NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

ANNUAL SUMMARY REPORT

O25: Use of Recycled Materials in Earthworks and Drainage 2020–21 (Year 1)

ARRB Project No.: 015718

Author/s: John Nguyen, Jeffrey Lee, Lincoln Latter

Prepared for: Queensland Department of Transport and Main Roads

26/08/21

Final

AN INITIATIVE BY:

arrb Queensland Government

Summary

The objective of this project is to identify how recycled materials may be utilised as road embankment and drainage materials. This report has focused on the current Australian state road agency and selected international road agency requirements regarding the use of recycled products in road construction to identify potential quick wins that could facilitate the immediate increased use of recycled materials in Queensland.

The key findings of the literature review are as follows:

- Recycled crushed glass (RCG) passing the 4.75 mm sieve has the potential to improve the engineering properties of drainage layers, embankment, structural fill and subgrade applications at quantities of 20–30% by mass. Non-structural applications such as pipe bedding may incorporate up to 100% RCG by mass.
- Bottom ash may be suitable as an aggregate replacement for subbase materials and embankment fills. Additionally, bottom ash may also be used for utility bedding and drainage layers.
- Recycled materials are widely accepted for use in earthworks and drainage applications throughout Australia, the USA and the UK.
- VicRoads permits the use of recycled materials in the greatest number of applications, although limits are not specified.
- The Department of Infrastructure Planning and Logistics (DIPL) permits up to 100% RCG by mass in bedding material for drainage works, the highest proportion in granular support layers of the road agencies reviewed.
- Oregon Department of Transportation (ODOT) permits up to 100% RCG by mass in non-structural and drainage layers.
- Washington Department of Transportation (WSDOT) permits up to 100% recycled crushed concrete (RCC) by mass for non-structural fill and in structural pavement layers.
- The UK Department for Transport permits up to 50% RAP and 25% RCG in non-structural backfill, drainage layers and pavement structural layers. The use of bottom ash is also permitted in non-structural fill applications, although there is no specified limit.

Recommendations are proposed to achieve 'quick wins' in terms of optimising the use of recycled materials in Queensland.

Contents

1 Introduction ... 1
1.1 Background ... 1
1.2 Objectives and Approach ... 1
2 Recycled Materials ... 2
2.1 TMR's Current Approach ... 2
2.2 Recycling and Recovery in Queensland ... 2
2.3 Recycled Materials Suitable for Earthworks and Drainage Applications ... 3
2.3.1 Recycled Crushed Concrete (RCC) ... 3
2.3.2 Recycled Crushed Brick (RCB) ... 3
2.3.3 Recycled Crushed Glass (RCG) ... 3
2.3.4 Reclaimed Asphalt Pavement (RAP) ... 5
2.3.5 Industrial By-Products ... 5
3 Previous NACOE and Related Research ... 8
3.1 P76: The Use of Recycled Glass in Pavements ... 8
3.2 P94: Optimising the Use of Recycled Materials in Queensland for Unbound and Stabilised Products ... 8
3.3 P116: Recycled Materials in Roads – State of Play ... 9
4 Current National Practice ... 10
4.1 Queensland ... 10
4.1.1 Granular Fill for Improved Subgrade Layers ... 11
4.1.2 Drainage and Earthworks ... 12
4.1.3 Recycled Crushed Glass Specification ... 13
4.1.4 Glass Backfill Trial ... 13
4.2 New South Wales ... 17
4.2.1 Recycled Material for Low and Medium Traffic Roads ... 17
4.2.2 Recycled Material for Heavy Duty Pavements ... 18
4.3 South Australia ... 20
4.4 Victoria ... 20
4.4.1 Drainage Applications ... 21
4.4.2 Earthworks ... 22
4.5 Western Australia ... 23
4.5.1 Recycled Materials in Earthworks Projects ... 24
4.6 Northern Territory ... 24
4.7 Comparison of Australian Practice ... 24
5 Selected International Practice ... 26
5.1 United States of America ... 26
5.1.1 Oregon ... 26
5.1.2 Washington ... 27
5.1.3 Texas ... 27
5.2 United Kingdom ... 28

TC-710-4-4-9a

5.3 Comparison of TMR and International Practice 29
6 Summary and Recommendations 31
6.1 Year 1 Recommendations 31
6.2 Year 2 Scope 32
References 33
Appendix A New Zealand Specifications 38

Tables

Table 2.1: Amount of waste recovery in Queensland in 2018–19 ... 2
Table 2.2: Effect of blending glass with sediment dredged from rivers and lakes ... 4
Table 2.3: Bottom ash: physical characteristics and mechanical properties ... 6
Table 4.1: Reviewed national documents ... 10
Table 4.2: TMR limits of constituents in recycled material blends ... 11
Table 4.3: TMR grading envelopes Type 2 (recycled material blends) ... 11
Table 4.4: TMR limits of foreign materials in recycled material blends ... 12
Table 4.5: Bedding material properties ... 12
Table 4.6: TMR drainage layer PSD ... 12
Table 4.7: TMR chemical and other materials requirements of RCG ... 13
Table 4.8: Recycled glass aggregate maximum concentration limits ... 13
Table 4.9: Byrne RCG chemical concentration testing ... 14
Table 4.10: Envirosand RCG chemical concentration testing ... 15
Table 4.11: Byrne chemical testing ... 15
Table 4.12: Envirosand chemical testing ... 15
Table 4.13: Byrne RCG sieve test results ... 16
Table 4.14: Envirosand RCG sieve test results ... 16
Table 4.15: Specification requirements for supply of recycled material ... 17
Table 4.16: Particle size distribution limits for selected material ... 19
Table 4.17: Other property limits for selected material ... 19
Table 4.18: TfNSW foreign material limits for selected material ... 19
Table 4.19: TfNSW materials requirements for RCG ... 19
Table 4.20: VicRoads grading requirements for granular filter material ... 21
Table 4.21: VicRoads granular filter material requirements ... 21
Table 4.22: VicRoads foreign material limits ... 22
Table 4.23: VicRoads permeable fill material ... 22
Table 4.24: TC and ASLP thresholds for clean fill materials ... 22
Table 4.25: MRWA requirements for PSD of RCG ... 23
Table 4.26: MRWA foreign material limits ... 23
Table 4.27: DIPL blend of RCG and granular material PSD ... 24
Table 4.28: DIPL foreign material limits for selected material ... 24
Table 4.29: Comparison of state road agency practice regarding the use of recycled materials ... 25
Table 4.30: Recycled materials permitted by SRAs ... 25
Table 5.1: ODOT requirements for PSD of sand drainage blanket ... 26
Table 5.2: ODOT requirements for PSD of granular drainage blanket ... 26
Table 5.3: WSDOT requirements for maximum recycled material content by application ... 27
Table 5.4: WSDOT requirements for PSD of backfill for sand drains and sand drainage blankets ... 27
Table 5.5: Type A testing requirements ... 28
Table 5.6: Recycled material trials for embankments and backfill ... 28
Table 5.7: Department for Transport UK requirements for maximum recycled material content by application ... 29
Table 5.8: Comparison of TMR and international practice regarding permitted recycled materials and their permissible uses ... 29

TC-710-4-4-9a

Table 5.9: Comparison of TMR and international practice for permitted recycled materials in earthworks and drainage 30
Table 6.1: Summary of recycled materials for use in earthworks and drainage 32

Figures

Figure 2.1: Relationship between CBR (left) and swelling percentage (right) with RCG contents.............. 5
Figure 4.1: Construction of trench 16
Figure 4.2: RCG over conduit pipe 16

1 Introduction

1.1 Background

Queensland Department of Transport and Main Roads (TMR) is committed to be an environmentally, socially, and economically sustainable organisation that plans, delivers and manages a transport system that connects Queensland now and in the future. To help facilitate the sustainable increased use of recycled waste materials, the aim of NACOE Project O25 – *Use of Recycled Materials in Earthworks and Drainage 2019–20 (year 1)* is to build on research undertaken through previous NACOE projects that have facilitated the increased use of recycled materials in unbound and bound pavements used by TMR.

Waste materials to be considered for use in earthworks and drainage include:

- construction and demolition (C&D) waste such as concrete, brick, tiles and concrete washout
- recycled crushed glass
- recovered pavement materials (including granular and stabilised material as well as asphalt that is not suitable for reuse into those applications)
- railway ballast
- bottom ash.

1.2 Objectives and Approach

The purpose of this project is to look at ways to reutilise waste materials as road embankment and drainage materials. This report outlines the first year of this multi-year project. The primary objective of Year 1 was to review the use of recycled materials nationally and to identify 'quick wins' that could help facilitate the immediate increased use of recycled materials in TMR road infrastructure targeting these applications. The approach undertaken may be summarised as follows:

- Define the waste streams for Queensland to provide context and summarise the literature of usage, both locally and internationally, of the use of recycled materials in pavement applications – Section 2.
- Establish the context of the previous research work undertaken relevant to this project – Section 3.
- Review existing practice for each of the Australian state road agencies (SRAs) regarding the specifications and permissible uses of recycled materials in earthworks and drainage – Section 4.
- Undertake a review of selected international practice regarding specifications and permissible uses of recycled materials in earthworks and drainage – Section 5.
- Document findings based on the project outcomes, recommend any changes to current TMR practice, and outline the scope for Year 2 of this project – Section 6.

2 Recycled Materials

2.1 TMR's Current Approach

TMR's current approach to recycled materials provides the contractor/supplier a choice whether to use conventional or recycled materials (Trochez et al. 2021). TMR aims to specify the use of recycled materials that:

- provide as good, if not better, performance than conventional materials (in the appropriate application).
- do not harm the environment, the community or workers.
- do not cause operational issues in the longer term.
- are 're-recyclable' at the end of their life.

TMR has typically not mandated the use of recycled materials due to the lack of availability, quality of such materials throughout the state and for some recycled materials, the benefits and risks of usage have not been fully understood. If mandated, the benefits from industry competition may be lost due to limited capacity of recycled materials.

2.2 Recycling and Recovery in Queensland

In 2020, the Queensland Government published *Recycling and Waste in Queensland 2019* (Queensland Government 2020). It presents data relevant to, and trends in, waste recovery and disposal during the 2018–19 financial year. This report estimates that approximately 5.2 million tonnes of C&D waste was generated, while 3.0 million tonnes (57.7%) was recovered, an increase from the 50.8% recovery reported in 2017–18. However, it is important to note that 'recovered' refers to waste that has been diverted from landfill through recycling, reprocessing or stockpiling.

The main waste produced in Queensland during 2018–19 was concrete, asphalt and ferrous scrap metal, as summarised in Table 2.1. This shows that the quantity of concrete, asphalt and bricks and tiles has significantly increased since the last Queensland Government report in 2017. Notably, there has been a 21,000-tonne reduction in packaging glass sent for recovery by local governments due to the introduction of the container refund scheme (Queensland Government 2020).

Table 2.1: Amount of waste recovery in Queensland in 2018–19

Material	Quantity recovered or sent for recovery in Queensland (tonnes)	Change from 2016–17
Concrete	1,927,501	+30.5%
Asphalt	438,221	+25.7%
Bricks and tiles	73,278	+74.9%
Fibre cement	17,804	−6.5%
Timber	28,848	+37.7%
Packaging glass	98,000	−14.0%
Non-packaging glass	12,954	−21.2%
Non-packaging plastic	1,583	+49.3%
Ferrous scrap metal	357,193	+28.0%
Non-ferrous scrap metal	15,981	−0.6%
Fly ash	942,534 (1)	−0.2%
Bottom ash	97,407 (2)	

1. 5,184,142 tonnes of fly ash generated with a recovery rate of 18.2%.
2. 719,342 tonnes of bottom ash generated with a recovery rate of 13.5%.

Source: Queensland Government (2020).

2.3 Recycled Materials Suitable for Earthworks and Drainage Applications

This project focusses on recycled materials suitable for earthworks and drainage applications, using but not limited to the materials most commonly recycled in unbound pavements outlined in the Austroads *Guide to Pavement Technology Part 4E: Recycled Materials* (Austroads 2009). This includes, recycled crushed concrete (RCC), recycled crushed brick (RCB), recycled crushed glass (RCG), reclaimed asphalt pavement (RAP) and industrial by-products such as slag and fly ash.

