6.2.

Table 6.2 – Maximum concentration limits for chemicals and other attributes

Column 1	Column 2	Column 3
Chemicals and other attributes	**Maximum average concentration[1] (mg/kg 'dry weight' unless otherwise specified)**	**Absolute maximum concentration (mg/kg 'dry weight' unless otherwise specified)**
Mercury	0.5	1
Cadmium	0.5	1.5
Lead	50	100
Arsenic	10	20
Chromium (total)	20	40
Copper	40	120
Molybdenum	5	10
Nickel	10	20
Zinc	100	300
Total Organic Carbon	1.0%	2.0%
Electrical Conductivity	1 dS/m or 1000 µS/cm	2 dS/m or 2000 µS/cm

Notes

[1] The average shall be based on the five most recent test results.

7 Compliance testing

7.1 General

The Contractor shall, as a minimum, undertake testing for the following properties to demonstrate the recycled glass aggregate conforms with the requirements of Clause 6:

a) particle size distribution

b) material finer than 75 µm, and

c) chemicals and attributes listed in Table 6.2.

A composite sample consisting of five discrete sub-samples of equal size shall be used to represent a lot of material.

Recycled glass aggregate shall be sampled and tested in accordance with the minimum frequencies listed in Table 7.1.

Table 7.1 – Minimum sampling and testing frequencies

Number of Historical Test Results for Each Test Property	Minimum Frequency
< 5	1 per 500 tonnes
≥ 5	1 per 1000 tonnes

> Transport and Main Roads has adopted a risk-based approach to sampling and testing recycled glass aggregate.

For new production facility / glass sources that have limited historical test data available, more frequent testing is required (i.e. 1 per 500 tonnes). Once a production facility has established a history of compliance with specification requirements, a reduced testing frequency can be adopted (i.e. 1 per 1000 tonnes).

7.2 Samples for the Administrator

When the Administrator requests a sample of the recycled glass aggregate, the Contractor shall riffle and/or quarter the sample taken for compliance testing and deliver the sub-sample to the Administrator in a sealed and labelled container identifying the following:

a) lot number

b) sample description

c) sampler

d) date produced and/or supplied

e) date sampled, and

f) any other quality system references, as appropriate.

7.3 Nonconformances

Unless otherwise approved by the Administrator, nonconforming recycled glass aggregate shall not be incorporated into the Works.

13 QGOV (13 74 68)
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Appendix C Further review of leaching

C1 General

The potential for metals to leach from the RCG and impact surface water or groundwater that may be accessed and used for drinking water or recreational water, or where such a water body has an aquatic environment has been considered.

The key issues related to leching relate to the infiltration of rainwater into the RCG materials and the ongoing leaching of metals from this material into pore water, the migration or movement of pore water to groundwater, the migration and discharge of groundwater to surface water. Where there is limited potential for infiltration to occur (such as where RCG is bound in asphalt or concrete or sits directly beneath sealed surfaces) the potential for leaching to occur is very low.

As noted in **Section 4.4** of this report, the nature of RCG is consistent with what is expected in natural materials or clean fill and hence the potential for metals present in the RCG to be of concern to health or the environment, even where leaching may occur is considered negligible.

To provide further support for this outcome, given that RCG is not a natural material, a simple review of leaching and potential impacts to health and the environment has been undertaken. This is a simple review only, intended to supplement the assessment presented in **Section 4.4**.

C2 Leach potential and phase partitioning

Limited data[2] is available in relation to the relationship between the concentration in RCG and leachate (refer to **Table 4** in the main report for data from Queensland suppliers), hence for the purpose of this assessment it has been assumed that leaching may occur from the solids in RCG on the basis of the published soil-water partitioning coefficient, Kd (L/kg). This is the equilibrium partitioning ratio of the chemical in soil/RCG to that dissolved in pore water – i.e. mg/kg-soil/ mg/L-pore water. It is noted that the available data for RCG shows that leaching from the RCG solids to pore water is approximately 10 times lower than the values for soil. Hence use of the published values for soil-water, and assuming these are the same for RCG-water is conservative.

It is noted that NEPM (NEPC 1999 amended 2013d) defines chemicals with a high potential to leach as those with Log Kd <3. For these compounds NEPM indicates that leaching should be addressed where there is a water source in the vicinity of the contamination (NEPC 1999 amended 2013d). Based on this criterion, leaching is of potential significance for all the metals except chromium. For the purpose of this assessment all the metals have been considered.

C3 Migration to point of exposure

The potential for leachate to be present in groundwater (that may be extracted and used) to an off-site surface water body needs to consider the factors that may attenuate concentrations in pore water. The consideration of dilution or attenuation of leachable concentration is consistent with

[2] The leach data is considered limited as not all metals have been quantified in the leach tests and leach tests have only been undertaken on a limited number of samples. The data is also relevant to the RCG as supplied and testing has not considered long-term leaching from RCG where any external metal fines may have been removed.

guidance in the NEPM (NEPC 1999 amended 2013d), USEPA (USEPA 1996) and in published reviews in relation to road base materials (Engelsen et al. 2012).

