RECYCLED CONCRETE

ROAD BASE

QUALITY INVESTIGATION

REPORT FOR SWIS GRANT 4003

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EXECUTIVE SUMMARY

The Strategic Waste Initiatives Scheme (SWIS) is a broad support scheme available to business, industry, local government and individuals for initiatives which are consistent with the former Waste Management Board's Statement of Strategic Direction for Waste Management in Western Australia.

C&D Recycling as proponent and Bowman & Associates as applicant were successful in securing funding under the scheme to analyse the recycled concrete road base produced over an extended time period from four leading Perth construction and demolition materials recyclers.

A NATA registered testing laboratory was engaged to sample and test the materials produced under “business as usual” conditions and compare the results to the Main Roads WA Specification 501 requirements for base course made from recycled concrete.

The first challenge of the project was to secure cooperation from several leading construction and demolition recyclers and obtain permission to sample, test and report the results from their products. To facilitate cooperation a Construction and Demolition (C&D) Working Group was set up within the WA Branch of the Waste Management Association of Australia.

Although the investigation did not result in C&D recyclers being able to produce within specification base course on a continual basis, it did however show that the recyclers have the capability to control the quality of the products produced and produce within specification lower end use sub-base on a continual basis.

The investigation highlighted the need for a revision of the MRWA 501 Specification for base course to more readily reflect base course made from “business as usual” operations whilst ensuring that the overall performance outcome of the road pavement is not compromised.

During the period of this investigation the City of Canning used sub-base (lower grade) and base course (higher grade) made from recycled concrete provided by C&D Recycling to upgrade Welshpool Road in Welshpool. The City of Canning used alternative test methods to those in the Main Roads WA 501 Specification to test the pavement materials. It was reported that the recycled concrete road base materials outperformed road base made from virgin materials.

The instigation of the project created a great deal of interest and confidence that locally produced recycled concrete can perform as an alternative base course to base course made from virgin quarry materials. The Main Roads WA and the Southern Gateway Alliance have approved the use of recycled concrete base course in a section of trial pavements proposed for the new Perth Bunbury Highway.

A primary outcome from the project is in relation to the Perth Bunbury Highway test pavement with the Main Roads WA providing a specific amendment to its 501 Specification to accommodate locally made recycled concrete base course on the Perth Bunbury Highway without compromising the overall performance of the road pavement.

CONTENTS

1. SYNONYMS

ARRB	Australian Road Research Board
BCC	Brisbane City Council
CBR	California bearing ratio
C&D	Construction and demolition
CMB	Crushed miscellaneous base
DEC	Department of Environment and Conservation
EPA	Environmental Protection Authority
FHWA	Federal Highway Administration
LA	Los Angeles abrasion
LL	Liquid limit
MRWA	Main Roads WA
MWAC	Municipal Waste Advisory Committee
NATA	National Association of Testing Authorities
OMC	Optimum moisture content
PSD	Particle size distribution
RCRB	Recycled concrete road base
SWIS	Strategic Waste Initiatives Scheme
WALGA	Western Australian Local Government Association
WMAA	Waste Management Association of Australia
WMB	Waste Management Board
VES	Veolia Environmental Services

2. DISCLAIMER

This document has been prepared by Bowman & Associates Pty Ltd on behalf of C&D Recycling as part of a project funded by the SWIS grant scheme. The content of this report is based on the scope of works as agreed between the Department of Environment and Conservation (DEC), C&D Recycling, and Bowman & Associates Pty Ltd. Content within this document has been prepared using industry standard skills and techniques normally exercised in the preparation of such documents.

This document, although made public is intended to be used for the sole purpose as agreed by the DEC, C&D Recycling, and Bowman & Associates Pty Ltd. Bowman & Associates Pty Ltd accepts no responsibility for any person or organisation that relies on or uses the information contained in this document for any other purpose or reasons other than those agreed by the DEC, C&D Recycling and Bowman & Associates Pty Ltd without first obtaining written consent from Bowman & Associates Pty Ltd.

3. INTRODUCTION

The construction and demolition (C&D) industry produces large volumes of heavy waste material. This material may include concrete, wood, steel, bricks, and asphalt. Traditionally all this material was sent to landfill. A greater concern for the environment, depletion of natural resources and diminishing availability of landfill space has resulted in a general move to rethink this practice with a tendency towards recycling and reuse, not just in WA but around the world. Waste concrete, bricks, sand, gravel, and asphalt can be crushed and used in site development and roads. Using recycled concrete has been standard practice for over 20 years in countries where there are economic and environmental benefits including reduced transportation, reduced gravel quarrying, decreased landfill volume, and conservation of virgin material.[1]

Western Australia recycled over 400,000 tonnes of C&D waste material in 2006-07, however, approximately 1.9 million tonnes ended up in landfill. The main components of this were sand, concrete, asphalt, and bricks (Cardno BSD, 2008). Much of this material has the potential to be used in place of virgin material as aggregate for concrete, road base and in the production of bricks.

In August 2006, Main Roads WA (MRWA) released a revision of its Specification 501 – Pavements, which includes specifications for recycled concrete road base (RCRB) materials. The specification was based on trials conducted during 2004 on RCRB materials placed during the construction of Gilmore Avenue in Kwinana Town.

MRWA, Local Governments and the road construction industry are not willing at this stage to widely adopt locally produced RCRB products outside of certain trials. Evidence is required to verify that the local C&D recycling industry is able to produce materials to specification on a continual basis.

The aim of this project is to gain industry acceptance of RCRB products and to promote their use in the construction of Local Government roads.

[1] Wikipedia contributors, "Concrete recycling", *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Concrete recycling&oldid=158370430 (accessed 22 January 2008)

4. PROPONENT AND OTHER PARTIES

4.1. PROPONENT: C&D RECYCLING

C&D Recycling, a company in the Lester Group, specialises in the collection and processing of construction and demolition waste to produce recycled materials for the building and construction industries. C&D Recycling commenced operations in 2006 at a central, strategic location at the Perth Airport industrial area in Hazelmere. This location is central to some of the busiest building development sites in the Perth metropolitan area, allowing demolition and building contractors to deliver their waste to C&D Recycling conveniently, and at a lower cost, than to Perth's landfills.

C&D Recycling has processed over 150,000 cubic metres of waste materials during its two years of operation. Products for sale are tested in accordance with Australian Standards by the NATA registered testing laboratory, Qualcon Laboratories. The three main recycled products for sale are clean fill, recycled road base, and drainage aggregate.

C&D Recycling's Managing Director, Adrian Lester, is also Chairman of the C&D Working Group of the Waste Management Association of Australia (WMAA). The group's aims are to increase the amount of C&D waste recycled in WA and the use of recycled products in buildings and road construction projects. C&D Recycling supplied the Recycled Concrete Road Base (RCRB) used by the City of Canning in its Welshpool Road upgrade and RCRB trial. [2]

4.2. APPLICANT: BOWMAN & ASSOCIATES PTY LTD

Bowman & Associates Pty Ltd is an Environmental Engineering Consultancy specialising in waste management, project management, tender preparation, transport logistics, and light extractive industry. Bowman & Associates are representing C&D Recycling in this proposal.

4.3. OTHER STAKEHOLDERS

Other stakeholders in this project include the C&D waste recycling companies, whose products were tested, the Waste Management Board (superseded by the Waste Authority) who supplied the grant funding and the Department of Environment and Conservation who administered the SWIS grant application. The recycling companies that participated in the trial are:

- C&D Recycling,
- Capital Demolition and Earthworks,
- All Earth Group, and
- Veolia Environmental Services.

Other parties who have an interest in the quality of recycled concrete road base products include Main Roads WA, private developers and Local Governments.