2.3.1 Recycled Crushed Concrete (RCC)

As shown in Table 2.1, during the 2018–19 financial year, concrete was the material most sent for recovery (approximately 2 million tonnes). RCC is generally considered to be a strong, durable construction material. It is commonly used in unbound and cementitious pavements throughout Australia (Latter et al. 2020). Additionally, recent work undertaken through the NACOE program included updating MRTS05 *Unbound Pavements* (TMR 2020a) to allow Type 2 and Type 3 materials to be sourced from quarries or recycled material suppliers provided specification limits are achieved (Latter 2020a). The outcomes of this project are further discussed in Section 3.2.

2.3.2 Recycled Crushed Brick (RCB)

RCB is a C&D waste material that is suitable for use in pavements. Crushed and screened to a consistent particle size distribution (PSD), it can be used as supplementary material as part of crushed rock/recycled blends. However, RCB is prone to breakdown under compaction: results from repeat load triaxial (RLT), California Bearing Ratio (CBR), and Los Angeles abrasion testing have indicated that RCB is best utilised as a relatively small constituent of blends primarily consisting of virgin aggregates or RCC (Arulrajah et al. 2011). As shown in Table 2.1, bricks represented a relatively small proportion of the total material recovered in Queensland during 2018–19. Similar to RCC, recent work undertaken through the NACOE program included updating MRTS05 which allows for greater proportions of RCB in Type 2 and Type 3 materials to be used in pavements.

2.3.3 Recycled Crushed Glass (RCG)

Following sustainability principles, reusing material is preferred compared to recycling the material for other purposes. Glass cullet is recycled container glass prior to processing, typically collected from the municipal waste stream (Austroads 2009). However, to be recycled back into new food and beverage containers made from glass, this material needs to colour-sorted and contaminant free.

Throughout Australia, container refund schemes are being used to help increase the volume of glass bottles that can be recycled. Data from the Queensland Government (2020) (Table 2.1) indicates that, although these schemes can help reduce the amount of glass collected through municipal collection, there are still existing stockpiles of mixed colour crushed glass that are yet to be utilised.

The use of recycled glass as a pavement material is currently being researched through NACOE project P76 *The use of Recycled Glass in Pavements.* The outcomes of this work have led to the publication of MRTS36 *Recycled Glass Aggregate* (TMR 2020b) and the update of other relevant specifications, as discussed further in Section 3.1. Recycled crushed glass is also used as part of recycled material blends in the 2020 update of the MRTS05 specification (TMR 2020a).

Typically, recycled glass fines (e.g. particle size up to 5 mm) can be used as a partial replacement of natural aggregates in unbound and bound pavement material applications. The allowable proportion varies depending on the materials type and application.

Physical characteristics

The inclusion of RCG in unbound granular pavement applications, and its effect on the engineering properties compared to natural aggregates (such as sand), has been reported in the contemporary literature.

A comprehensive study undertaken by Stroup-Gardiner and Wattenberg-Komas (2013) on recycled materials and by-products in highway applications found the following:

- Physical properties such as permeability, soil classifications, maximum dry density and porosity depended on the final gradation of the glass cullet. RCG gradations could be classified as SP (poorly graded) or SW (well-graded) fine to coarse sand. Additionally, the constant head hydraulic conductivity at 90% modified compaction showed similar results to SW soil – indicating it should be relatively free draining.
- The ability of RCG to carry a load was very low, regardless of gradation, with a low California Bearing Ratio (CBR), indicating it was not suitable for base or subbase material.
- RCG may be used as a drainage material because of its good frictional characteristics and resistance to breakage under high confining pressures; it is suited for use as pipe bedding.
- RCG can enhance the permeability of material and decrease runoff from basecourse mixes.
- Material blends utilising RCG may result in a reduction in the amount of water needed to achieve OMC, potentially benefitting construction in areas with restricted access to water.
- RCG used as a drainage material worked best in combination with synthetic liners, geogrids or geotextiles when it was not placed directly on the liner materials. It was recommended to use RCG as a drainage material when there was a minimum depth of ground water or bedrock of 4 ft (approx. 1.2 m) and a minimum distance of 150 ft (45m) away from any surface water body.

Earthworks applications

In a study on the effect of blending glass with sediment dredged from rivers and lakes, Grubb et al. (2006a) blended dredged material (DM) (USCS classification OH) with a nominal size 9.5 mm RCG (USCS classification SP) at 20%, 40%, 50%, 60% and 80% by dry weight, as well as testing 100% mixes of both materials. The compaction and hydraulic conductivity results are summarised in Table 2.2, indicating that with as little as 20% RCG the compaction, moisture content and hydraulic conductivity improved.

Table 2.2: Effect of blending glass with sediment dredged from rivers and lakes

Material blend	Max. dry density (Standard compaction) (t/m³)	OMC (%)	Max dry density (Modified compaction) (kN/m³)	OMC (%)	Hydraulic conductivity (cm/s)
100% RCG	1.71	8	18.7	8	6.2E-02
80/20 RCG-DM	1.73	14	18.2	10	7.4E-03
60/40 RCG-DM	1.56	19	17.3	10.5	2.9E-05
50/50 RCG-DM	1.48	24	16.6	15	4.2E-06
40/60 RCG-DM	1.37	25	16.1	11.5	1.7E-06
20/80 RCG-DM	1.18	29	15.1	11	1.2E-06
100% DM	1.08	39	12.2	29	3.6E-06

Source: Grubb et al. (2006a).

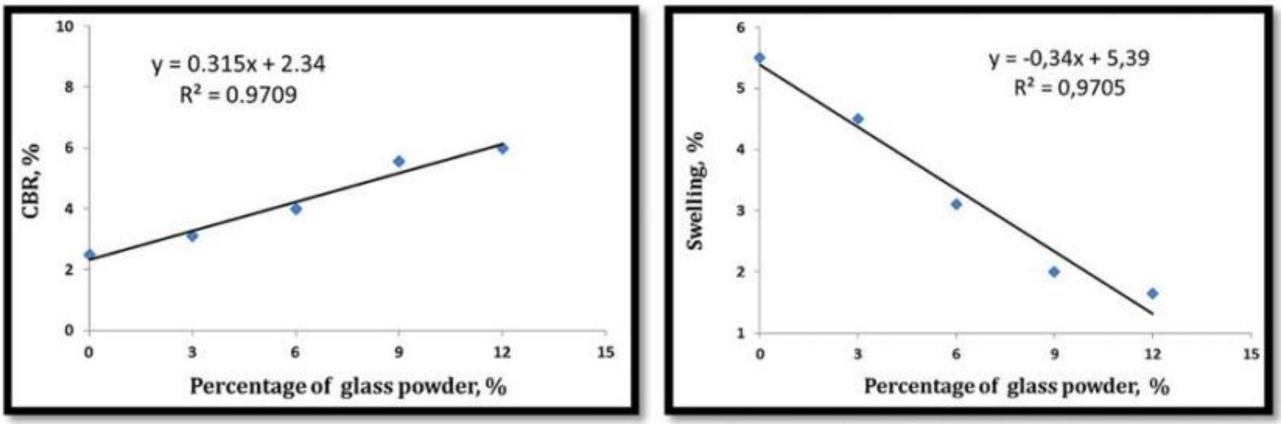
Based on the laboratory results, a field evaluation was undertaken on three RCG-DM blends, 20/80, 50/50 and 80/20 RCG-DM mixes focussing on compaction, workability, cone penetration and economic issues (Grubb et al. 2006b). This found that for embankment and structural fill applications the DM could be significantly improved using standard construction equipment with as little as 20% RCG, increasing the compaction and decreasing OMC. Additionally, this study noted that in metropolitan areas the use of RCG-DM blends leads to significant overall savings compared to the use of conventional fill materials. An investigation conducted by Mohsenian et al. (2015) found the following:

- Blending RCG with other materials can enhance the engineering properties as RCG is similar to natural aggregates. They are typically classified as well-graded sand or gravel materials based on gradation. The specific gravity (2.41–2.54) is lower than for most soils (2.65–2.72).
- RCG particles has low cohesion; therefore, it is recommended that, for load bearing applications such as pavement basecourse or subbase, RCG is only used as a replacement for fine aggregates.
- Studies of basecourse and subbase blends incorporating RCG have showed that, with increasing RCG contents, CBR values decreased for both Modified and Standard compactive effort.

- Whilst the moisture-density curve of an RCG is convex, similar to natural aggregates, it is flatter, indicating the relative insensitivity of RCG to moisture content. Therefore, RCG shows stable compaction behaviour and workability in large range of moisture content.
- The hydraulic conductivity for 100% RCG is between 0.000161 and 0.26 cm/s, classifies the material as relatively free-draining. This could result in satisfactory performance in filtration and drainage applications.

International studies have also shown that RCG may be used to improve the engineering properties of clayey soil, such as Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Atterberg limits and CBR. Davidovic et al. (2012) found that, with the incorporation of 20% RCG by mass in a clayey mix, the CBR increased by approximately 10%, from 6.4% to 7.3%. Similarly, a review on current practice conducted by Canakci et al. (2016) found that incorporating RCG fines passing the 0.3 mm sieve at up to 12% by mass, resulted in the CBR increasing from approximately 2% to 6% while the swelling reduced from 5.5% to 1.65%, as illustrated in Figure 2.1.

Figure 2.1: Relationship between CBR (left) and swelling percentage (right) with RCG contents



Source: Canakci et al. (2016).

2.3.4 Reclaimed Asphalt Pavement (RAP)

RAP is asphalt that has been milled or excavated from existing pavements, or unused asphalt returned from job sites (TMR 2020a). The Queensland waste recovery statistics for 2018–19 (Table 2.1) show that asphalt was the second highest recovered product. RAP is a high-value product typically reused in asphalt as both the amount of new aggregate and bitumen needed for mixes can be reduced, leading to significant economic and sustainability benefits. Although primarily used in new asphalt mixes, RAP that is too variable in nature or physical properties may be considered for use in granular pavement or fill applications. Similar to RCC, RAP is considered to be a strong, durable construction material as constituents are typically sourced from high-quality quarried materials. Its use is commonly permitted in pavement applications throughout the country.

2.3.5 Industrial By-Products

Industrial by-products include materials such as blast furnace slag (BFS), fly ash and bottom ash from coal-fired power stations. The consumption of coal in the boiler produces two main waste products, bottom ash and fly ash in the range of 10–30% and 70–90%, respectively (Abdullah et al. 2019). However, as there is an established use of fly ash as a binder additive for modified and stabilised pavement layers throughout Australia, this review will focus on high-value alternative recycling applications for bottom ash. Additionally, as there is no current producer of slag in Queensland, applications incorporating this by-product are imported from Japan, China or Thailand (TMR 2015), and as such, will not be included in this report.

The engineering properties and potential pavement applications of coal bottom ash are further discussed in the following sections.

Physical characteristics

A study by Kim and Lee (2015) noted that the size distribution of bottom ash particles is well-graded, ranging from gravel (40 mm) to silt-clay (0.075 mm), although this depends on the coal source and power plant configuration. Similarly, a review by Jayaranjan et al. (2014) found that bottom ash has a particle size in the range of 0.1–10 mm and a specific gravity of 2.30–3.00. Compared to fly ash, it is a coarse granular material. Research undertaken by Mohammed and Karim (2017) indicated that coal bottom ash exhibits similar properties to conventional aggregates, being an angular, porous particle with sizes similar to a well-graded sand with very low percentages of silt-clay-sized particles. A summary of the physical characteristics and mechanical properties of bottom ash is presented in Table 2.3.

Chemical characteristics

The chemical composition of bottom ash typically includes silicate, carbonate, aluminate, ferrous materials, heavy metals and metalloids, although the exact composition varies based on the raw coal source, size and operating conditions of the power plant (Jayaranjan et al. 2014; Kim & Lee 2015; Mohammed & Karim 2017). Similar to fly ash, bottom ash has the potential to provide pozzolanic reactivity when used with cement or cementitious materials due to the high amorphous silica and alumina content (Kim & Lee 2015). It is important to note that environmental testing has indicated that bottom ash is safe to use in civil engineering applications (Mohammed & Karim 2017).