The migration and mixing of pore water into groundwater results in some level of dilution or attenuation. The default dilution attenuation factor (DAF) adopted in the NEPM for assessing potential impacts to aquatic environments, related to contaminated soil which can extend over a large area, is 20. This is a default attenuation factor from the USEPA (USEPA 1996) and can be considered relevant for a general assessment of potential groundwater quality where RCG is used (regardless of the nature of the use). For this aspect:

Concentration (groundwater) = (Concentration leachate)/20

Where groundwater may then further migrate to and discharge to surface water, further dilution or attenuation occurs, including mixing within the surface water body. Assuming no mixing with migration of groundwater to surface water, Engelsen et al (2012) determined a generic factor of 20 for mixing into a small river or waterbody. This attenuation factor has been adopted in this review. Where this is then applied:

Concentration (surface water) = Concentration (groundwater)/20

which means,

Concentration (surface water) = Concentration (leachate)/400

C4 Evaluation of risks

Based on the calculation of leaching/phase partitioning and attenuations water concentrations have been estimated.

To enable an assessment of potential risks to human health, potential concentrations in groundwater and surface water have been compared against drinking water and recreational water guidelines relevant to Australia. This comparison is presented in **Table C1**.

To enable an assessment of potential risks to the environment, potential concentrations in surface water have been compared against available default Australian and New Zealand toxicant guideline values (DGVs) for fresh and marine water (ANZG 2018). The default toxicant values principally relate to the 95% species protection level, with the exception of some metals where bioaccumulation is of potential importance and the 99% species protection value is adopted as the default value. This comparison is presented in **Table C2**.

Table C1: Review of impacts to water – Human health

Metals	Limits for RCG (mg/kg dry weight unless otherwise specified)		Kd (L/kg)*	Concentration in groundwater (= RCG limit/Kd/20) (mg/L)		Concentration in surface water (= RCG limit/Kd/400) (mg/L)		Health based guideline (mg/L)	
	Maximum average concentration	Absolute maximum concentration		Maximum average concentration	Absolute maximum concentration	Maximum average concentration	Absolute maximum concentration	Drinking water N	Recreational water R
Mercury	0.5	1	52	0.0005	0.001	0.00002	0.00005	0.001	0.01
Cadmium	0.5	1.5	75	0.0003	0.001	0.00002	0.00005	0.002	0.02
Lead	50	100	900	0.003	0.006	0.0001	0.0003	0.01	0.1
Arsenic	10	20	29	0.02	0.03	0.0009	0.002	0.01	0.1
Chromium (total)	20	40	1800000	6×10^{-7}	1×10^{-6}	3×10^{-8}	6×10^{-8}	0.05 (as Cr VI)	0.5
Copper	40	120	35	0.06	0.2	0.003	0.009	2	20
Molybdenum	5	10	20	0.01	0.02	0.0006	0.001	0.05	0.5
Nickel	10	20	65	0.008	0.02	0.0004	0.0007	0.02	0.2
Zinc	100	300	62	0.08	0.2	0.004	0.01	3[a]	3[a]

* Kd values available from RAIS database, accessed in March 2020
N = Australian Drinking Water Guideline (NHMRC 2011 updated 2018); a = aesthetic guideline (taste) as no health based guideline available
R = Recreational water guideline, which is 10 times greater than the drinking water guideline as per NHMRC guidance (NHMRC 2008)

Table C2: Review of impacts to water – Aquatic ecosystems

Metals	Limits for RCG (mg/kg dry weight unless otherwise specified)		Kd (L/kg)*	Concentration in surface water (= RCG limit/Kd/400) (mg/L)		Aquatic guideline (DGV) N (mg/L)	
	Maximum average concentration	Absolute maximum concentration		Maximum average concentration	Absolute maximum concentration	Fresh water	Marine water
Mercury	0.5	1	52	0.00002	0.00005	0.00006 (99)	0.0001 (99)
Cadmium	0.5	1.5	75	0.00002	0.00005	0.0002	0.0007 (99)
Lead	50	100	900	0.0001	0.0003	0.0034	0.0044
Arsenic	10	20	29	0.0009	0.002	0.024 (As III) 0.013 (As V)	
Chromium (total)	20	40	1800000	3 x 10^{-8}	6 x 10^{-8}	0.0033 (Cr III) 0.001 (Cr VI)	0.027 (Cr III) 0.0044 (Cr VI)
Copper	40	120	35	0.003	0.009	0.0014	0.0013
Molybdenum	5	10	20	0.0006	0.001	0.034	0.011
Nickel	10	20	65	0.0004	0.0007	0.011	0.007 (99)
Zinc	100	300	62	0.004	0.01	0.008	0.015