[2] Lester Group Website: http://www.lestergroup.com.au/index.php?option=com_content&view=article&id=65&Itemid=58. (Accessed 26 August 08)

5. STAKEHOLDERS

5.1. DEPARTMENT OF ENVIRONMENT AND CONSERVATION

The DEC is the government department that has the lead role in the protection and conservation of the State's environment. Its responsibilities include: managing the State's parks (national, marine, and conservation), State forests and timber reserves, nature reserves, and marine reserves and management areas. The DEC also manages the environmental impact assessment process, regulates certain industries, issues licenses for premises, responds to pollution incidents, develops policies, and is responsible for fire preparedness and weed control on crown land and reserves. The DEC also provides support to, or assists, a number of boards or authorities, including providing assistance to the Waste Authority and recipients of grants.[3]

5.2. WASTE AUTHORITY

The Waste Authority is the new independent statutory body that replaced the former Waste Management Board with the enacting of the Waste Avoidance and Resource Recovery (WARR) Act 2007. The Waste Authority is a five member board whose main areas of responsibility include:

> "developing, promoting and reviewing a waste strategy for Western Australia and coordinating its implementation; promoting community awareness and understanding of resource efficiency, waste avoidance and resource recovery; working with local government to coordinate local efforts to prevent waste; administering the Waste Avoidance and Resource Recovery Account and advising and making recommendations to the Minister for Environment; Youth on matters relating to the *Waste Avoidance and Resource Recovery Act 2007".*

The Waste Authority and its activities are funded from the Waste Avoidance and Resource Recovery Account, which is managed by the Authority. The DEC assists the Waste Authority by providing administrative, executive, and contract management support as well as coordinating specific projects and activities.

5.3. BOWMAN & ASSOCIATES PTY LTD

Bowman & Associates is very active in the waste management and recycling industries in Western Australia. Bruce Bowman, the Director, is the current President of the Western Australian branch of the Waste Management Association of Australia and also a member of the C&D Working Group. Bowman & Associates believes in minimising waste and maximising the recovery, reuse, and recycling of valuable resources. Thus Bowman & Associates has previously, and continues to be, awarded a number of Strategic Waste Initiative Scheme (SWIS) grants for innovative projects that increase the knowledge or recycling capacity of industry and governments in Western Australia.

5.4. C&D RECYCLING

C&D Recycling is one the four major construction and demolition waste recyclers in WA. Along with the three other C&D waste recyclers, C&D Recycling participated in this project to further increase their capacity to produce recycled road base products. C&D Recycling was also the proponent for this project, which would not have proceeded without their support and enthusiasm.

[3] Department of Environment and Conservation, *Corporate Plan.* http://www.dec.wa.gov.au/about-us/about-dec/corporate-plan.html (Accessed 12 September 2008)

5.5. VEOLIA ENVIRONMENTAL SERVICES

Veolia Environmental Services (VES) is a major player in the waste management industry and operates a number of construction and demolition waste recycling centres across Australia. These centres are designed to maximise the recovery of building and demolition materials for reuse. An innovative sorting process, which separates the various waste streams for different methods of processing, is used to produce a range of products. At the time the trial was undertaken VES operated the WA Construction Waste Recovery Centre in Jandakot where VES processed C&D waste and produced products such as recycled road base. [4]

At the time of writing the report VES advised that it had shut down its crushing and screening plant and now supports the recycling industry by providing feed stock to other recyclers.

5.6. CAPITAL DEMOLITION AND EARTHWORKS

Capital Demolition and Earthworks is one of the four major C&D waste recyclers in WA. Capital Demolition currently operates a C&D waste recovery and recycling centre in Bayswater. Capital Demolition participated in this project to further the C&D waste recycling industry and the market for recycled road base.

5.7. ALL EARTH GROUP

All Earth Group is a West Australian owned company that specialises in logistics, resource recovery and the supply of recycled and new construction, civil and landscaping products to the public, industry, and government sectors. All Earth currently recycles over 100,000 cubic metres of material each year. All Earth supports government and industry initiatives that promote the use of recycled materials and is a member of the WMAA as well as the C&D Working Group. [5]

[4] Veolia Environmental Services: http://www.veoliaes.com.au/resource-recovery/resource-recovery-facilities/construction-waste-recovery.asp (Accessed 26 August 2008)
[5] All Earth Group: http://www.allearth.com.au/go/all-earth-group/what-we-do (Accessed 26 August 2008)

6. BACKGROUND

6.1. CONSTRUCTION AND DEMOLITION WASTE IN WA

Currently 50% of Perth's waste going to landfill is C&D waste. It is estimated that only 21% of the total 1.9 million tonnes (2006-7) of C&D waste generated in Perth each year is recycled. Although most high value materials are recycled, low value/high volume materials are landfilled, including recyclable concrete. [6]

Close to half a million tonnes of construction and demolition waste were recovered through recycling in WA in 2005/06. Of this recovered material: 46% was sand, 29% was bricks and rubble, and 18% was concrete. This waste material was cleaned, screened, crushed, reused and recycled to produce clean fill, aggregate, drainage fill, general fill and road base.[7]

The latest data from Cardno's most recent report, which reviewed the recycling activity in WA for 2006-07 and was released in mid-August 2008, indicated that approximately 403,870 tonnes of C&D material was recovered in 2006/07. This is an increase of approximately 39,500 tonnes over the previous year. The report also noted that C&D recycling activity has shown "steady growth" since 2004/05 when the first annual report of recycling activity in the state was produced. Still, the total amount of C&D waste sent landfill was approximately 1.9 million tonnes, almost 5 times the amount recovered. Therefore the recycling rate for C&D waste is still around 21%.

In 2006-07, approximately 214,720 tonnes of sand, 64,770 tonnes of bricks and rubble, 102,260 tonnes of concrete/bitumen, 12,120 tonnes of whole bricks, and 10,000 tonnes of timber were recovered. Recovered concrete, bitumen, brick and rubble material is crushed and screened to create a mixed or separate material of a uniform aggregate size. Recovered sand is screened to remove undesired materials such as contaminants like litter, metal, and wood. Bricks can either be crushed and turned into aggregate or cleaned and reused as whole bricks. Recycled aggregates are either sold separately as raw materials or mixed together to produce products such as road base or drainage aggregate. The recovered material is processed, sold, and used in Western Australia for new construction and development. The recycled material competes directly with quarried virgin material in the market and can be used for sub-base, roadbase, hardstands, drainage aggregate and fill (Cardno, 2008).

The report also, for the first time, outlined some key barriers identified by the C&D recycling industry as inhibiting future growth. These barriers include low landfill gate fees, a regular supply shortage of material, an uneducated marketplace, and noncompliant operators. Also mentioned was the fact that the C&D recyclers are unable to meet the high demand for recycled building products because of a shortage of supply of C&D waste. This is due to low landfill gate fees for inert waste, which encourages the construction and demolition industry to send potentially recyclable material to landfill. The C&D recycling industry can be further developed by *"a continual increase of the landfill levy, support for waste producers that separate their waste stream into material type, a compulsory submission of a waste management plan when tendering for*

[6] Municipal Waste Advisory Committee, "Construction and Demolition Waste": http://www.wastenet.net.au/information/streams/cons demo (Accessed 23 January 2008)

[7] Cardno BSD (2008) *Review of Total Recycling Activity in Western Australia 2005/06*. Western Australia, June 2008: http://www.zerowastewa.com.au/documents/rec_activity_review_0506.pdf

contracts, an increased landfill levy for mixed waste streams and greater market education". As long as it is more economical to send material to landfill rather than to a recovery facility, the amount of material recycled will continue to remain a small portion of the amount of waste material generated until either economic or regulatory factors are changed (Cardno, 2008).

Cardno's report also provided an optimistic view of what can be achieved:

> *"If Western Australia could divert 50% of C&D material from landfill, Western Australia would then be comparable with the Eastern States with a recovery per capita in excess of 1 tonne per person. This could be easily achievable with a push from government and industry towards recycling and uptake of recycled building products in construction activities in conjunction with an increase in the cost of Class 1 inert landfills."* (Cardno, 2008)

6.2. HISTORY

6.2.1. Interstate

Victoria

Victoria has been using recycled concrete for road building for at least 15 years. In 1993 the State Roads Authority of Victoria, VicRoads, included specific clauses in its standard road works specifications that officially allowed the use of recycled concrete as a stabilised sub-base material.