Earthworks applications

A review of the literature indicated that bottom ash may be a suitable sand or fine aggregate replacement due to its properties being similar to natural sand. It provides adequate bearing capacity for lower-strength applications such as subbase materials and embankments fill. However, the compressive strength reduces as the bottom ash replacement percentage increases, although the data for these findings was not provided in this reference (Jayaranjan et al. 2014; Mohammed & Karim 2017; Abdullah et al. 2019). Other applications of bottom ash for geotechnical fill include (Kim & Lee 2015):

- The lower bulk density and excellent drainage capacity allow bottom ash to be used as a lightweight fill in soft ground.
- Bottom ash mixed with fly ash may be used as a backfill material with minimal thermal resistivity (approximately 30–60% of natural soils). It is therefore useful for dissipating the heat generated by buried utilities such as high-voltage power cables and oil and gas pipelines.
- Its high permeability and rough particle shape make it useful in geotechnical and drainage applications.

Table 2.3: Bottom ash: physical characteristics and mechanical properties

Property	Bottom ash [1]	Reference [2]
Physical characteristics		
Specific gravity Bulk density Saturated surface dry	 1.3–2.5 1.8–2.7	 2.3–2.7
Dry bulk density (t/m^3)	0.7–1.60	1.60–2.00
Absorption (wt. %)	0.8–6.0	< 2.0
Porosity (vol. %)	5–13	< 4.0
Uncompacted void content (vol. %)	30–50	< 35

Property	Bottom ash [1]	Reference [2]
Mechanical properties		
Angle of shearing resistance (°) Loose condition Dense condition	 32–45 46–55	 30–40 40–46
Optimum moisture content (%)	12–20	9–11
Los Angeles abrasion loss (%)	24–50	5–35
Soundness of particles by sodium sulfate (%)	1–10	< 15
California Bearing Ratio (CBR) (%)	36–110	10–80
Water permeability (m/sec)	10^{-2}–10^{-5}	10^{-1}–10^{-8}

1. Including boiler slag.
2. General sands and gravels with similar gradation of bottom ash.

Source: Kim and Lee (2015).

3 Previous NACOE and Related Research

3.1 P76: The Use of Recycled Glass in Pavements

In 2018, TMR sponsored a multi-year project under the National Asset Centre of Excellence (NACOE) research program. The aim of the project was to investigate how the use of RCG in pavement applications could be increased in both unbound granular pavement layers and asphalt layers. The findings from the first year of this project are detailed in *P76: Increasing the Use of Recycled Glass in Pavements* (Latter & Coomer 2020) and can be summarised as follows:

- 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.
- TMR requirements for RCG management are generally in line with the other Australian SRAs. 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 in DGA wearing courses.

Following the findings of the first year of this project, the second year involved an investigation of the performance of an asphalt mix containing up to 10% RCG by mass. The variability of RCG sourced from suppliers throughout Queensland was evaluated as a means of facilitating the increased use of RCG by developing new and updating current specifications. The main findings were as follows (Latter 2020b):

- Up to 10% RCG may be incorporated into asphalt intermediate layers without detrimentally impacting performance.
- Recycled glass suppliers in Queensland can produce a consistent product appropriate for use in asphalt and unbound pavement layers.
- There were no concerns in relation to environmental damage if RCG that complies with the proposed environmental specification limits was 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* (TMR 2020b) specifies the requirements for the use of RCG in asphalt and unbound granular applications. MRTS30 *Asphalt Pavements* (TMR 2020c), MRTS101 *Aggregates for Asphalt* (TMR 2020d) and Technical Note 148 *Asphalt and Microsurfacing Mix Registration* (TMR 2020f) were updated to allow RCG to be used in accordance with MRTS36.

It is important to note that, at the time of writing, the third year of this project is underway which provisionally includes the undertaking of a demonstration trial to assess the suitability of incorporating up to 5% RCG in an asphalt surfacing layer and visually inspecting sites containing RCG in the wearing course.

3.2 P94: Optimising the Use of Recycled Materials in Queensland for Unbound and Stabilised Products

NACOE project P94 is a multi-year project that commenced in 2018. The aim of the project is to identify how the use of recycled materials, focusing on RCC, can be optimised on TMR projects to achieve cost, sustainability and long-term performance benefits. The project included a literature review of existing practice in Australia for Year 1, while Year 2 included a performance assessment of materials sourced from various suppliers in Queensland with a view to updating TMR specifications. The findings can be summarised as follows (Latter et al. 2020):

- Recycled materials are suitable for base and subbase applications.
- In general, there is a strong alignment between specifications for traditional quarried materials and recycled materials.
- Recycled materials such as crushed concrete, crushed brick, RAP and crushed glass have been widely used in Australia and there may be scope to allow increased percentages in Queensland pavements.
- In terms of environmental considerations, there is general alignment across Australia in the testing and threshold values allowed.

The findings and outcomes of Year 2 can be summarised as follows (Latter 2020a):

- Type 2.1 and Type 2.3 recycled material blends (RMBs) produced by recycled material suppliers in Queensland consistently meet the requirements of MRTS05 and provide a practical alternative to quarried materials.
- Including up to 20% glass to an RMB has the potential to improve mix characterisation properties and performance measured using the wheel tracker and repeat load triaxial (RLT) test, although this was based on the comparison of material from only one supplier.
- TMR specification MRTS05 *Unbound Pavements* (TMR 2020a) was updated to become a single specification for all material suppliers, regardless of source.

Similar to NACOE project P76, the third year of this project is currently ongoing. The aim is to disseminate research outcomes by conducting knowledge transfer workshops/webinars for industry and internal stakeholders regarding the changes to the specification made as a result of Year 2 of the project. Additionally, Year 3 will include consultation with TMR districts with a view to setting up demonstration project, possibly including assistance with the monitoring and surveillance of these projects to help address any issues.

3.3 P116: Recycled Materials in Roads – State of Play

NACOE project P116 (Trochez et al. 2021) examined the current use of recycled materials across the TMR's network, including materials covered by TMR's standard specifications and also ongoing NACOE research into recycled materials.

The report explored potential and current applications for recycled materials such as crumb rubber, RAP, crushed concrete, crushed glass, crushed brick, fly ash, slag and plastics. It was concluded that the main barriers to the use of recycled materials included awareness; the availability of materials; procurement; perceived inferior performance; perceived health, safety and environmental concerns; and cost. Many of these barriers are being addressed through NACOE projects.

4 Current National Practice

Implementing recycled materials in earthworks and drainage is well established in some Australian jurisdictions, especially in metropolitan centres where a continuous supply of recycled materials is available. The management and permissible usage of recycled materials varies between jurisdictions. National specifications and documents reviewed are summarised in Table 4.1.

Table 4.1: Reviewed national documents

Jurisdiction	Documents reviewed
Queensland	MRTS04 *General Earthworks* (TMR 2020e) MRTS05 *Unbound Pavements* (TMR 2020a) MRTS36 *Recycled Glass Aggregate* (TMR 2020b) *Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology* (TMR 2018)
New South Wales	QA Specification R44 *Earthworks* (Transport for New South Wales (TfNSW) 2020a) QA Specification 3071 *Selected Material for Formation Layers* (TfNSW 2020b) QA Specification 3154 *Granulated Glass Aggregate* (TfNSW 2020c) Roads and Maritime Services (RMS) Supplement to Austroads *Guide to Pavement Technology Part 2: Pavement Structural Design* (RMS 2018)
South Australia	RD-EW-C1 *Earthworks* (DIT 2020a) RD-PV-S1 *Supply of Pavement Material* (DIT 2020b) RD-PV-D1 *Pavement Design (Austroads Supplement)* (DPTI 2019)
Victoria	Section 204 *Earthworks* (VicRoads 2015) Section 702 *Subsurface Drainage* (VicRoads 2019a) Section 801 *Material Sources for the Production of Crushed Rock and Aggregates* (VicRoads 2019b) Code of Practice RC 500.00 *Source Rock Investigations* (VicRoads 2012) Code of Practice RC 500.02 *Registration of Crushed Rock Mixes* (VicRoads 2017) Code of Practice RC 500.22 *Selection and design of pavements and surfacings* (VicRoads 2018) Technical Note 107 *Use of Recycled Materials in Road Pavements* (VicRoads 2019c)
Western Australia	Specification 302 *Earthworks* (Main Roads Western Australia (MRWA) 2019) Specification 501 *Pavements* (MRWA 2020)
Northern Territory	*Standard Specification for Roadworks* (Department of Infrastructure, Planning and Logistics (DIPL) 2020)

The Department of State Growth, Tasmania, has aligned their specifications with VicRoads. Similarly, the Australian Capital Territory (ACT) Transport Canberra and City Services (TCCS) has adopted the relevant Transport for NSW (TfNSW) specifications in many areas of road infrastructure and management. The required properties of recycled materials to be used as pavement materials are in accordance with TfNSW specifications and practice.

It is important to note that this literature review focused on the use of recycled materials in earthworks and drainage applications. Recycled materials used in unbound and bound pavement layers were considered in a separate NACOE project P94 (Latter et al. 2020; Latter 2020a).

4.1 Queensland

TMR manages earthworks in roadworks through MRTS04 *General Earthworks* (TMR 2020e). Currently, this specification only permits the use of recycled crushed glass materials for drainage applications, while the use of conventional and recycled materials is specified in MRTS05 *Unbound Pavements* (TMR 2020a). MRTS05 outlines requirements and permissible uses of RMBs for the construction, rehabilitation and maintenance of road pavements. Additionally, RCG materials are specified in MRTS36 *Recycled Glass Aggregate* (TMR 2020b).

4.1.1 Granular Fill for Improved Subgrade Layers

The incorporation of both conventional and recycled materials in pavement layers is outlined in TMR (2018). Whilst this report focuses primarily on earthworks, this section is included to provide context on current permissible uses of recycled materials in layers above earthworks.

MRTS05 (TMR 2020a) classifies unbound pavements materials into the following four types and up to five subtypes:

- Type 1 – high standard granular (HSG) used in the basecourse of heavy duty unbound pavements; it shall consist only of premium natural gravel or quarried materials.
- Type 2 – standard material typically used in basecourse, subbase and lower pavement layers that may be produced from either natural, quarried or recycled materials.
- Type 3 – standard materials similar to Type 2 except these are only intended for use in relatively dry environments. Type 2 material of the same subtype produced from either natural, quarried or recycled material may be used where a Type 3 material is specified.
- Type 4 – non-standard materials, typically used in drier parts of Queensland with low traffic volumes.

The proportion of recycled materials permitted in each subtype varies based on the intended usage of the material. Generally, RCC is the primary constituent in recycled material blends. Other recycled material limits such as RAP, RCB and RCG vary with material subtype, as summarised in Table 4.2. The grading envelopes for the Type 2 recycled material blends are summarised in Table 4.3. The material shall be free from clay and other aggregations of fine material, laminated particles, soil, organic matter and any other deleterious material as summarised in Table 4.4.

The TMR *Pavement design supplement* (TMR 2018) states that granular fill for improved subgrade layers may be comprised of Type 2.4 or Type 2.5 material, indicating that up to 100% RCC, 45% RAP and RCB and 20% RCG may be used for granular fill applications.

Table 4.2: TMR limits of constituents in recycled material blends

Subtype	Maximum limit of each constituent (% by mass of mix)				
	Natural gravel or quarry material	RCC	RAP	RCB	RCG
2.1	100	100	0	0	0
2.2	100	100	15	15	0
2.3	100	100	20	20	10
2.4	100	100	20	45	10
2.5	100	100	45	45	20

Source: TMR (2020a).

Table 4.3: TMR grading envelopes Type 2 (recycled material blends)

Sieve size (mm)	Percentage passing by mass of each subtype (%)		
	2.1 and 2.2	2.3 and 2.4	2.5
26.5	100	100	100
19.0	95–100	95–100	84–100
13.2	78–92	75–95	69–95
9.5	63–83	60–90	56–90
4.75	44–64	42–76	37–77
2.36	30–48	28–60	23–63
0.425	13–21	10–28	8–30
0.075	5–11	3–11	2–14

Source: TMR (2020a).

Table 4.4: TMR limits of foreign materials in recycled material blends

Constituents of foreign material type	Test method	Subtype	Maximum percent in mix (% by mass)
Brick	Q477	2.1	1.0
Asphalt		2.1	1.0
Metal, ceramics and slag (other than blast furnace slag)		All	3.0
Plaster, clay lumps and other friable material		All	1.0
Rubber, plastic, bitumen not part of asphalt, paper, cloth, paint, wood and other vegetable matter		All	0.2
Asbestos	0.0		

Source: Adapted from TMR (2020e).