* Kd values available from RAIS database, accessed in March 2020

N = Aquatic guidelines: Default guideline values (DGVs) for fresh or marine water as per the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018). The DGVs principally relate to the 95% species protection level, unless noted otherwise

(99) = 99% species protection level adopted as the DGV due to the bioaccumulative nature of the metal (in the environment evaluated)

Review of **Table C1** indicates that all predicted water concentrations are well below the relevant recreational water guideline and the drinking water guideline, with the exception of arsenic. For arsenic the estimated concentrations in in groundwater, where groundwater is accessed from the area where RCG is applied over a large area and used for the purpose of potable water exceeds the drinking water guideline. Groundwater is rarely extracted and directly used for drinking water. In some areas of Australia, groundwater is extracted from a number of locations, mixed and treated prior to being supplied as drinking water. Where this occurs a guideline that is 10 times higher than the drinking water guideline is adopted for an individual groundwater well. The arsenic concentrations in groundwater and lower than 10 x drinking water guidelines. In addition, where the 10-fold difference in leaching from RCG is considered there would not be expected to be any exceedance of drinking water guidelines.

Review of **Table C2** indicates that with the exception of copper, all predicted water concentrations are lower than the DGVs for the protection of fresh and marine water ecosystems.

In relation to copper, the water concentrations predicted exceed the fresh and marine water guidelines. It is noted that when evaluating potential impacts, it is not relevant to consider the absolute maximum limit. Where the water concentration derived from the maximum average limits is considered the water concentration only just exceeds the DGVs. For copper, some RCG leachate data is available from Queensland suppliers (refer to **Table 4** in the main report). This data suggests that Kd for RCG is in the range 220 to 880 (based on data from 10 samples). This is significantly less conservative than the published value of 35 adopted in the calculations undertaken. Where a Kd of 220 is adopted, the predicted water concentration for copper is below the DGVs for fresh and marine water.

Copper is also noted to be commonly present in surface water in Australia at levels that exceed the DGVs, due to background sources such as natural mineralogy. The water concentrations predicted are generally consistent with background and would not be considered to be of concern in relation to aquatic health.

On the basis of the above there are no risk issues of concern, for human health or the environment, in relation to the leaching of metals from RCG materials.

Appendix D SQP Report

Suitably qualified person written report

An application for an end of waste approval under section 173I of the Waste Reduction and Recycling Act 2011 *(the WRR Act) and an application to amend an end of waste approval under section 173M of the WRR Act must be accompanied by a written report prepared by a suitably qualified person about the application. This form is the approved form for the written report. Where more than one suitably qualified person has contributed to the written report, the lead suitably qualified person is required to complete this form.*

1. Report description

Please provide the following details regarding the suitably qualified person's report:

A BRIEF DESCRIPTION OF THE WASTE PROPOSED TO BE USED AS A RESOURCE AND THE PROPOSED USE:
Recycled crushed glass (RCG) proposed to be used by TMR in road pavements, which includes sealed asphalt, concrete and unbound granular pavement materials, pipe bedding and drainage, in accordance with a Techical Specification.

REPORT(S) TITLE; DATE; VERSION NUMBER AND AUTHOR:
Recycled Glass Specification and test Results: Technical Review, Revision C, 9 October 2020

NAME(S) OF SUITABLY QUALIFIED PERSON(S):
Dr Jackie Wright

APPLICATION TYPE: ☐ New end of waste approval application ☐ Amendment of end of waste approval

2. Information required

Please attach a document which addresses the following matters about the waste proposed to be used as a resource in the following format.

1. A summary of the application
2. An assessment of the technical validity, relevance, and accuracy of the information provided in the application
3. An assessment of the technical feasibility and benefits of the proposed use of the resource
4. An assessment of the risks associated with the proposed use of the resource and the adequacy of mitigation and protection measures
5. Conclusions and recommendations
6. ~~A statutory declaration as an attachment, providing:~~
   - ~~(i) confirmation that the information presented in the end of waste approval application or amendment application is, to the best knowledge of the person, accurate; and~~
   - ~~(ii) the contact details of the suitably qualified person~~
7. A signed statement which demonstrates that the person has the qualifications and experience appropriate for preparing the report – refer to Appendix A

Where more than one suitably qualified person is involved, please provide a signed statement for each person.

☐ Please tick this box to indicate that you have complied with the above format for the report.

3. Suitably qualified person details

SUITABLY QUALIFIED PERSON'S NAME:	COMPANY NAME:
Dr Jackie Wright	Environmental Risk Sciences Pty Ltd Contact: jackie@enrisks.com.au; +61 425 206 295
SIGNATURE: [signature]	DATE: 9 October 2020

Page 1 of 1 • ESR/2016/3290 • Version 2.01 • Effective: 15 SEP 2017

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