In 1997, about 350,000 tonnes of recycled crushed concrete (RCC) was produced in Victoria; much of it was used for road construction in unbound or cement stabilised pavement layers.[8]

The use of recycled crushed concrete increased 800% between 1993 and 1998. A 1997 report by VicRoads on the performance of crushed concrete stated that "Recycled crushed concrete is a viable alternative to class 3 crushed rock in stabilised sub-base applications with respect to strength considerations."[9] Since then, VicRoads has created standard specifications for Class 2 and 4 recycled crushed concrete sub-base.

In 1998 recovery and recycling programs diverted over 830,000 tonnes of concrete from landfill in Victoria, some of which was used for road base construction.[10]

In 1999, around 70% of the concrete and bricks in construction and demolition waste were recovered and recycled for reuse in Victoria. The recovery rate for asphalt was close to 90%.[11]

Alex Fraser Group has provided RCC for sub-base for a range of projects, including the Albert Park Grand Prix circuit, Western Ring Road, and Westgate Freeway widening.[12]

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[8] YEO R and FOLEY (1997) *Recycled Crushed Concrete Stabilised with Cementitious Binders*. VicRoads Report GR 97-11.
[9] EcoRecycle. (1997). *Investigation into the use of recycled crushed concrete for road base use*. Prepared for EcoRecycle by VicRoads.
[10] EcoRecycle Victoria. (1999). *Annual Survey of Victoria's Recycling Industry 1997 – 98*. Prepared for EcoRecycle by Salmon Consulting.
[11] Institute of Quarrying Australia. "*Can We Recycle Aggregates?*" http://www.quarry.com.au/page/can_we_recycle_aggregates.html (Accessed 25 January 2008)
[12] Sustainability Victoria. Fact Sheet; Crushed Concrete. http://www.sustainability.vic.gov.au/resources/documents/06_Fact_Sheet_Crushed_Concrete.pdf. (Accessed 23 January 2008)

The Alex Fraser Group, established in 1879, has been selling recycled C&D waste materials for over two decades in Victoria. Alex Fraser has worked closely with CSIRO and ARRB (Australian Road Research Board) to ensure recycled materials offer performance that matches or exceeds the characteristics of virgin quarried material. In Victoria and Queensland, many major freeway, civil construction and municipal projects have used recycled materials from Alex Fraser. Currently, Alex Fraser has the capacity to produce three million tonnes of recycled material per year.[13]

Boral produces Envirocrete which fully complies with Vic Roads specifications for road works and bridgeworks. The sections of the Specification relating to recycled products are:

820- Recycled Crushed Concrete for Pavement sub-base and Light Duty Base

821- Cementitiously Treated Crushed Concrete for sub-base pavement[14]

In its Opportunities for Material Reuse Information Sheet – Concrete, published July 2006, Vic Roads identified recycled crushed concrete as a suitable material for road works. The sheet also indicates that there are many companies in Victoria that produce recycled crushed concrete (RCC) for road construction and that RCC has lower costs in terms of transportation and purchasing than virgin materials.[15]

New South Wales

New South Wales has been using recycled concrete for road base for a number of years.[16]

In NSW, concrete recycling grew from 300,000 tonnes in 1996 to 1.2 million tonnes in 1999, replacing 10% of the virgin aggregate materials extracted from quarries. Most of the recycled concrete was used in road construction and maintenance. The use of recycled materials as aggregates is expected to extend the life of existing quarries.[17]

NSW Waste Avoidance and Resource Recovery Strategy 2003 set a target for the increased recovery and utilisation of materials from the construction and demolition sector from 65% in 2000 to 76% by 2014. Increasing the demand for and use of recycled concrete, brick, tile and asphalt materials will make an important contribution towards achieving this target. Resource NSW in its Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage, which was first released in 2001, sets out industry standard specifications required for recycled concrete to be used in road building. Prior to this, individual Local Governments had used their own specifications for many years. The Specification also aims to encourage local government and others in the public works sector to use recycled concrete. This Specification sets out performance standards for the supply of quality recycled materials, which provides the

[13]Alex Fraser Group. "Construction and Demolition Materials Recycling." http://www.alexfraser.com.au/recycling.html (Accessed 25 January 2008)
[14]Boral Limited. "Envirocrete Recycled Concrete Products Range". http://www.boral.com.au/docs/product/quarries/product_quarries_16012004_103704.asp?AUD=contractorBuilder_QuarryProducts. (Accessed 22 January 2008)
[15] Vic Roads. (2006) *Opportunities for Material Reuse* Information Sheet – Concrete. http://www.vicroads.vic.gov.au/NR/rdonlyres/0F7712CC-EFD1-4BB0-89A1-C6F4BB44BB78/0/FinalRecycledMaterialFactSheets.pdf (Accessed 24 January 2008)
[16] Resource NSW (2003) "*Specification for Supply of Recycled Material for Pavements, Earthworks & Drainage*" Issue No. 2 dated June 2003.
[17] New South Wales Environmental Protection Agency. *State of the Environment 2003,* Chapter 2 Human Settlement. http://www.epa.nsw.gov.au/soe/soe2003/chapter2/chp_2.5.htm (Accessed 25 January 2008)

confidence required in the marketplace to make greater use of these materials. It also supports the NSW Government's policy for the increased recovery and use of recycled materials to minimise the consumption of natural resources. This will make a positive contribution to the protection of the environment and to a more sustainable future.[18]

Concrush Pty Ltd, a C&D recycler in the Hunter region of NSW, produces recycled concrete for sub-base and base course in accordance with Resource NSW's Specification for Supply of Recycled Materials for Pavements, Earthworks & Drainage.

Concrush's projects include: Belmont Hospital Ambulance Roadway 2002, Hutton Street Apartments internal road 2003, Lake Macquarie Private Hospital Car Parks 2003, Hunter Health Rehabilitation Entry Road, Rankin Park 2003, and Energy Australia Stadium.[19]

As part of a redevelopment of Sydney's International Port, recycled concrete was used as road base and fill for the new internal Port roads at Glebe Island during the 2002/2003 financial year. The material was recovered from the demolition of two banks of disused silos at Glebe Island in 2000, which had been stored for reuse within the port. The demolition of the disused silos was conducted with a focus on minimising environmental impact, including waste, resulting in 110,000 tonnes of recycled concrete, which would otherwise have been disposed of to landfill. Sydney Ports and the contractor, Metropolitan Demolitions, were awarded the NSW Case Earth Award in 2000 for the way the silos were deconstructed with minimum impact.[20]

Queensland

The Brisbane City Council (BCC) has developed a specification for recycled concrete for use in the construction of pavements. This specification requires recycled concrete to be free from any foreign materials and limits its use to class 2 or class 3 materials (sub-base and base course). BCC indicates recycled concrete for road base has not been widely used since a trial was conducted in 1992. A Draft Specification for Supply of Recycled Material for Roads, Drainage and Fill has recently been released that aims to maximise the use of recycled materials in public and civil works by local governments and other key stakeholders.[21]

"The Eastern States have an environment which makes it much more attractive to recycle, especially in regards to recycling of high tonnage C&D materials" (Cardno, 2008). This attractiveness comes in the form of higher landfill gate fees and higher landfill levies, more expensive and scarce virgin material, and more support from government and industry to the recycling industry and for use of recycled products.

6.2.2. Internationally

United States

[18] Resource NSW. (2003) *Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage*. Issue No 2. http://www.environment.nsw.gov.au/resources/spd_030618_greenspec.pdf (Accessed 25 January 2008)

[19] Concrush Pty Ltd. "20mm Minus Road Base". http://www.concrush.com.au/index.asp?pgid=9. (Accessed 22 January 2008).

[20] Sydney Ports Corporation. (2003). Environmental Report. http://www.sydneyports.com.au/__data/assets/pdf_file/0010/1225/EnvironReport.pdf (Accessed 25 January 2008)

[21] Environmental Protection Agency. (2002) "Construction and Demolition Waste: Waste management and resource use opportunities". July 2002. Queensland Government. http://www.epa.qld.gov.au/publications/p00484aa.pdf/Construction_and_demolition_waste_waste_management_and_resource_use_opportunities.pdf (Accessed 25 January 2008).