4.1.2 Drainage and Earthworks

In accordance with TMR specification MRTS03 *Drainage, Retaining Structures and Protective Treatments* (TMR 2019), drainage structure bedding and haunch zone materials shall be placed in accordance with MRTS04 *General Earthworks* (TMR 2020e). MRTS04 allows well-graded bedding material made from RCG to be used for the foundation, bedding and haunch zone of drainage structures and services. The well-graded bedding material is required to meet the requirements in Table 4.5.

Table 4.5: Bedding material properties

Test sieve (mm)	Well-graded (per cent passing my mass)
19.0	100
9.5	–
2.36	50–100
0.6	20–90
0.075	0–10
Other properties: Linear Shrinkage (%)	6 maximum

Source: TMR (2020b).

MRTS04 states that Type 2.4 material may be used as unbound granular drainage layer material in the construction of subgrades. However, the drainage layer shall conform to the PSD summarised in Table 4.6. This indicates that up to 100% RCC, 20% RAP, 45% RCB and 10% RCG by mass may be used in unbound granular drainage layers.

Table 4.6: TMR drainage layer PSD

Sieve size (mm)	Per cent passing by mass
53	100
37.5	100
26.5	90–100
19.5	75–100
9.5	50–65
4.75	30–45
2.36	20–30
0.425	6–13
0.075	2–5

Source: TMR (2020a).

4.1.3 Recycled Crushed Glass Specification

The RCG utilised in TMR assets must meet the requirements set in MRTS36 *Recycled Glass Aggregate* (TMR 2020b):

- A nominal size of 5 mm or less.
- Produced from food and beverage container glass.
- 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 and free from any putrid odour.
- The maximum allowable concentration or other value of that attribute in any recovered glass aggregate must not exceed the values presented in Table 4.7.

Table 4.7: TMR chemical and other materials requirements of RCG

Chemicals and other attributes	Maximum average concentration	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 (2020b).

4.1.4 Glass Backfill Trial

TMR conducted a glass backfill trial on the M1 Sports Drive to Gateway upgrade project. The trial was conducted to PSTS118 *Recycled Glass Aggregate* (TMR 2020g) with the chemical concentration limits seen in Table 4.8. The results of the chemical concentration testing can be seen below in Table 4.9, Table 4.10, Table 4.11 and Table 4.12. The Byrne RCG samples were found to exceed zinc acidic pH test and on times the maximum characterisation average concentration. The recycled crushed glass was placed in a trench used for street lighting power cables and conduits. The glass was compacted in the same manner as bedding sand. Initially, a coarser glass was used which was found to be very dusty and have a pungent smell. The RCG was switched to a finer glass resulting in a significantly improved workability and a decreased amount of dust. In comparison to bedding sand, RCG was found to be self-draining and did not hold any water. It performed better in all weather conditions and when moisture was present in trenches. If presented the opportunity, the contractor stated they would use RCG as a backfill for trenches again.

Table 4.8: Recycled glass aggregate maximum concentration limits

Chemicals and other attributes	Maximum characterisation average concentration (mg/kg)	Maximum routine average concentration (mg/kg)	Absolute maximum concentration (mg/kg)	Absolute maximum leachate concentration (mg/L)
Mercury	0.5	Not required	1	0.1
Cadmium	0.5	0.5	1.5	0.01
Lead	50	50	100	0.1

Chemicals and other attributes	Maximum characterisation average concentration (mg/kg)	Maximum routine average concentration (mg/kg)	Absolute maximum concentration (mg/kg)	Absolute maximum leachate concentration (mg/L)
Arsenic	10	Not required	20	0.2
Chromium (total)	20	Not required	40	2
Copper	40	Not required	120	0.2
Molybdenum	5	Not required	10	2
Nickel	10	Not required	20	0.002
Zinc	100	100	300	2
Total organic carbon	1.0%	Not required	2.0%	-
Electrical conductivity	1,000 µS/cm	1,000 µS/cm	2,000 µS/cm	-
Foreign material	Contractor to nominate a process to ensure that the recycled glass aggregates are essentially free from foreign materials			
Metal				
Plaster, clay lumps and other friable materials				
Rubber, plastic, bitumen, paper, cloth, paint, wood and other vegetable matter				

Source: TMR (2020g).

Table 4.9: Byrne RCG chemical concentration testing

Chemicals and other attributes	Byrne S06 – 231A	Byrne S07 – 231B	Byrne S08 – S231C	Byrne S09 – 231D	Byrne S10 – 231E	Average
Mercury	< 2	< 2	< 2	< 2	< 2	< 2
Cadmium	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Lead	9.8	7.7	7.4	16	7	10
Arsenic	< 2	< 2	< 2	< 2	< 2	< 2
Chromium (total)	< 5	< 5	< 5	< 5	< 5	< 5
Copper	6	5.7	73[1]	5.7	5.7	19
Molybdenum	< 10	< 10	< 10	< 10	< 10	< 10
Nickel	<5	11	11	<5	<5	8
Zinc	90	83	83	180[1]	60	99
Total organic carbon	0.2	0.3	0.1	0.4	0.2	0.2
Electrical conductivity	54	69	52	300	61	107
Plaster, clay lumps and other friable materials	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %
Rubber, plastic, bitumen, paper, cloth, paint, wood and other vegetable matter	< 0.05 %	< 0.05 %	< 0.05 %	< 0.05 %	< 0.05 %	< 0.05 %

1. Exceeds the maximum average concentration.

Table 4.10: Envirosand RCG chemical concentration testing

Chemicals and other attributes	Envirosand S11 – 237A	Envirosand S12 – 237B	Envirosand S13– 237C	Envirosand S14– 237D	Envirosand S14– 237E	Average
Mercury	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cadmium	0.7	< 0.5	< 0.5	< 0.5	< 0.5	0.5
Lead	25	19	14	5.4	12	15
Arsenic	< 2	< 2	< 2	< 2	< 2	< 2
Chromium (total)	< 5	< 5	< 5	< 5	< 5	< 5
Copper	14	15	7.6	8.8	6.7	10
Molybdenum	< 10	< 10	< 10	< 10	< 10	< 10
Nickel	<5	<5	<5	<5	<5	<5
Zinc	50	49	15	18	25	31
Total organic carbon	0.2	0.2	0.6	2	0.3	1
Electrical conductivity	110	130	120	97	110	113
Plaster, clay lumps and other friable materials	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %	< 0.1 %
Rubber, plastic, bitumen, paper, cloth, paint, wood and other vegetable matter	< 0.05 %	< 0.05 %	< 0.05 %	< 0.05 %	< 0.05 %	< 0.05 %

Table 4.11: Byrne chemical testing

Chemicals and other attributes	Absolute maximum leachate concentration (mg/L)	Byrne acidic pH Test	Byrne neutral pH Test	Byrne alkaline pH Test
Lead	0.1	0.182	0.018	0.012
Copper	0.2	0.09	0.01	0.018
Zinc	2	4.34[1]	0.148	0.082

1. Exceeds maximum leachate concentration.

Table 4.12: Envirosand chemical testing

Chemicals and other attributes	Absolute maximum leachate concentration (mg/L)	Envirosand acidic pH test	Envirosand neutral pH Test	Envirosand alkaline pH Test
Lead	0.1	0.182	0.018	0.016
Copper	0.2	0.034	0.01	0.018
Zinc	2	4.34	0.148	0.082

In Table 4.13 and Table 4.14, the sieve test results can be seen with the Byrne RCG results showing the material is marginally coarser on the top end. However, it was noted by the contractor that this material was more sand-like than Envirosand RCG which was a more one-sized material which can be seen in the gradings. Figure 4.1 and Figure 4.2 show the construction process of the trench with the RCG used as backfill.

Table 4.13: Byrne RCG sieve test results

Property	Requirement	Byrne S06 – 231A	Byrne S07 – 231B	Byrne S08 – S231C	Byrne S09 – 231D	Byrne S10 – 231E
% passing 2.36 mm test sieve	85–100	82	83	81	85	82
% passing 0.075 mm test sieve	≤ 10	2	2	2	2	2
Linear shrinkage	6	N/A	N/A	N/A	N/A	N/A

Source: TMR (2020e).

Table 4.14: Envirosand RCG sieve test results

Property	Requirement	Envirosand S11 – 237A	Envirosand S12 – 237B	Envirosand S13 – S237C	Envirosand S14 – 237D	Envirosand S15 – 237E
% passing 2.36 mm test sieve	85–100	100	100	100	100	100
% passing 0.075 mm test sieve	≤ 10	3	4	3	3	5
Linear shrinkage	6	N/A	N/A	N/A	N/A	N/A

Source: TMR (2020e).

Figure 4.1: Construction of trench

Figure 4.2: RCG over conduit pipe

4.2 New South Wales

Transport for New South Wales (TfNSW) manages the use of recycled materials in earthworks and drainage applications through Quality Assurance (QA) Specification R44 *Earthworks* (TfNSW 2020a), *Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage* (Savage 2010) and QA Specification 3071 *Selected Materials for Formation Layers* (TfNSW 2020b).

Additionally, the use of RCG is managed through QA Specification 3154 *Granulated Glass Aggregate* (TfNSW 2020c). The pavement design methodology is described in the *Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design* (RMS 2018).

4.2.1 Recycled Material for Low and Medium Traffic Roads

The specification for the supply of recycled material for pavements, earthworks and drainage was written for light and medium traffic loadings. For design traffic loadings greater than 4 x 10^6, other specifications such as QA Specification 3051 should be used. Table 4.15 shows the specification requirements for various material types.

Select fill is placed on the subgrade to raise site levels in embankments, bedding material can be used for pipe bedding, and a drainage medium can be used as backfill material for stormwater pipes, sewer pipes or sub-surface drainage lines (Savage 2010).

Table 4.15: Specification requirements for supply of recycled material

		Material type				
Constituent/Property	**Test method**	Select fill	Bedding material	Drainage medium		
		Class S	Class B	Class D75	Class D20	Class D10
Suggested material proportions (max% by mass)						
Concrete(1)		100	100	100	100	100
Reclaimed asphalt		50	20	5	5	5
Clay brick tile, crushed rock, masonry		100	100	100	100	100
Run-of-station fly ash(2)		5	5	5	5	5
Crushed glass fines(3)		10	50	50	50	100
Maximum allowable contaminants (max% by mass)						
Asbestos		0	0	0	0	0
Metal, glass and ceramics(4)	T276 (RMS 2012d)	5	5	5	5	5
Plaster, clay lumps and other friable materials	T276 (RMS 2012d)	1	0.5	0.5	0.5	0.5
Rubber, plastic, bitumen, paper, cloth, paint, wood and other vegetable matter	T276 (RMS 2012d)	0.2	0.5	0.5	0.5	0.5

Particle size distribution						
Sieve size (mm)		Class S	Class B	Class D75	Class D20	Class D10
		Per cent passing (%)				
100	AS 1141.11, AS 1141.12 or AS 1289.3.6.1	100		100		
75		95–100		80–100		
53						
37.5						
26.5					100	
19.0		50–85		5–10	80–100	
13.2					5–10	100
9.5		40–80	100			
4.75			80–100			0–10
2.36		35–70	50–80			
0.425			10–35			
0.075			5–20	0–5	0–5	0–5
Atterberg limits						
Liquid Limit (%)	AS 1289.3.1.2 & AS 1289.3.2.1	NA	30 max	NA	NA	NA
Plasticity Index (%)		12 max	12 max	NA	NA	NA
% passing 0.425 mm sieve x PI		300 max	240 max	NA	NA	NA
Strength Properties						
CBR (%) – 4 day soak	AS 1289.6.1.1	30 min	NA	NA	NA	NA
Wet Strength (kN)	AS 1141.22	NA	NA	70 min	70 min	70 min
Wet/Dry Strength Variation (%)		NA	NA	35 max	35 max	35 max
Maximum Dry Compressive Strength (MPa)	T114 (RMS 2012a)	NA	1.0 min	NA	NA	NA
Unconfined Compressive Strength (MPa)	AS 1141.51	NA	1.5 max	NA	NA	NA
Particle Shape						
% Misshapen (2:1)	AS 1141.14	NA	NA	NA	NA	NA

1. The design of pavements using high percentages of crushed concrete must take into account the amount of available cement which may rehydrate when subject to moisture to create a rigid or semi-rigid pavement which may result in subsequent shrinkage cracking.
2. The design of pavements using fly ash must take into account the possibility of hydration and binding when subject to moisture which may create a rigid or semi-rigid pavement which may result in subsequent shrinkage cracking.
3. Crushed glass fines refer to clean glass, which has been processed to produce an aggregate product for which an exemption has been issued.
4. Glass referred to in Maximum Allowable Contaminants is unprocessed glass which has been roughly crushed but has not been processed to produce an aggregate product for which an Exemption has been issued.