The US produces around 135 million tonnes of construction and demolition waste annually. Most concrete from urban areas is not disposed of in landfills anymore but is recycled and used as fill or road base. Concrete pieces from demolished structures may also be reused to protect shorelines.[22]

In March 1995, the City of Los Angeles passed a motion requiring that road base in all city projects include "crushed miscellaneous base (CMB) with 100 percent recycled asphalt, concrete, and other inert materials, except when site conditions or standards require another specification."

Construction and demolition waste materials make up about 22 percent of California's disposed waste stream, or approximately 8.7 million tonnes. Asphalt and concrete represent over 977,000 tonnes of this material or around 2.4 percent. There are approximately 100 producers of recycled aggregate in California.[23]

In 1995 the Stapleton International Airport in Denver, Colorado, which had been in use for 66 years, was demolished. Most of the concrete from the demolition of the old airport was recycled. The recycled concrete was derived from 975 acres of runways, taxiways, service drives, and aprons with an average thickness of 600 mm. The total amount of concrete recycled, about six million tonnes, would have been enough to construct a two-lane roadway roughly (1,600 km) long. The Colorado School of Mines conducted a study that found the recycled concrete from Stapleton was equal to or of a higher quality than virgin mixes.[24]

The Federal Highway Administration (FHWA), Federal Aviation Administration, Army Corps of Engineers, Environmental Protection Agency, State Departments of Transportation and many municipalities have approved standards for and use recycled concrete for road base.[25]

The Interstate 5 Improvement project in Anaheim, California sourced all its aggregate from recycled concrete and asphalt. The six year project, which saw the freeway widened from three to six lanes on each side, required 800,000 tonnes of aggregate. The 100% use of recycled aggregate led to Caltrans saving US$5 million from not having to purchase and transport virgin material from a quarry.[26]

6.2.3. Western Australia

The history of using recycled concrete for road base is virtually nonexistent in Western Australia compared to other locations, with only recent trials held into its use for road base. There have been limited government initiatives and laws created that deal with the issue of reduction of waste; however there has been nothing to date regarding the use of recycled concrete to build WA's roads.

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[22] Portland Cement Association. "Recyclable". http://www.concretethinker.com/Papers.aspx?DocId=25. (Accessed 22 January 2008)

[23] California Integrated Waste Management Board. "Recycled Aggregate". http://www.ciwmb.ca.gov/ConDemo/Aggregate/. Last updated November, 2007. (Accessed 22 January 2008).

[24] Portland Cement Association. "Case Studies: World Record Recycling Project". http://www.concretethinker.com/Papers.aspx?DocId=261. (Accessed 22 January 2008).

[25] Construction Materials Recycling Association. "Barriers to the Market". http://www.concreterecycling.org/barriers.html. (Accessed 24 January 2008).

[26] Construction Materials Recycling Association. "Case Histories". http://www.concreterecycling.org/histories.html. (Accessed 24 January 2008).

In 1995, a pavement engineer from Main Roads WA concerned about a future shortage of basic raw materials created the first draft specification for the use of recycled C&D material in road construction. Material was sourced from Vic Park Salvage and laboratory tested to assess the general engineering properties of the material. A report was produced outlining the results from the testing program as well as a draft specification. It appears that this was not followed up with a real trial until the Gilmore Ave trial in 2003.[27]

The Department of Environment's *2020 Waste Report and Recommendations* was the first step in publicly creating the aim of reducing WA's waste to landfill to zero by 2020.[28]

The Waste Management Board (WMB), 2004, *Statement of Strategic Direction for Waste Management in WA* put forward a slightly altered vision of "towards zero waste in WA", with the goal that all Western Australians will live in a waste free society. The WMB stated that the vision and goal were to be achieved through reduction of waste generation (*Avoidance*), recovery of waste materials for reuse (*Recovery*) and responsible disposal of any residual waste (*Disposal*).[29]

In 2003-04 Main Roads WA conducted a trial of crushed recycled concrete (CRC) during its Gilmore Road upgrade in the Town of Kwinana. 400m of roadway was constructed using 125mm of CRC as base course. The CRC was sourced from the nearby Waste Stream Management crushing plant at the Town of Kwinana landfill. The CRC was laboratory tested before being laid and field tested for months afterwards. The trial found "the CRC is a superior basecourse to the CRB (crushed rock base)".[30]

In August 2006, Main Roads WA (MRWA) released a revision of Specification 501 – Pavements, which includes specifications for recycled concrete road base (RCRB) materials. Prior to this, RCRB materials were not allowed for use as sub-base or basecourse in road construction. The specification was primarily based on trials conducted during 2004 on RCRB materials placed during the construction of Gilmore Avenue in Kwinana.

The City of Canning recently installed a test section of road built using recycled demolition material. The section is part of the Welshpool Road upgrade. The section was split with one half using recycled concrete for the sub-base only and the other half using recycled pavement throughout. The completed pavement is being monitored to see how well it performs under normal road conditions. Preliminary findings indicate that the performance of the recycled materials is comparable to, if not better than, virgin roadbase under test conditions. Conclusions from this trial indicate that recycled materials have "considerable" economic and environmental benefits, can be used with confidence as base for lightly trafficked roads and as sub-base for heavily trafficked roads and are likely to be suitable as a base for heavily trafficked roads.[31] [32]

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[27] Cray, A.R. (1995). Material Specifications Using Recycled C & D Waste (Alternatives to Quarry Products). Main Roads WA.

[28] Department of Environmental Protection (2001) WAste 2020 Report and Recommendations. Government of Western Australia, Perth, Western Australia.

[29] Waste Management Board, (2004). *Statement of Strategic Direction for Waste Management in WA: Vision and Priorities*. Government of Western Australia. September 2004

[30] Cheema, D. (2004). *Crushed Recycled Concrete for basecourse Construction (Kwinana Town)*. Main Roads WA.

[31] Municipal Waste Advisory Council. Information Bulletin. January 2008. Issue 109. Page 3.

[32] Leek, Colin. (2008). "Recycled Materials in Road Construction: Welshpool Road – A Demonstration Project". Powerpoint presentation.

The City of Cockburn only allows recycled concrete to be used in industrial developments for the construction of non trafficable pavement and drainage areas as a base course or sub grade.[33]

MRWA, Local Governments and industry are not willing at this stage to adopt locally produced RCRB products. Evidence is required to verify that the local concrete recycling industry is able to produce materials to specification on a continual basis.

6.3. GOVERNMENT INITIATIVES

Historically the Western Australian State Government has done comparatively little to reduce the ever increasing amount of construction and demolition waste to landfill or to encourage the growth of the concrete recycling industry. Even though legislation has been passed and a number of strategies and policy documents produced there has been a consistent lack of action to increase the amount of C&D waste being recycled and reduce the amount of valuable landfill space occupied by C&D waste. Actions that would further the recycling industry include increasing the economic costs of landfilling by raising the landfill levy, increasing the economic costs of extracting basic raw materials possibly by imposing a rehabilitation levy within extractive industries permits and assisting market development for RCRB.

In 1991 the WA State Government set a State goal of reducing per capita waste to landfill by 50% over 1990 levels by 2000. This was consistent with the national goal. To provide an incentive for recycling and to raise funds to further recycling initiatives, a levy on waste landfilled was finally set in 1998 under the *Environmental Protection (Landfill) Levy Act 1998*. A levy on waste had been discussed in Government since 1991. (Hon Max Evans, Hansard, 19-8-97)

The levy on waste sent to landfill in the Metropolitan area was set at $3 per tonne for putrescible wastes and $1 per cubic metre for inert wastes. Unfortunately the goal of reducing per capita waste to landfill was not met. The amount of waste landfilled per capita actually increased by 25% and the total amount of waste landfilled increased by 42%. (WMB, Summary Report of Waste to Landfill, 2003)

In 2000 the Waste 2020 Taskforce was established to create a “vision for the future” of waste management in WA. The Government embraced the Taskforce’s strategy of Zero Waste by 2020.

In 2002 the Waste Management Board (WMB) was established to provide advice to the Minster on the future of waste management in WA. In 2004 the WMB changed the waste strategy for WA to Towards Zero Waste in its Statement of Strategic Direction (WMB, 2004).

The Municipal Waste Advisory Committee (MWAC) is a standing committee of the Western Australian Local Government Association (WALGA). The MWAC is involved in “statewide co-ordination of recycling issues, review of waste management legislation, production of position papers on waste management, and promotion of Integrated Resource Recovery techniques”.[34]

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[33] City of Cockburn. “Industrial Development Information Required for Applications in Industrial Zones”. http://www.cockburn.wa.gov.au/documents/CouncilServices/CityDevlpmt/FinalDCUinfopackageindustrial.pdf. (Accessed 23 January 2008).

[34] WALGA. “Environment & Waste Management”. http://www.walga.asn.au/about/policy/environment_waste. (Accessed 23 January 2008).

In the MWAC's submission to the Waste Management Board's paper, *Draft Building Products Strategy*, there were a number of recommendations that if implemented would greatly increase the market for recycled concrete. One such recommendation is that an investigation be undertaken into a tax on virgin materials similar to the one in the UK, to better reflect the environmental externalities from their use instead of using recycled materials.[35]

In 2005 the WMB undertook a review of the landfill levy. The WMB published two documents, the *Discussion Paper on the Landfill Levy and the Programs it Funds* and a Discussion Paper on *Re-investing Landfill Levy Funds in Zero Waste Incentive Schemes*. Through these documents the WMB recommended that the landfill levy be raised. The Board proposed an initial increase in the landfill levy at 1 July 2006 to $6.00 per tonne for waste directed to Class 2, 3 and 4 landfills and $3.00 per cubic metre for waste directed to Class 1 landfills. The levy rate would then be raised by a small amount every year so that the *"levy rate in 2020 would be approximately $35 per tonne, for all waste, so that by then landfill pricing is at, or approaching, the full environmental cost of landfilling."* The board thought that a low levy failed to provide sufficient economic incentive to increase waste avoidance and resource recovery activities. (WMB, 2005)

In 2006 the WMB applied this thinking to the construction and demolition waste stream in its *Draft Building Products Strategy*. *"Experience interstate has shown that an increase in the landfill levy will encourage more people to look for other methods of disposal for their building products waste. The proposed increases in the levy may lead to more industries looking at using building products recyclers, rather than disposing to landfill"*. (WMB, 2006)

In 2006 Cardno BSD prepared the *Issues Relating to the Generation, Collection, and Treatment of Building Product Waste in Western Australia* report for the DEC. The report stated:

"To meet the state's goals of reducing waste and increasing recycling the report proposes that one of the options that should be taken would be to increase the landfill levy at inert landfills by 0.5 to 2 dollars per year over the next ten years. This would result in an increase in the levy of 5 to 20 dollars more than current levels. This would make recycling a more cost effective option for waste producers."

The report identified low landfill gate fees as one of the main barriers to increasing the rate of recycling.

In 2006, the Government indicated that the outlook for the levy involved a gradual increase to $9 per tonne and $9 per cubic metre for putrescible and inert wastes respectively by 2010-11. (Media Statement by the Hon Mark McGowan MLA, 20 May 2006)

In 2006 the Productivity Commission undertook an inquiry into waste management in Australia. It found that landfill levies should only be used if the gate fees at landfills do not adequately account for the environmental and social cost of the landfill. It found that levies should not be used to achieve waste diversion targets or raise funds generally

[35] Municipal Waste Advisory Council. WALGA Submission on the Draft Building Products Strategy. http://www.wastenet.net.au/policy/reports/mwacsubbuildstrat/file/at_download. (Accessed 23 January 2008).

earmarked to decrease waste. It said that other regulatory options had a lower cost to the community than using a levy for these purposes.[36]

The *Landfill Levy Administration Policy Regulations* 2006 set the timeline for future increases in the landfill levy. For inert wastes the levy would be $3 before 1 July 2008, $5 in 08/09, $7 in 09/10, and $9 after 1 July 2010.[37]

In 2007 the WMB commissioned the consultant Dr Michael Blyth of Four Scenes Pty Ltd to undertake a review of the landfill levy. He produced the Landfill Levy Review report in late 2007. Dr Blyth consulted stakeholders over 3 mornings as part of this desktop study for the review. In this report he states:

"Looking to the future the Landfill Levy is likely to be more effective in influencing waste management practices, including reducing waste to landfill. As the levy rate rises, alternatives will become more attractive especially for inert wastes."

Specifically relating the levy price to inert waste diversion and recycling Dr Blyth found:

"The increase in the Landfill Levy in 2006 for inert wastes from $1 a cubic metre to $3 a cubic metre was more significant. At $3 the levy represents between 22% and 33% of the total landfill gate fees (which range from $9 to $15.50 per cubic metre). Evidence from B&D [building and demolition] recyclers indicated that the $2 increase triggered an increase in diversion of inert material from landfill. The increase in the Levy to $9 by 2010-11 will divert more wastes to recyclers. If it is too high, the amount of recycled material generated will exceed market demand and the amount of illegal dumping will increase. However, based on feedback from B&D industry operators a Landfill Levy of $10 in 2007 is unlikely to result in surplus supplies."

Table 1 below shows the amount of C&D waste generated and recovered and the percentage diverted from landfill for the five mainland states in 2004-05. The table also shows respective landfill levies for those states. Thus a correlation can be drawn between a high landfill levy and a high percentage of recovery of C&D materials.

[36] Productivity Commission (2006), *Waste Management*, Report no. 38, Canberra
[37] DEC (2006) *Landfill Levy Regulation Administration Policy 2006*. Department of Environment and Conservation, November 2006)

Table 1

	Inert Landfill Levy (Metropolitan)		Construction and Demolition Waste 2004/2005		
State	Current	In 2005	Diverted for Recovery (Mill tonnes)	Total Generated (Mill tonnes)	% Diverted
South Australia	$24.20 /tonne	$10.50 /tonne	1.103	1.595	69.2
Victoria	$15.00 /tonne	$11.00 /tonne	2.423	4.817	50.3
New South Wales	$46.70 /tonne	$21.20 /tonne	3.139	5.118	61.3
Queensland	0	0	0.128	1.409	9.1
Western Australia	$3.00 /$m^3$	$1.00 /$m^3$	0.452	2.078	21.8

Table 1 References:
NSW Department of Environment and Climate Change. "About the levy and waste reporting". DECC website: http://www.environment.nsw.gov.au/wr/index.htm. Accessed 12-8-08.
Environmental Protection Agency, South Australia. EPA Guidelines: Waste Levy Regulations. 2008. http://www.epa.sa.gov.au/pdfs/guide_levy.pdf
Zero Waste SA. Review of Solid Waste Levy. 2007. Hyder Consulting.
Waste Avoidance and Resource Recovery Levy Regulations 2008. Government of Western Australia. State Law Publisher. http://www.slp.wa.gov.au
Environmental Protection Agency, Victoria. "Landfill Levies". EPA website: http://www.epa.vic.gov.au/waste/landfill_levies.asp. Accessed 12-8-08
Waste Management Board, Western Australia. Resourcing the Zero Waste Vision: A Discussion Paper on the Landfill Levy and Programs it Funds. 2005.
The Blue Book - Australian Waste Industry, 2007/08 Industry and Market Report. WCS Market Intelligence and Waste Management & Environment Media Pty Ltd.

In December 2007 the WA Parliament passed the Waste Avoidance and Resource Recovery (WARR) Bill. On July 1, 2008 the *Waste Avoidance and Resource Recovery (WARR) Act 2007* and the Waste *Avoidance and Resource Recovery Levy Act 2007* came into force. The WARR Act 2007 provides the legislative underpinning needed to institute a comprehensive system of waste management in WA. The act provides for the establishment of a statutory waste management board, introduction of a waste strategy that will establish waste priorities for the whole State, waste management plans for local councils, changes to the responsibility for waste collection, and a framework for extended producer responsibility schemes.

These Acts replace the Waste Management Board with a statutory Waste Authority and provide options for Government to implement Extended Producer Responsibility schemes. The Waste Authority will set the landfill levy by making recommendations to the Minister and have control over the funds from the levy.[38]

The Waste Authority will have the power to introduce measures like higher landfill fees or bans to increase recycling of construction and demolition waste.