Source: Savage (2010).

4.2.2 Recycled Material for Heavy Duty Pavements

TfNSW defines heavy duty pavements as roads having a design traffic loading of at least 10^7 equivalent standard axles (ESAs) in the design lane for the first 20 years of service (RMS 2018). Typically, these pavements have a layer on top of the natural subgrade comprised of selected subgrade material deemed the selected material zone (SMZ).

QA Specification 3071 states that the selected material may be naturally occurring, recycled or manufactured (TfNSW 2020c). The use of recycled materials must comply with material requirements for the selected material zone shown in Table 4.16 and Table 4.17. RAP may be used when blended with selected material up to a mass of 25% if it complies with TfNSW 3153 (TfNSW 2020c) However, the inclusion of recycled materials in these layers is governed by the foreign material limits summarised in Table 4.18.

Table 4.16: Particle size distribution limits for selected material

AS sieve (mm)	Per cent passing by mass (1)
53	100
37.5	95–100
19.0	50–85
6.7	40–80
2.36	35–70

1. Determined using Test Method TfNSW T106 (TfNSW 2021a), after pre-treatment specified in Annexure 3071/AX.

Source: TfNSW (2020c).

Table 4.17: Other property limits for selected material

Property	Test method	Requirement
$CBR_{4\ day}$, characteristic value (%)	RMS T117 (RMS 2012b)	
SMZ, upper 150 mm thick layer		33 min
SMZ, lower layer		19 min
Plasticity Index (PI)	TfNSW T108 (TfNSW 2021b) and T109 (TfNSW 2021c)	15 max
MDCS (MPa)	RMS T114 (RMS 2012a)	2 min (if PI < 3)
UCS (MPa)	RMS T131 (RMS 2012c)	1.5 max

Source: TfNSW (2020c).

Table 4.18: TfNSW foreign material limits for selected material

Material	Maximum % retained by mass on 4.75 mm sieve
Metal, glass (1) and ceramics	5.0
Plaster, clay lumps and other friable material	1.0
Rubber, plastic, paper, cloth paint, wood and other vegetable matter	0.2

1. Glass must comply with TfNSW QA Specification 3154 (TfNSW 2020c).

Source: TfNSW (2020c).

TfNSW allows RCG to be used as fine aggregate in road applications provided the material is of a granular form with a nominal size of 5 mm in accordance with QA Specification 3154 (TfNSW 2020c). Suppliers of RCG are required to have an established quality management system compliant with AS/NZS ISO 9001:2016 to ensure conformance to the requirements outlined in Table 4.19. RCG shall be primarily manufactured by crushing container glass and must not include glass from ceramics, cathode ray tubes, fluorescent light fittings or laboratory glassware (TfNSW 2020c).

Table 4.19: TfNSW materials requirements for RCG

Property	Acceptance criteria	Test method
Nominated PSD envelope Material finer than 75 µm	Within the nominated PSD report Report	AS 1141.11 AS 1141.2
Dry density	Report for all properties	RMS T279 (RMS 2012e)
Percentage of oversize material		
Flow time		
Uncompacted void content		

Property	Acceptance criteria	Test method
Water absorption	≤ 1.0 %	RMS T129 (RMS 2012f)
Dry particle density	Report for all properties	RMS T129 (RMS 2012f)
SSD density		

Source: TfNSW (2020c).

Additionally, the NSW Environmental Protection Authority (EPA) outlines further requirements for the supply of RCG for road building with respect to environmental concerns. This includes undertaking sampling and testing of the RCG in accordance with AS 1141.3.1-2012. When RCG is manufactured as part of a continuous process, characterisation shall be undertaken by collecting five samples per 4,000 tonnes to test the chemical attributes.

4.3 South Australia

The South Australian Department of Planning, Transport and Infrastructure (DPTI) specifies the requirements for the supply and delivery of materials to be used in earthworks through Specification RD-EW-C1 *Earthworks* (DIT 2020a) while Specification RD-PV-S1 *Supply of Pavement Materials* (DIT 2020b) contains the material requirements. The RD-PV-D1 *Pavement Design (Austroads Supplement)* (DPTI 2019) is used in conjunction with the material specifications to provide specific guidance on the permissible uses of recycled materials.

The materials permitted for use in earthworks by DPTI are separated into different classifications based on the intended usage. DPTI material classifications are:

- Type A – sand-clay, sand, rubble, quarry or pit overburden or by-product. Typically used as select fill support layers for heavy duty pavements.
- Type B – sand-clay, sand, rubble, quarry or pit overburden or by-product. Typically used as select fill support layers for heavy duty pavements.
- Type C – sand-clay, sand, clay, rubble, quarry or pit overburden or by-product. Typically used as select fill for pavement layers and for bedding fill applications.
- Type D – other material.
- General fill (GF) – requirements set out by project-specific contract documents, used in fill applications.
- Oversize – does not meet Type A, B or C criteria but is capable of being compacted in accordance with Specification R10 (DPTI 2017).

The use of recycled materials in these classes is permitted if the contractor can provide evidence that the materials will not cause any detrimental environmental effects and meet quality requirements in accordance with Specification RD-PV-S1 (DPTI 2020b).

Reclaimed concrete and blast furnace slag are allowed but limits on use are not listed. RCB, RAP and crushed tiles are classified as supplementary materials and are limited to 20% of the mass. The specifications do not make a specific mention of RCG while fly ash is only specified for use in stabilised and modified material applications.

4.4 Victoria

In Victoria, the use of recycled materials in pavement support layers is managed through the VicRoads Code of Practice RC 500.00 *Source Rock Investigations* (VicRoads 2012) and Code of Practice RC 500.02 *Registration of Crushed Rock Mixes* (VicRoads 2017) while pavement design is covered in Code of Practice RC 500.22 *Selection and Design of Pavements and Surfacings* (VicRoads 2018).

Specific requirements are outlined in Section 204 *Earthworks* (VicRoads 2015), Section 702 *Subsurface Drainage* (VicRoads 2019a) and Section 801 *Material Sources for the Production of Crushed Rock and Aggregates* (VicRoads 2019b). General guidance and a summary of recycled material practice is presented in Technical Note 107 *Use of Recycled Materials in Road Pavements* (VicRoads 2019c).

4.4.1 Drainage Applications

VicRoads permits the use of RCG and electrical arc furnace (EAF) slag in subsurface drainage, granular filter material in accordance with Section 702 (VicRoads 2019a). The grading requirements and property requirements are summarised in Table 4.20 and Table 4.21, respectively. The RCG must comply with the VicRoads Code of Practice RC 500.00 and Code of Practice RC 500.02 and shall meet the following requirements (VicRoads 2017):

- Crushed into a cubical shape without sharp edges or elongations and be a uniformly graded product with maximum particle size of 5 mm.
- Generally free of contaminants such as paper, corks, metals, and other harmful materials (maximum limit of 2% by mass).
- Sourced primarily from container glass and shall not include glass from ceramics, cathode ray tubes, fluorescent light fittings and laboratory glassware.
- Thoroughly washed and retested prior to use, where the measured total dissolved solids (TDS) of the granular filter material exceeds 1500 mg/L.
- The granular filter material shall be tested with the minimum frequencies outlined in Table 4.21 to ensure that all materials comply with the specified requirements.
- The Los Angeles Abrasion Value (LAV) shall be less than or equal to 35 (VicRoads 2019b).

Table 4.20: VicRoads grading requirements for granular filter material

Sieve size (mm)	Single and first stage filters					Second stage filters			
	A2	A3	A4	A5	A6	B1	B2	B3	B4
37.5	–	–	–	–	100	–	–	–	–
26.5	–	–	–	–	–	–	–	–	100
19.0	–	–	–	100	85–100	–	100	100	70–100
13.2	–	–	–	90–100	–	–	90–100	90–100	0–70
9.50	100	100	100	70–100	65–100	100	70–100	40–70	0–25
4.75	90–100	90–100	70–100	28–100	48–82	70–100	28–100	0–15	–
2.36	75–100	70–100	0–50	0–28	30–60	0–50	0–28	0–5	0–5
1.18	50–98	40–65	0–10	0–8	15–40	0–10	0–8	–	–
0.60	30–80	12–40	–	–	5–25	–	–	–	–
0.30	10–40	0–16	0–5	0–5	0–10	0–5	0–5	–	–
0.15	0–7	0–4	–	–	0–5	–	–	–	–
0.075	0–3	0–3	0–3	0–3	0–3	0–3	0–3	0–3	0–3

Source: Adapted from VicRoads (2019a).

Table 4.21: VicRoads granular filter material requirements

Test	Value	Minimum frequency of test
Grading	Table 4.20	On each production day – one per 500 tonnes
Unsound rock content by mass Total of marginal and unsound rock by mass	5% 10%	On each production day – one per 500 tonnes
Sand equivalent	80	On each production day – one per 500 tonnes
pH	6.0–10.0	One per 5000 tonnes
Total dissolved solids (glass fines only)	1500 mg/L	One per 5000 tonnes

Source: Adapted from VicRoads (2019a).

4.4.2 Earthworks

Recycled materials including RCC, RCB, RAP, RCG and slag are permitted to be blended to produce the following fill materials in accordance with Section 204 (VicRoads 2015):

- Type A material – a superior-quality material, typically used for capping layers, selected material, structural material, and verge material.
- Type B material – a medium-quality material that does not meet the requirements of Type A material and is usually specified with a minimum CBR value. It is typically used in selected material layers above the natural subgrade.
- Type C material – a lesser-quality material that does not meet the requirements of Type A or Type B material, but which may be used in Type C material zones of embankments.
- Permeable fill material – self-draining material.

The property requirements for Type A, Type B and Type C materials are not altered with or without the inclusion of recycled materials with the exception of foreign material limits (Table 4.22) although a maximum percentage of recycled materials is not specified.

Table 4.22: VicRoads foreign material limits

Foreign material	Maximum % retained by mass on 4.75 mm sieve
Low density and other friable materials (plastic, plaster, etc.)	3.0
Wood and other vegetable matter	0.5

Source: VicRoads (2015).

The permeable fill material shall be hard, durable, clean sand, gravel or crushed aggregate which is free of clay balls and perishable matter. The permitted gradings of this material are summarised in Table 4.23.

Table 4.23: VicRoads permeable fill material

Location	Type of permeable fill material (1)
Against structures	Grade A4, A5 or A6
Backfill for open jointed pipes	Grade A4, A5 or A6
Drainage blanket material	Grade A6 or B4

1. Grading requirements are in accordance with Section 702.

Source: VicRoads (2015).

Recycled material blends used in earthworks applications shall be classified as 'clean fill' in accordance with the *Hazard Categorisation and Management* (EPA 2009). This document contains guidance on waste characterisation, sampling and analysis and specific contaminant recommended thresholds. The simplified clean fill total concentration (TC) and Australian Standard Leaching Potential (ASLP) are summarised in Table 4.24.

Table 4.24: TC and ASLP thresholds for clean fill materials

Contaminant concentration thresholds	Clean fill material upper limits	
	ASLP (mg/L)	TC (mg/kg)
Arsenic	–	20
Barium	–	–
Beryllium	–	–
Boron	–	–
Cadmium	–	3
Chromium (VI)	–	1
Copper	–	100
Lead	–	300
Mercury	–	1

Contaminant concentration thresholds	Clean fill material upper limits	
	ASLP (mg/L)	TC (mg/kg)
Molybdenum	–	40
Nickel	–	60
Selenium6	–	10
Silver6	–	10
Tributyltin oxide	–	
Zinc	–	200

Source: EPA (2009).

4.5 Western Australia

The state road network in Western Australia is managed by Main Roads Western Australia (MRWA). The usage and management of recycled materials in earthworks and drainage applications is documented in Specification 302 *Earthworks* (MRWA 2019).

Specification 302 only directly references the use of recycled sand (recovered C&D waste) and RCG, although only RCG is specifically permitted for use as imported fill for embankment construction up to a maximum of 20% by mass. RCG used by MRWA must adhere to the following (MRWA 2019):

- Sourced from food and beverage containers or window glass. Shall not include recycled glass classified as hazardous waste such as, laboratory equipment, televisions, computers, cathode ray tubes, porcelain products or cook tops.
- Cleaned to eliminate undesirable odours.
- Comply with the Department of Water and Environmental Regulation (DWER) requirements for recycled materials.
- Well graded and comply with the PSD in Table 4.25, crushed into a cubical shape without sharp edges or elongations, and be a uniformly-graded product with maximum particle size of 5 mm.
- A shape crushing plant shall be included in the process to produce RCG.
- The 4.75 mm material shall not contain greater than 1% of particles with a maximum dimension ratio greater than 5:1.
- Contaminants are limited to the values outlined in Table 4.26.

Table 4.25: MRWA requirements for PSD of RCG

Sieve size (mm)	Per cent passing (%)
9.5	100
4.75	70–100
2.36	35–88
1.18	15–45
0.30	4–12
0.075	0–5

Source: MRWA (2019).

Table 4.26: MRWA foreign material limits

Material	Maximum % retained by mass on 4.75 mm sieve
High density materials (brick, glass, etc.)	5.0
Low density materials (plastic, plaster, etc.)	2.0
Wood and other vegetable matter	1.0

Source: MRWA (2019).

4.5.1 Recycled Materials in Earthworks Projects

The Northlink WA – Northern section project was a 22 km four-lane dual carriageway completed in 2020. The project used over 70,000 tonnes of crushed recycled glass as embankment fill. The material was primarily used to stabilise clay-based soils and materials and for dust suppression in the embankment layer due to its ability to hold more water than limestone. The project overcame issues such as the lack of glass recycling facility in the state and the cost of this material over virgin materials. (MRWA 2021).

4.6 Northern Territory

The Department of Infrastructure Planning and Logistics (DIPL) *Standard Specification for Roadworks* (DIPL 2020) permits the use of up to 100% RCG by mass as a bedding material for drainage works. RCG shall meet the following requirements:

- Sourced from container glass, building and window glass and plain ceramic and shall not include glass classified as hazardous waste, reinforced and laminated glass, light bulbs, fluorescent tubes and cathode ray tubes.
- Clean, hard, durable and meet the PSD summarised in Table 4.27 with a Plasticity Index less than 6.
- Free of debris such as paper, cardboard, plastic, fabrics and toxins where the foreign material limits are in accordance with the requirements summarised in Table 4.28 (Andrews 2009).
- Washed post-crushing to remove odours, traces of original contents, soil, sugars and labels (Andrews 2009).

Table 4.27: DIPL blend of RCG and granular material PSD

Sieve size (mm)	Percentage passing by dry mass (%)
19.0	100
2.36	50–100
0.60	20–90
0.30	10–60
0.15	0–25
0.075	0–10

Source: DIPL (2020).

Table 4.28: DIPL foreign material limits for selected material

Material	Maximum % retained by mass on 4.75 mm sieve
Metal	0.1
Plaster, clay lumps and other friable material	2.0
Rubber, plastic, paper, cloth paint, wood and other vegetable matter	0.2
Asbestos	0

Source: Adapted from Andrews (2009).

4.7 Comparison of Australian Practice

This section presents a comparison of practice in Queensland to the other Australian states and territories. The permissible use by each of the Australian SRAs is presented in Table 4.29 while Table 4.30 presents a comparison of the percentage of allowable recycled materials for each application. Generally, the Australian RCG requirements are similar between jurisdictions, although there is diversity in some respects which may be attributed to local materials and experience.

Table 4.29: **Comparison of state road agency practice regarding the use of recycled materials**

Criteria	TMR	TfNSW	DPTI	VicRoads	MRWA	DIPL
Materials permitted	• RCC • RCB • RCG • RAP	• RCC • Slag • RCB • RCG • RAP • Fly ash • Bottom ash (BA)	• RCC • BFS • RCB • Crushed tiles • RAP	• RCC • RCB • RCG • RAP	• RCG • Recycled sand	• RCG
Permissible uses	• Granular fill for improved subgrade layers • Unbound granular drainage layer • Drainage structure bedding and haunch zone	• Selected material for on top of natural subgrade	• Bedding fill applications • General fill • Type A, B, C and D select fill	• Subsurface drainage • Granular filter material • Capping layers • Selected material • Permeable fill	• Imported fill for embankment construction (RCG only)	• Bedding material for drainage works

Table 4.30: **Recycled materials permitted by SRAs**

Road agency	Application	Max allowable contents by mass (%)							
		RCC	Slag	RAP	RCB	RCG	FA	BA	Tiles
TMR	Granular fill for improve subgrade (Type 2.4)	100	–	20	45	10	–	–	–
	Granular fill for improve subgrade (Type 2.5)	100	–	45	45	20	–	–	–
	Unbound granular drainage layer (Type 2.4)	100	–	20	45	10	–	–	–
	Drainage structure bedding and haunch zone	–	–	–	–	N/S	–	–	–
TfNSW	Selected material zone	N/S	N/S	25	N/S	5	N/S	N/S	–
DPTI	Select fill, general fill and bedding fill	N/S	N/S	20(1)	20(1)	–	–	–	20(1)
VicRoads	Type A, B and C fill	N/S	N/S	N/S	N/S	N/S			
	Subsurface drainage and granular filter	–	N/S	–	–	100	–	–	–
MRWA	Embankment construction	–	–	–	–	20	–	–	–
DIPL	Bedding for drainage works	–	–	–	–	100	–	–	–

1. DPTI classifies recycled material (including RCB, crushed tile and RAP) other than RCC to be supplementary materials and individual limits are not generally specified. DPTI states that no more than 20% of supplementary materials may be incorporated into material blends.

Note: N/S = limit not specified.

General observations from the comparison between the current TMR requirements and other Australian practice include:

- Recycled materials are accepted for use in earthworks layers throughout certain states in Australia.
- The permissible percentage of RCC ranges from 0% to 100% in non-structural fill applications, excluding drainage layers.
- The permissible percentage of RAP ranges from 0% to 15% in non-structural fill applications, excluding drainage layers.
- The permissible percentage of RCG ranges from 0% to 20% in non-structural fill applications, excluding drainage layers.
- The DIPL permits up to 100% RCG by mass in bedding material for drainage works, the highest proportion in granular support layers of the agencies.

5 Selected International Practice

Selected international practice was reviewed regarding the use of recycled materials in pavement and earthworks layers. It is important to note that this international practice review focused on the UK and the USA as these countries have readily available specifications in English. New Zealand's specifications were also reviewed; however, recycled materials were only found to be used in pavements layers. More information can be found in Appendix A.

5.1 United States of America

Similar to Australia, recycled material usage and managements practices in the USA vary between each state jurisdiction. Practices in selected states are discussed in the following sections.

5.1.1 Oregon

The Oregon Department of Transportation (ODOT) is responsible for the construction and management of pavements in accordance with the *Standard Specifications for Construction* (ODOT 2021). Although no other recycled materials for earthworks layers are specifically mentioned, RCG is permitted to be used as a substitute for virgin aggregates in non-structural backfill up to 100% with the following requirements:

- Nominal size 5.66 mm and maximum 5% passing the 0.075 mm sieve.
- Clean, hard and durable with a maximum 10% foreign, deleterious materials that impacts the performance of the backfill.
- Minimum standard compaction of 90%.

Additionally, the ODOT permits RCG to be substituted for selected granular backfill and selected stone backfill fines. It is important to note that both the selected granular backfill and selected stone backfill do not have a required PSD envelope and are only required to contain no particle greater than 76.2 mm and 152.4 mm, respectively.

RCG may also be substituted for sand drainage blanket and granular drainage blanket material, provided the blend conforms to the PSD requirements summarised in Table 5.1 and Table 5.2, respectively. This implies that, for a sand drainage blanket, up to 100% RCG may be used but for a granular drainage blanket, a maximum of 10% by mass shall be included, based on the PSD and the 5.66 mm nominal size of RCG.

Table 5.1: ODOT requirements for PSD of sand drainage blanket

Sieve size (mm)	Per cent passing (%)
2.00	95–100
0.420	50–100
0.250	20–40
0.074	0–5

Source: ODOT (2021).

Table 5.2: ODOT requirements for PSD of granular drainage blanket

Sieve size (mm)	Per cent passing (%)
152.4	100
101.6	90–100
12.7	60–80
2.00	0–10
0.149	0–5

Source: ODOT (2021).

5.1.2 Washington

Pavement design and construction in Washington is managed by the Washington State Department of Transport (WSDOT) through the *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT 2020). This permits the use of RCC, RCG, RAP and slag to be blended with natural materials for pavement applications, as summarised in Table 5.3. The PSD requirements for RCG used in backfill for sand drains and sand drainage blankets is presented in Table 5.4.

Table 5.3: WSDOT requirements for maximum recycled material content by application

Application	Maximum allowable per cent by mass (%)			
	RAP	RCC	RCG	Slag
Coarse aggregate for concrete pavement	0	100	0	0
Aggregates for asphalt	varies	0	0	20
Ballast and permeable ballast	25	100	20	20
Crushed surfacing	25	100	20	20
Aggregate for gravel base	25	100	20	20
Gravel backfill for foundations	25	100	20	20
Gravel backfill for walls and pipe bedding	0	100	20	20
Gravel backfill for drains and drywells	0	0	20	0
Sand drainage blanket	0	0	20	0
Trench backfill	25	100	20	20
Gravel, select and common borrow	25	100	20	20
Select and common borrow (> 1 m below subgrade)	100	100	20	20
Pavement foundation	0	100	20	20

Source: WSDOT (2020).

Table 5.4: WSDOT requirements for PSD of backfill for sand drains and sand drainage blankets

Sieve size (mm)	Per cent passing (%)	
	Backfill for sand drains	Sand drainage blanket
63.5	–	90–100
12.7	90–100	–
4.76	57–100	24–100
2.00	40–100	14–100
0.297	3–30	0–30
0.149	0–4	0–7
0.074	0–3	0–3

Source: WSDOT (2020).

5.1.3 Texas

The Texas Department of Transport (TxDOT) permits the use of recycled materials in earthworks and drainage applications. Item 132 and Item 400 sets out the requirements for their use in embankments and backfill for structures such as piping.

RCC, RCG and RAP can be used in embankments depending on the plans of the project. RCG is permitted for use in bedding for pipes.

The following is a list of different types used in embankments from Item 132 (TxDOT 2014):

Type A – Granular material that is free from vegetation or other objectionable material and meets the requirements of Table 5.5.

Table 5.5: Type A testing requirements

Property	Specification Limit
Liquid Limit	≤ 45
Plasticity index (PI)	≤ 15
Bar linear shrinkage	≥ 2

Source: TxDOT (2014).

Type B – Materials such as rock, loam, clay or other approved materials.

Type C – Material meeting the specification requirements shown on the plans.

Type D – Material from required excavation areas shown on the plans.

TxDOT has conducted trials with recycled materials in embankments and backfill. Table 5.6 shows the different materials used in embankments and backfill trials.

Table 5.6: Recycled material trials for embankments and backfill

Material	District name	Results	Installed	Additional comments
RCG	Beaumont	Good	1997	Used 100% glass as driveway pipe fill material
RCC	Beaumont	Good	1994	Used for embankment to control erosion on Intercoastal Waterway
RCC	Corpus Christi	Excellent	1977	
RCC	Lufkin	Excellent	1982	
Coal Bottom Ash	Armarillo	Excellent	1993	
Coal Fly Ash	Armarillo	Good	1987	
Coal Fly Ash	Atlanta	Good – Poor	1985	
Coal Fly Ash	Childress	Good	1989	
Coal Fly Ash	Lubbock	Excellent	1987	
Coal Fly Ash	Lubbock	Excellent	1993	

Source: TxDOT (1998a), TxDOT (1998b), TxDOT (1998c).