[38] Environmental Defender's Office. (2007). *Waste management in Western Australia*. Found on http://www.edowa.org.au/submissions/EDOwastemanagementreport.pdf. (Accessed 23 January 2008).

As noted above it was only in 2006 that Main Roads WA allowed the use of RCRB materials for road construction.

The new 70km Perth to Bunbury highway that is being constructed will require over 9 million cubic metres of road base material. This will include virgin sand and limestone gravel. Some of this material has to be transported long distances from a quarry to the site. If recycled concrete and other materials were used as a substitute for some of this material, the economic cost of the project could have been less than the $511 Million price tag. The environmental cost of the project could have been reduced as well, as using recycled materials produces less greenhouse gas emissions and does not deplete finite natural resources.[39]

6.4. INDUSTRY

The recycled concrete industry in WA is in its infancy compared to the eastern states. The abundance of cheap limestone products in the Perth region has kept recycled concrete out of the local sub-base markets.

With the recent release of the revised 501 Specification from MRWA, which includes a specification for both sub-base and base course, RCRB can now compete against base course manufactured from laterite and hard rock. This has created a new market opportunity for RCRB. However, due to the low profit margins and the competitive nature of the recycled concrete industry, recycling companies are not prepared to invest in higher level quality control programs to qualify their RCRB for sale as MRWA approved base course. Currently most RCRB produced in Perth is sold to low risk markets for domestic driveways and site access roads.

The construction and demolition materials recycling industry in WA has four main market players; Veolia Environmental Services, C&D Recycling, Capital Demolition and Earthworks, and Allearth Group. These companies mainly supply recycled crushed concrete for driveway and patio construction. If measures were taken to increase the viability of using RCRB a significantly larger amount of construction and demolition waste could be diverted from WA landfills.

6.5. MAIN ROADS WA SPECIFICATION 501 PAVEMENTS

Specification 501 was updated in 2006 to include specifications for the use of crushed recycled concrete for base course and sub-base. This is as a result of trials undertaken in 2003 and 2004 by Main Roads WA and the Town of Kwinana.

In 1995, a pavement engineer from Main Roads WA concerned about a future shortage of basic raw materials, created the first draft specification for the use of recycled C&D material in road construction. Material was sourced from Vic Park Salvage and laboratory tested to assess the general engineering properties of the material. A report was produced that included results from the testing program as well as a draft specification. It appears that this was not followed up with a real trial until the Gilmore Ave trial in 2003. In describing the different tests conducted the report stated:

"Maximum dry compressive strength (MDCS) determines whether a material with a low plasticity is deficient in binding properties and hence likely to ravel. Acceptable values are 1700kPa for base materials and 1000kPa for sub-base materials. Testing was carried out in accordance with WA 140.1 returning values of 2310kPa for 0% brick

[39] Main Roads WA. "New Perth Bunbury Highway". http://www.mainroads.wa.gov.au/NR/mrwa/run/start.asp (Accessed 24 February 2008).

content and 1310kPa for 15% brick content. This test does not allow for curing after compaction and some gain in strength, through cementation, is likely with time."

The draft specification for C&D waste material included in the report is almost identical to the current 501 Specification except that the draft specification does not include a minimum limit on Maximum Dry Compressive Strength or limits on Unconfined Compressive Strength.[40]

In 2003-04 Main Roads WA conducted a trial of crushed recycled concrete (CRC) during its Gilmore Road upgrade in the Town of Kwinana. 400m of roadway was constructed using 125mm of CRC as basecourse. The CRC was sourced from the nearby Waste Stream Management crushing plant at the Town of Kwinana dumpsite. The CRC was laboratory tested before being laid and field tested four months afterwards. The trial found "the CRC is a superior basecourse to the CRB (crushed rock base)".

In the report, a specification for the use of crushed recycled concrete is included. This new specification has only minor changes from the one created nine years previously. Again this specification does not include a limit for Maximum Dry Compressive Strength. This specification does, however, include a limit of less than 1 MPa for Unconfined Compressive Strength.[41]

Within the resulting MRWA Specification 501 for crushed recycled concrete base course the Unconfined Compressive Strength is included as 0.6MPa to 1.0MPa and the Maximum Dry Compressive Strength is included as 1.7MPa minimum.[42]

It is concluded that the inclusion of these two test parameters and their corresponding limits were not as a result of the Gilmore Avenue trial or previous field trials undertaken by MRWA.

[40] Cray, A.R. (1995). Material Specifications Using Recycled C & D Waste (Alternatives to Quarry Products). Main Roads WA.
[41] Cheema, D. (2004). *Crushed Recycled Concrete for basecourse Construction (Kwinana Town)*. Main Roads WA.
[42] Main Roads WA, (2007) *Specification 501 Pavements. Western Australia*

7. PROJECT

7.1. OVERVIEW

In August 2006, Main Roads WA (MRWA) released a revision of Specification 501 – Pavements, which includes specifications for recycled concrete road base (RCRB) materials. The specification was based on trials conducted during 2004 on RCRB materials placed during the construction of Gilmore Avenue in Kwinana Town.

Included within the document are specifications for both sub-base and base course. Currently in the eastern states crushed recycled concrete is generally only used for sub-base and not base course. The inclusion of a base course specification for WA allows for RCRB to compete against the higher value virgin road base products thus improving the viability of the developing C&D recycling industry. This project compares the products produced by the participating recyclers against the higher end use base course Specification.

MRWA, Local Governments and industry are not willing at this stage to adopt locally produced RCRB products. Evidence is required to verify that the local concrete recycling industry is able to produce materials to specification on a continual basis.

The aim of this project is to gain acceptance of RCRB products for the construction of Local Government roads. To achieve this aim, potential users of RCRB products need greater assurance and confidence that RCRB products meet specifications, specifically Main Roads' Specification 501. This project was undertaken to develop this confidence in currently available RCRB products. The major component of this project was testing of the four main RCRB facilities' products against the specifications over a seven month period.

The Strategic Waste Initiative Scheme (SWIS) provides support and funding for projects in specific priority areas. SWIS is administered by the Waste Authority and DEC and funding is from monies raised through the Landfill Levy. The proponent received a SWIS grant to fund this project.

This project fits into the Waste Management Board's preferred project area of building products (use of recycled concrete in secondary roads). From a strategic perspective:

- Currently 50% of Perth's waste going to landfill is C&D waste.
- It is estimated that only 22% of the total 1.5 Million Tonnes of C&D waste generated in Perth each year is recycled.
- A ban to landfill of C&D waste has the potential to grow the C&D recycling industry fivefold.
- The C&D recycling industry currently has the capacity to process this additional material.
- Gaining acceptance of RCRB for road construction will be instrumental in the success of the C&D recycling industry in Perth.

This project aims to decrease environmental impacts resulting from construction and is important to sustainability, mainly through increasing resource use efficiency. Some of the benefits of this project include:

- Reduction in the dependence on virgin quarried materials.
- Lower processing effort required for recycled concrete compared to mining virgin

hard rock.

- RCRB processing plants are located in Perth metropolitan area requiring less transport effort to reach markets than raw material extraction and processing companies.
- Reduction in waste concrete going to landfill.

This project has positive social impacts through:

- Reduction in the number of road haulage movements from outlying quarries.
- Reduction in transport movements to landfills.
- Community awareness as a result of C&D processing plants requiring DEC Works Approval and licensing. The DEC permitting process requires extensive community consultation and environmental investigation.

Economic impacts of this project include:

- RCRB products are produced from a waste resource, diverting waste away from landfill.
- The disposal of recycled concrete is subject to the landfill levy.
- Recycled concrete requires less energy to process than hard rock.

Success of this project, meaning that all facilities are able to produce RCRB products in specification, is not guaranteed, however preliminary trials have indicated that selected recycled concrete RCRB products can be produced within or at least close to specification. Not all recycled concrete will produce products within specification.

This project will benefit other organisations and project areas, not just the recycling facilities that have undergone testing, including;

- Local Government – cheaper materials for road construction.
- Inert landfills – extended life of landfills due to the diversion of concrete from landfill.
- MRWA – Introduction of RCRB in the construction of minor roads.
- Hard rock quarries – conservation of hard rock resources extending the life of their quarries.
- DEC – reduction in waste to landfill due to increased markets for quality RCRB removing concrete disposal from landfills.