5.2 United Kingdom

The Department for Transport UK outlines the requirements for pavement materials and construction through the *Manual of Contract Documents for Highway Works* (MCHW). MCHW *Series 600 Earthworks* (Department for Transport 2016) includes the national alterations (supplements) of the overseeing organisations of Scotland, Wales and Northern Ireland, which specifies the use of recycled materials in earthworks.

Series 600 permits recycled aggregate resulting from the processing of inorganic or mineral material previously used in construction up to 50% RAP and 25% RCG in earthworks applications. Notably, the recycled material must comply with BS EN 13242: 2013 *Aggregates for Unbound and Hydraulically Bound Materials for Use in Civil Engineering Work and Road Construction*.

Additionally, the Department for Transport classifies furnace bottom ash (FBA) as agglomerated pulverised fuel ash obtained from the bottom of the power station furnace and having particle size no larger than 10 mm and complying with BS EN 13242. Table 5.7 shows the permitted recycled materials by application, although maximum limits are not provided for all materials.

Table 5.7: **Department for Transport UK requirements for maximum recycled material content by application**

Application	Permitted recycled materials (% by mass)						
	RCC	RAP	RCB	RCG	Slag	Fly ash	FBA
General fill	Yes	50	Yes	25	Yes	Yes	Yes
Selected granular fill – starter layer	Yes	50	Yes	25	Yes	Yes	Yes
Selected granular fill – capping layer	Yes	50	Yes	25	Yes	Yes	Yes
Selected granular fill – drainage layers to reinforced soil and anchored earth structures	Yes	No	Yes	5	No	No	No
Selected granular fill – fill to reinforced soil and anchored earth structures	Yes	No	Yes	5	Yes	No	No
Selected granular fill – lower and upper bedding or surrounds for corrugated steel buried structures	Yes	No	Yes	5	No	No	No
Selected granular fill – fill to structures	Yes	No	Yes	5	Yes	No	No
Miscellaneous fill – lower trench fill	Yes	50	Yes	25	Yes	Yes	Yes

Source: Department for Transport (2016).

5.3 Comparison of TMR and International Practice

A summary of the practice specified in the international specifications reviewed compared to TMR practice regarding the permitted recycled materials and their allowable limits is presented in Table 5.8 while permitted materials by mass and application are summarised in Table 5.9. General observations from the comparison between the current TMR requirements and selected international practice include:

- Recycled materials are permitted to be used in New Zealand, the USA and the UK.
- ODOT permits up to 100% RCG by mass in non-structural and drainage layers while WSDOT permits up to 20% RCG by mass in structural and non-structural applications, including drainage layers.
- WSDOT permits up to 100% RCC by mass for non-structural fill and in structural pavement layers. However, RCC is not permitted in drainage blankets.
- The UK permits up to 50% RAP and 25% RCG in non-structural fill. The use of bottom ash is also permitted in non-structural fill applications, although there is no specified limit.

Table 5.8: **Comparison of TMR and international practice regarding permitted recycled materials and their permissible uses**

Criteria	Queensland	Texas	Oregon	Washington	United Kingdom
Materials permitted	• RCC • RCB • RCG • RAP	• RCC • RCG • RAP	• RCG	• RCC • RCG • RAP • Slag	• RCG • RAP • Bottom ash
Permissible uses	• Granular fill for improved subgrade layers • Unbound granular drainage layer • Drainage structure bedding and haunch zone	• Embankment Fill • Structural backfill	• Non-structural backfill (up to 100% by mass) • Drainage layer (up to 100% by mass)	• Non-structural backfill • Drainage layer • Select fill • Pavement structural layers	• Non-structural fill

Table 5.9: Comparison of TMR and international practice for permitted recycled materials in earthworks and drainage

Road agency	Application	Max allowable contents by mass (%)						
		RCC	Slag	RAP	RCB	RCG	Fly ash	FBA
TMR	General fill	N/P	N/P	N/P	N/P	N/P	N/P	N/P
	Granular fill for improve subgrade (Type 2.4)	100	–	20	45	10	–	–
	Granular fill for improve subgrade (Type 2.5)	100	–	45	45	20	–	–
	Unbound granular drainage layer (Type 2.4)	100	–	20	45	10	–	–
	Drainage structure bedding and haunch zone	–	–	–	–	N/S	–	–
ODOT	General fill	N/P	N/P	N/P	N/P	N/P	N/P	N/P
	Non-structural backfill	–	–	–	–	100	–	–
	Sand drainage blanket	–	–	–	–	100	–	–
	Granular drainage blanket	–	–	–	–	10	–	–
WSDOT	General Fill	N/P	N/P	N/P	N/P	N/P	N/P	N/P
	Ballast, crushed surfacing, basecourse, backfill for foundations, trench backfill and borrow materials	100	20	25	–	20	–	–
	Backfill for walls and pipe bedding and pavement foundation	100	20	0	–	20	–	–
	Backfill for drains and drywells and sand drainage blanket	0	0	0	–	20	–	–
	Borrow materials > 1 m below subgrade	100	20	100	–	20	–	–
TxDOT	General Fill/Embankment fill	N/S	N/P	N/S	N/P	N/S	N/P	N/P
	Structural backfill	–	–	–	–	N/S	–	–
Department for Transport UK	General fill, select granular fill for starter layer and capping layer and lower trench fill	N/S	N/S	50	N/S	25	N/S	N/S
	Select granular fill for; fill to reinforced soil and anchored earth structures and fill to structures	N/S	N/S	50	N/S	5	–	–
	Select granular fill for; drainage layers to reinforced soil and anchored earth structures and lower and upper bedding or surrounds for corrugated steel buried structures	N/S	–	–	N/S	5	–	–

Note: N/S = limit not specified, N/P = not permitted.

6 Summary and Recommendations

The objective of this project is to identify how recycled materials may be reutilised as road embankment and drainage materials. This report has focused on the current Australian state road authorities and selected international road agency requirements regarding the use of recycled products in road construction to identify potential quick wins that could facilitate the immediate increased use of recycled materials in Queensland.

The key findings of the literature review are as follows:

- RCG passing the 4.75 mm sieve has the potential to improve the engineering properties of drainage layers, embankment, structural fill and subgrade applications at quantities of 20–30% by mass. Non-structural applications such as pipe bedding may incorporate up to 100% RCG by mass.
- Bottom ash may be suitable as an aggregate replacement for subbase materials and embankment fills. Additionally, bottom ash may also be used for utility bedding and drainage layers.
- Recycled materials are accepted for use in earthworks and drainage applications throughout Australia, the USA and the UK in limited applications.
- VicRoads permits the use of recycled materials in the greatest number of applications, although limits are not specified.
- DIPL permits up to 100% RCG by mass in bedding material for drainage works, the highest proportion in granular support layers of the road agencies reviewed.
- ODOT permits up to 100% RCG by mass in non-structural and drainage layers.
- WSDOT permits up to 100% RCC by mass for non-structural fill and in structural pavement layers.
- The UK Department for Transport permits up to 50% RAP and 25% RCG in non-structural backfill, drainage layers and pavement structural layers. The use of bottom ash is also permitted in non-structural fill applications, although there is no specified limit.

6.1 Year 1 Recommendations

The following recommendations from Year 1 of the project are proposed to achieve 'quick wins' in terms of optimising the use of recycled materials in Queensland:

- Allow the use of RCG in embankment fill in MRTS04 up to 20% by mass, matching MRWA. Add Table 4.25 to Clause 19.2.2 of MRTS04. For example, up to 20% by of RCG mass may be used in embankments if it complies with Table 4.25 and MRTS36.

  The allowable proportion of RCG permitted in bedding material and drainage aggregate could be clarified to allow up to 100% RCG by mass, aligning TMR limits more closely with DIPL and based on the environmental findings of NACOE P76.

  For example, change Clause 19.2.7 in MRTS04 to 'well-graded bedding material may be manufactured from up to 100% recycled crushed glass that complies with the requirements of MRTS36 recycled glass aggregate with potential additional grading requirements'.
- Allow the use of recycled materials in Cl 14.2 Materials. For example:
  - 'Fill material used in embankments shall be either earth fill or rock fill material, and shall be sourced from:
    - general excavations on the site
    - borrow areas on or off the site, or
    - other stockpiled materials (including quarried materials and recycled materials such as RCC, RCG, RCB, RAP'.
- With Year 2 of this project involving the use of RCC in drainage applications, Clause 19.2.7 can be changed to 'Bedding material and drainage aggregate (including recycled crushed glass and recycled crushed concrete)'.

These constituent limits may be further reviewed following laboratory determination of recycled material properties, proposed for Year 2 of this project (Section 6.2). It is also envisaged that this laboratory testing will inform possible changes to TMR recycled property requirements, gradings and permissible uses.

Table 6.1 shows the current allowable content with recycled materials and the proposed changes t to the specification.

Table 6.1: Summary of recycled materials for use in earthworks and drainage

Material	Application	Current max allowable contents (% by mass)	Proposed max allowable contents (% by mass)	Reference
RCC	Granular fill for improve subgrade (Type 2.4 and Type 2.5)	100	100	TMR (2018) TMR (2020a)
	Unbound granular drainage layer (Type 2.4)	100	100	TMR (2018) TMR (2020a)
	General fill	0	20	TMR (2020e)
	Backfill for bedding and drainage	0	100	TMR (2020e)
RAP	Granular fill for improve subgrade (Type 2.4)	20	20	TMR (2018) TMR (2020a)
	Granular fill for improve subgrade (Type 2.5)	45	45	TMR (2018) TMR (2020a)
	Unbound granular drainage layer (Type 2.4)	20	20	TMR (2018) TMR (2020a)
	General fill	0	20	TMR (2020e)
RCB	Granular fill for improve subgrade (Type 2.4 and Type 2.5)	45	45	TMR (2018) TMR (2020a)
	Unbound granular drainage layer (Type 2.4)	45	45	TMR (2018) TMR (2020a)
	General fill	0	20	TMR (2020e)
RCG	Granular fill for improve subgrade (Type 2.4)	10	20	TMR (2018) TMR (2020a)
	Granular fill for improve subgrade (Type 2.5)	20	20	TMR (2018) TMR (2020a)
	Unbound granular drainage layer (Type 2.4)	10	20	TMR (2018) TMR (2020a)
	Drainage structure bedding & haunch zone	N/S	100	TMR (2020e)
	Embankment fill	0	20	TMR (2020e)
	General fill	0	20	TMR (2020e)

6.2 Year 2 Scope

It is anticipated that, in Year 2 of the project, further laboratory testing will be undertaken on waste stream material that has the potential to be reused for drainage and earthwork applications.

Recycled crushed concrete will be tested and the results compared with the MRTS04 requirement. Recommendation from a suitably qualified person will also be sought based on the test results from associated chemical analysis.

Depending upon the budget constraints, other waste streams such as the bottom ash and/or RAP will also be investigated in Year 2. Any amended changes to MRTS04 will be disseminated in future industry workshops.

References

Abdullah, MH, Rashid, ASA, Anuar, UHM, Marto, A & Abuelgasim, R 2019, 'Bottom ash utilization: a review on engineering properties and environmental aspects', *IOP Conference Series: Materials and Science Engineering,* vol. 527, p. 9.

Andrews, R 2009, *Specification for Recycled Crushed Glass as an Engineering Material*, prepared for the Packing Stewardship Forum of the Australian Food and Grocery Council, ARRB Group, Vermont South, Vic.

Arulrajah, A, Piratheepan, J, Aatheesan, T & Bo, MW 2011, 'Geotechnical properties of recycled crushed brick in pavement applications', *Journal of Materials in Civil Engineering,* vol. 23, no. 10, pp. 1444–52.

Austroads 2009, *Guide to pavement technology part 4e: recycled materials*, AGPT04E-09, Austroads, Sydney, NSW.

Canakci, H, AL-Kaki, A & Celik, F 2016, 'Stablization of Clay with Waste Soda Lime Glass Powder', University of Gaziantep, Turkey.

Davidovic, N, Bonic, Z & Prolovic, V 2012, 'Waste glass as additive to clayey material in subgrade and embankment of road pavement', *Architecture and Civil Engineering*, vol. 10, no. 2, pp. 215–22, doi: 10.2298/FUACE1202215D.

Department for Transport 2016, *Manual of contract documents for highway works, Volume 1: specification for highway works – Series 600: Earthworks*, London, UK.

Department of Infrastructure and Transport 2020a, *Earthworks,* RD-EW-C1, DPTI, Adelaide, South Australia.

Department of Infrastructure and Transport 2020b, *Supply of pavement material,* RD-PV-S1, DPTI, Adelaide, South Australia.

Department of Infrastructure and Transport 2020c, *Pavement design (Austroads supplement),* RD-PV-D1, DPTI, Adelaide, South Australia.

Department of Infrastructure, Planning and Logistics 2020, *Standard specification for roadworks,* DIPL, Darwin, NT.

Department of Planning, Transport and Infrastructure 2017, *Specification part R10: construction of earthworks*, DPTI, Adelaide, SA.

Department of Planning, Transport and Infrastructure 2019, *Pavement design (Austroads supplement),* RD-PV-D1, DPTI, Adelaide, SA.

Environment Protection Agency 2009, Soil h*azard categorisation and management,* EPA, Victoria.

Grubb, DG, Gallagher, P, Wartman, J, Liu, Y & Carnival, M 2006a, 'Laboratory evaluation of crushed glass-dredged material blends', *Journal of Geotechnical and Geoenvironmental Engineering*, pp. 562–76, doi: 10.1061/(ASCE)1090-0241(2006)132:5(562).

Grubb, DG, Atwood, FD, Steven, CS, Carnivale, M, Wartman, J & Gallagher, P 2006b, 'Field evaluation of crushed glass-dredged material blends', *Journal of Geotechnical and Geoenvironmental Engineering,* pp. 577–590, doi: 10.1061/(ASCE)1090-0241(2006)132:5(577).

Jayaranjan, MLD, van Hullebusch, ED & Annachhatre, AP 2014, 'Reuse options for coal fired power plant bottom ash and fly ash', *Reviews in Environmental Science and Biotechnology,* vol. 13, pp. 467–86.

Kim, HW & Lee, HK 2015, ‘Coal bottom ash in field of civil engineering: a review of advanced applications and environmental considerations’, *KCSE Journal of Civil Engineering,* vol. 19, no. 6, pp. 1802–18.

Latter, L & Coomer, J 2020, ‘P76: the use of recycled glass in pavements year 1 (2018/2019): annual summary report’, contract report PRP10846, prepared for Queensland Department of Transport and Main Roads under the NACoE program, ARRB, Port Melbourne, Vic.

Latter, L 2020a, ‘P94: optimising the use of recycled materials in Queensland for unbound and stabilised products year 2 (2018/2019): annual summary report, contract report 014396’, prepared for Queensland Department of Transport and Main Roads under the NACoE program, ARRB, Port Melbourne, Vic.

Latter, L 2020b, ‘P76: increasing the use of recycled glass in pavements year 2 (2019/2020), annual summary report’, contract report 014959, prepared for Queensland Department of Transport and Main Roads under the NACoE program, ARRB, Port Melbourne, Vic.

Latter, L, Mohammadinia, A & Beecroft, A 2020, ‘P94: optimising the use of recycled materials in Queensland for unbound and stabilised products year 1 (2018/2019): annual summary report’, contract report PRP18038, prepared for Queensland Department of Transport and Main Roads under the NACoE program, ARRB, Port Melbourne, Vic.

Main Roads Western Australia 2019, *Earthworks*, Specification 302, MRWA, Perth, WA.

Main Roads Western Australia 2020, *Pavements*, Specification 501, MRWA, Perth, WA.

Main Roads Western Australia 2021, *Recycled materials at Main Roads*, MRWA, Perth, WA.

Mohammed, SA & Karim, MR 2017, ‘Review: application of coal bottom ash as aggregate replacement in highway embankment, acoustic absorbing and asphalt mixtures’, *Materials Science and Engineering,* vol. 210, pp. 1–4.

Mohsenian, Valillancourt & Carter 2015, *Current state of the art practice of use of glass in pavement structures,* Transportation Association of Canada, Ottawa, Ontario.

Oregon Department of Transportation 2021, *Standard specifications for construction,* ODOT, Oregon, USA.

Queensland Department of Transport and Main Roads 2015, *How ‘Green’ is our Concrete,* Technical Note 59

Queensland Department of Transport and Main Roads 2018, *Supplement to ‘Part 2: pavement structural design’ of the Austroads guide to pavement technology*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2019, *Drainage, retaining structures and protective treatments,* MRTS03, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2020a, *Unbound pavements,* MRTS05, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2020b, *Recycled glass aggregate,* MRTS36, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2020c, *Technical specification – Transport and Main Roads specifications MRTS30: Asphalt pavements*.

Queensland Department of Transport and Main Roads 2020d, *Technical specification – Transport and Main Roads specifications MRTS101: Aggregates for asphalt*.

Queensland Department of Transport and Main Roads 2020e, *General earthworks,* MRTS04, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads 2020f, *Asphalt and microsurfacing mix registration,* Technical Note 148.

Queensland Department of Transport and Main Roads 2020g, *Project specific technical specification – Transport and Main Roads specifications PSTS118: Recycled glass aggregate*.

Queensland Government 2020, *Recycling and waste in Queensland 2019*.

Roads and Maritime Services 2012a, Maximum dry compressive strength of road construction materials, test method T114, RMS, Sydney, NSW.

Roads and Maritime Services 2012b, California Bearing Ratio of remoulded specimens of road construction material, test method T117, RMS, Sydney, NSW.

Roads and Maritime Services 2012c, Unconfined compressive strength of road construction materials (blended in the laboratory with cementitious binders), test method T131, RMS, Sydney, NSW.

Roads and Maritime Services 2012d, Foreign materials content of recycled crushed concrete, test method T276, RMS, Sydney, NSW.

Roads and Maritime Services 2012e, Flow time and voids content of fine aggregate by flow cone, test method T279, RMS, Sydney, NSW.

Roads and Maritime Services 2012f, Particle density and water absorption of the fine sand fraction of soils, test method T129, RMS, Sydney, NSW.

Roads and Maritime Services 2018, *Supplement to Austroads guide to pavement technology part 2: pavement structural design*, RMS, Sydney, NSW.

Savage, M 2010, *Specification for supply of recycled material for pavements, earthworks and drainage*, Department of Environment, Climate Change and Water, Sydney, NSW.

Stroup-Gardiner, M & Wattenberg-Komas, T 2013, *Recycled materials and byproducts in highway applications: volume 8: manufacturing and construction byproducts,* NCHRP Synthesis of Highway Practice no. 435, NCHRP, Washington, DC, USA.

Texas Department of Transportation 1998a, *January crushed concrete, year of the recycled roadway materials*, TxDOT, Austin, Texas.

Texas Department of Transportation 1998b, *February glass cullet, year of the recycled roadway materials*, TxDOT, Austin, Texas.

Texas Department of Transportation 1998c, *November coal combustion products, year of the recycled roadway materials*, TxDOT, Austin, Texas.

Texas Department of Transportation 2014, *Embankment,* Item 132, TxDOT, Austin, Texas.

Transit New Zealand 2006, *Specification for basecourse aggregate,* M/4, TNZ, Wellington, NZ.

Transport for New South Wales 2020a, *Earthworks,* QA Specification R44, TfNSW, Sydney, NSW.

Transport for New South Wales 2020b, *Selected materials for formation layers,* QA Specification 3071, TfNSW, Sydney, NSW.

Transport for New South Wales 2020c, *Granulated glass aggregate,* QA Specification 3154, TfNSW, Sydney, NSW.

Transport for New South Wales 2021a, Coarse particle size distribution of road construction materials (by washing), Test method T106.

Transport for New South Wales 2021b, *Liquid limit of road construction materials*, Test method T108.

Transport for New South Wales 2021c, *Plastic limit and plasticity index of road construction materials*, Test method T109.

Trochez, J, Grenfell, J & Harrison, J 2021 'P116: recycled materials in roads: Queensland state of play (2019-20)', contract report 015264, prepared for Queensland Department of Transport and Main Roads under the NACoE program, ARRB, Port Melbourne, Vic.

VicRoads 2012, *Source rock investigations,* Code of Practice RC 500.00, VicRoads, Melbourne, Vic.

VicRoads 2015, *Earthworks,* Section 204, VicRoads, Melbourne, Vic.

VicRoads 2017, *Registration of crushed rock mixes,* Code of Practice RC 500.02, VicRoads, Melbourne, Vic.

VicRoads 2018, *Selection and design of pavements and surfacings,* Code of Practice RC 500.22, VicRoads, Melbourne, Vic.

VicRoads 2019a, *Subsurface drainage,* Section 702, VicRoads, Melbourne, Vic.

VicRoads 2019b, *Material sources for the production of crushed rock and aggregates*, Section 801, VicRoads, Melbourne, Vic.

VicRoads 2019c, *Use of recycled materials in road pavements,* TN107, VicRoads, Melbourne, Vic.

Washington State Department of Transportation 2020, *Standard specifications for road, bridge and municipal construction,* WSDOT, Olympia, WA, USA.

Australian Standards

AS1141.2 2015, and 2018, *Methods for sampling and testing aggregates – basic testing equipment*.

AS1141.3.1-2012, *Methods for sampling and testing aggregates – sampling – aggregates*.

AS1141.11-2009, *Methods for sampling and testing aggregates: particle size distribution – sieving method.*

AS1141.12-1996, *Methods for sampling and testing of aggregates - Materials finer than 75 micrometre in aggregates (by washing)*.

AS1141.14-2007, *Methods for sampling and testing aggregates – particle shape, by proportional caliper*.

AS1141.22-2008, *Methods for sampling and testing aggregates – wet/dry strength variation*.

AS1141.51-1996, *Methods for sampling and testing aggregates – Unconfined Compressive Strength of compacted materials, superseded in 2017*.

AS1289.3.1.2-2009, *Methods of testing soils for engineering purposes Soil classification tests – Determination of the liquid limit of a soil – One point Casagrande method (subsidiary method)*.

AS1289.3.2.1-2009, *Methods of testing soils for engineering purposes: soil classification tests – determination of the plastic limit of a soil – standard method*.

AS1289.3.6.1-2009, *Methods of testing soils for engineering purposes Soil classification tests – Determination of the particle size distribution of a soil – standard method of analysis by sieving*.

AS1289.6.1.1-2014, amendment 1 2017, *Methods of testing soils for engineering purposes – soil strength and consolidation tests – Determination of the California Bearing Ratio of a soil – Standard laboratory method for a remoulded specimen*.

AS/NZS ISO 9001:2016, *Quality management systems – requirements*.

UK Standard

BS EN 13242: 2013 *Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction*.

Appendix A New Zealand Specifications

In New Zealand, RCC and RCG are permitted to be used in pavement basecourses in accordance with Transit New Zealand (now NZTA) M/4: *Specification for Basecourse Aggregate* (TNZ 2006). However, there is no specified limit for the use of RCC in base or subbase layers. The requirements outlined by the New Zealand Transport Agency (NZTA) for RCG are similar to those recommended in Australia. The RCG must adhere to the following (TNZ 2006):

- RCG shall be manufactured from glass food and drink containers, drinking glasses, window glass or plain ceramic dinnerware.
- RCG shall not be manufactured from vehicle windscreens, light bulbs, hazardous waste containers, fluorescent tubes or cathode ray tubes.
- RCG shall be washed to remove odours.
- Foil, paper, plastics, food residue, metals, organic matter and other contaminants shall not exceed 5% by mass of the RCG as tested according to RMS Test Method T276 (RMS 2012d).
- RCG shall not contain more than 1% of particles passing the 4.75 mm sieve with a maximum dimension to minimum dimension ratio greater than 5:1.
- RCG shall achieve the gradation set out in Table A 1.
- Testing for PSD, particle dimension ratio and contamination shall be carried out at a frequency of two tests (each) per RCG stockpile.

Table A 1: NZTA requirements for PSD of RCG

Sieve size (mm)	Per cent passing (%)
9.5	100
4.75	70–100
2.36	3–88
1.18	15–45
0.30	4–12
0.075	0–5

Source: TNZ (2006).

Specifications allow the use of 5% RCG in granular subbase materials provided the blended product meets the same requirements of a virgin granular material. Greater than 5% RCG can be added to a granular material provided the relevant requirements are met at the discretion of the TNZ Engineering Policy Manager (TNZ 2006).