This project will allow the recycled concrete industry, on a collective and collaborative basis, to undertake higher level quality control auditing of RCRB produced across the four major recyclers without negative impact on their current operational costs.

At the completion of the project the recycled concrete industry wishes be able to demonstrate that over a seven month period they were able to produce within specification RCRB products.

In the event that the project demonstrates that certain facilities are unable to meet the specification, these facilities will have knowledge of any contributing factors to their inability to meet specification.

Recommendation will also be made on the suitability of the 501 Specification for the processing of locally produced recycled concrete.

7.2. PROPOSED OUTCOMES

There are four proposed outcomes for this project:

- Establish a C&D Working Group to facilitate development of the recycling industry;
- Independently analyse the performance of locally produced RCRB against the 501 Specification;
- Increase market confidence in RCRB products; and
- Final report compiling the results of the testing program.

7.2.1. C&D Working Group

A C&D industry Working Group will be formed as part of this project. It is intended that this group will be a working group set up within the WA branch of the WMAA. The following are industry and government representatives interested in becoming involved:

- Bruce Bowman – Bowman & Associates
- Peter Tapsell – DEC (now with EPA)
- Ross Keeley – MRWA
- Colin Leek – City of Canning (now with ARRB)
- Reza Nagafzadeh – City of Mandurah (now with Town of Kwinana)
- Adrian Lester – C&D Recycling
- Peter Grassi – Veolia Environmental Services
- Paul Tarzia – All Earth
- Ray Gullotto – Capital Demolition

7.2.2. Market Confidence

It is intended that this project will develop market confidence in RCRB through demonstrating that facilities and products can consistently meet specifications over a given timeframe.

7.2.3. Final Report

A report will be prepared and presented to the Waste Authority, DEC, WMAA, MRWA and other stakeholders. The report will be provided to local councils, architects, civil contractors and developers to confirm compliance of RCRB with MRWA specification.

7.3. TESTING PROGRAM

7.3.1. Overview

A comprehensive testing program was conducted over 31 weeks, forming the basis of this project. RCRB products from four Perth based C&D recycling facilities (C&D Recycling (Hazelmere), Veolia Environmental Services (Jandakot), Capital Demolition and Earthworks (Bayswater), and All Earth Group (Maddington) were tested 25 times over the seven month period from 31 October 2007 to 4 June 2008. Testing was

conducted by a NATA certified laboratory (Qualcon Laboratories Pty Ltd) that has extensive experience with Main Roads WA Specification 501 and Main Roads WA Test Methods. A laboratory technician visited each facility approximately once a week and took a sample of the most recently produced RCRB product. The samples were then tested and analysed in the NATA certified laboratory. This was repeated 25 times at each facility, except for All Earth Group's Maddington facility which was only sampled 21 times.

7.3.2. Laboratory Selection

The laboratory was selected through soliciting quotes for the proposed testing program from a number of soil testing laboratories around Perth. Qualcon Laboratories Pty Ltd, based in Malaga, was selected as the preferred testing laboratory based on price and workload.

7.3.3. Sampling Procedures

To ensure consistency, sampling procedures were followed each time a facility was sampled. These procedures included:

- attempting to visit each facility at a regular time on a given day of the week;
- sampling the most recently produced RCRB products;
- Using front end loaders to mix the pile in order to secure a representative sample; and
- Sampling the correct pile of material.

These procedures should produce meaningful and consistent results over the sampling period. They also provide Qualcon Laboratories Pty Ltd and Bowman & Associates Pty Ltd with fewer variables and hence a greater ability to interpret and analyse the data.

Qualcon Laboratories carried out sampling for the project in accordance with Main Roads WA Test Method 100.1 Sampling Procedures for Soil and Granular Pavement Materials.

Over the 31 week testing period, samples were taken on 25 occasions.

7.3.4. Testing Procedures

Qualcon Laboratories specialises in the testing of soil, rock, and road construction materials. Qualcon Laboratories is NATA accredited for Technical Competence and complies with ISO/IEC 17025 requirements. Qualcon Laboratories has extensive experience with MRWA testing methods and Specification 501. Bowman & Associates has confidence in the reliability of the data received from Qualcon's laboratory testing.

A number of tests were conducted on the RCRB products, including:

- particle size distribution (PSD);
- soil compaction;
- Atterberg limits;
- California bearing ratio of re-moulded specimen; and
- maximum dry compressive strength.

Samples were tested as soon as possible after collection.

The samples were tested in accordance with Main Roads WA Test Methods: 115.1 Particle Size Distribution: Sieving and Decantation Method, 120.1 Plasticity Index, 120.2 Liquid Limit: Cone Penetrometer Method, 123.1 Linear Shrinkage, 220.1 Los Angeles Abrasion Value, 140.1 Maximum Dry Compressive Strength, 141.1 California bearing Ratio, 143.1 Determination of the Unconfined Compressive Strength of Laboratory Compacted Specimens, 133.1 Dry Density/Moisture Content Relationship: Modified Compaction Fine and Medium Grained Soils or 133.2 Dry Density/Moisture Content Relationship: Modified Compaction Coarse Grained Soils, and 110.1 Moisture Content: Convection Oven Method or 110.2 Moisture Content: Microwave Oven Method. This is in accordance with Main Roads WA Specification 501.[43]

7.3.5. Results Analysis

The 501 Specification provides acceptance limits over a range of test parameters for both sub-base and base course. As the aim of the investigation was to gain acceptance of RCRB at the highest level of end use the test results are reported in comparison to the base course Specification. The base course Specification has tighter limits on most parameters as well as including acceptance criteria for compressive strength. All four facilities are able to meet the requirements for the lower market sub-base Specification.

The testing program provided the following data:

- Particle size distribution (PSD);
- Liquid limit;
- Linear shrinkage;
- Los Angeles abrasion value;
- Maximum dry compressive strength;
- California bearing ratio (CBR);
- Maximum dry density; and
- Optimum moisture content.

The results were analysed to show when and how many times each facility's RCRB product met the specification. The particle size distribution results were "scored" to assist analysis. Scoring is a simple way to determine how many times and by how far a certain sample falls outside the specified limits envelope for each grade (sieve size). Each grade of material in each sample was given a score based on how far it was outside the specified limits and these values were totaled to give a score for each sample and from this a total score for each facility was derived. If a grade was within the limits then it was scored as zero. Otherwise a value determined by the distance outside the envelope was given to each grade. Therefore, a sample that met the specification (every grade was inside the particle size distribution envelope) would have a total score of zero. A sample with a score of one means that one grade had an extra 1% of material either passing or not passing a certain sieve size. A sample with a score of ten may have an extra 10% of material passing or not passing one sieve size or an extra 2% passing or not passing five sieve sizes. Scoring each sample provides a quick and simple method for analysing each facility's progress through the 31 week period and comparing the facilities against each other and the desired result (a total score of zero).

[43] Main Roads WA, (2007). *Specification 501 Pavements*. Western Australia

8. RESULTS

8.1. OVERALL

The overall results appear to be consistent. A number of difficulties were noted during the sampling period, including machinery breakdowns, sampling the wrong pile of material, changing screen sizes, installing new screens, using material from different sources and having different equipment operators. This resulted in a number of outliers that have been attributed to these difficulties. The data from Capital's 7 May 2008 sample was not included in the analysis as the wrong material was sampled.

The most important data in terms of the scope of this project are particle size distribution, plasticity limits, and optimum moisture content testing.

The particle size distribution grading was passed by 26 of 95 material samples. As shown in Figure 1 below, seven All Earth samples, two C&D Recycling samples, eleven Capital samples and six Veolia samples met the PSD specification.

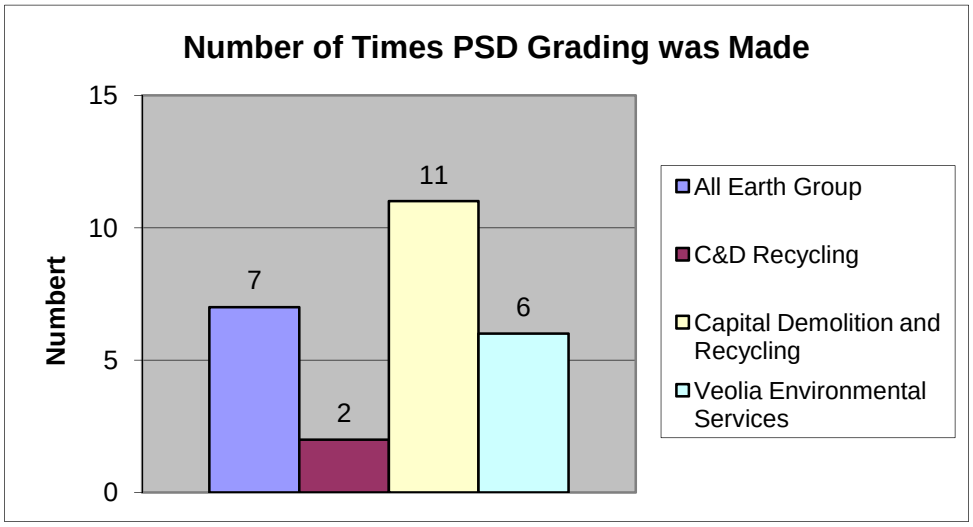

Figure 1: Number of Times PSD Grading was Met

As All Earth was only sampled 21 times and Capital only has 24 samples in the analysis, the corresponding percentages were also calculated and are shown in Figure 2 below. 33.3% of All Earth, 8% of C&D Recycling, 45.8% of Capital and 24% of Veolia samples met the PSD specification.

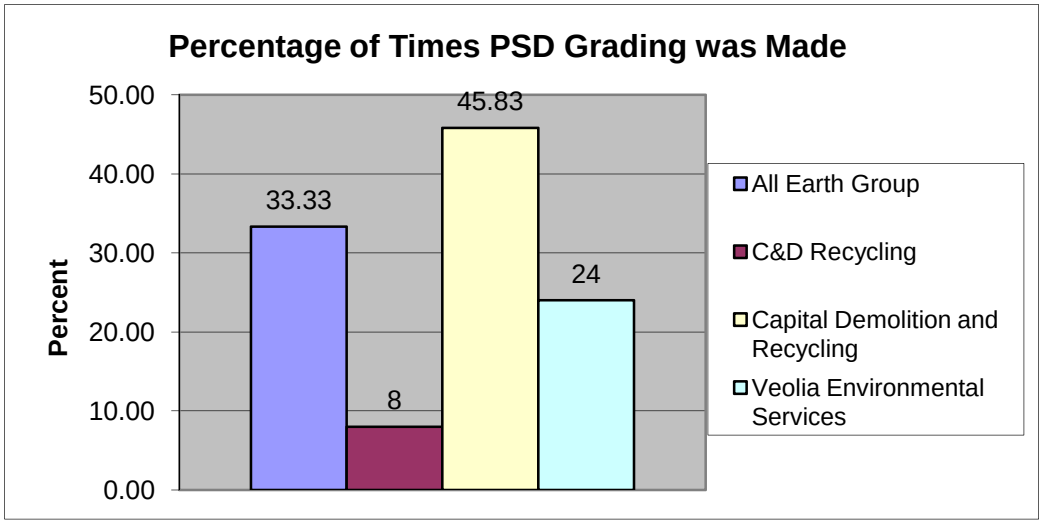

Figure 2: Percentage of Samples Meeting PSD Specification

The samples that did not make the PSD specification at every grade (a score of greater than zero) were scored and then totaled to create a facility total score. The total scores for each facility are shown in Figure 3 below: All Earth – 109, C&D Recycling – 142, Capital – 189, and Veolia – 382.

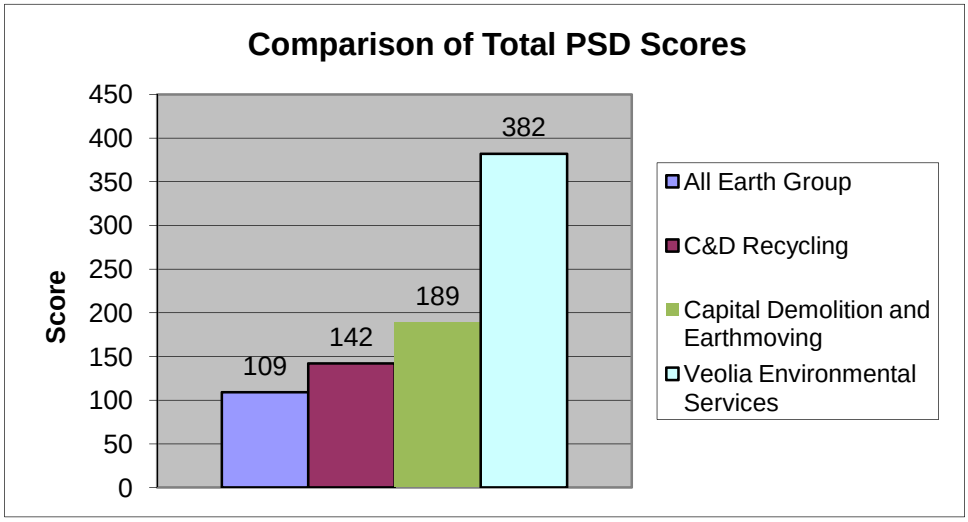

Figure 3: Comparison of Total PSD Scores

Keeping in mind that the facilities were sampled a number of times; the average score for each sample that did not meet the specification is shown in Figure 4 below. Average scores per sample were 7.79 for All Earth, 6.17 for C&D Recycling, 14.54 for Capital, and 20.11 for Veolia. Therefore, even though All Earth had the lowest total score, C&D Recycling had on average the least amount of material exceeding the PSD limits per sample.

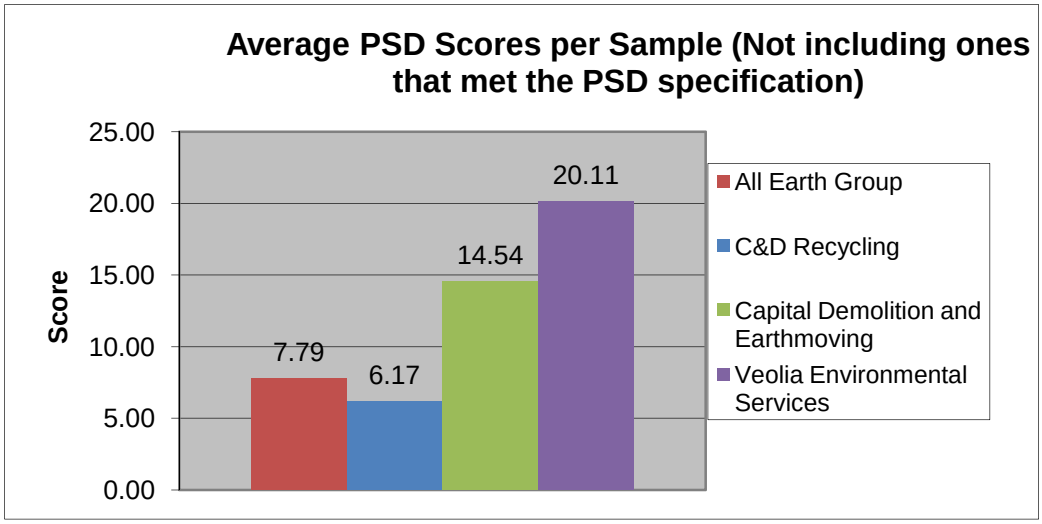

Figure 4: Average PSD Score per Sample for Each Facility

Figures 5 to12, below, display the PSD scores over the test period.

The results of other tests conducted on the samples are included in the following sections. A range of results were produced across these tests as reflected in the PSD results. The data from the testing program is included in the Appendix.

8.2. ALL EARTH GROUP

All Earth Group's facility was only sampled 21 times over the 31 week period, however this still provided reliable data for analysis. Figure 5, below, shows All Earth's PSD scores for the 21 samples, 7 of which made the specification. A linear trend line was added to the graph to illustrate the trend in scores. The trend line shows scores were consistent throughout the test period (flat line graph).

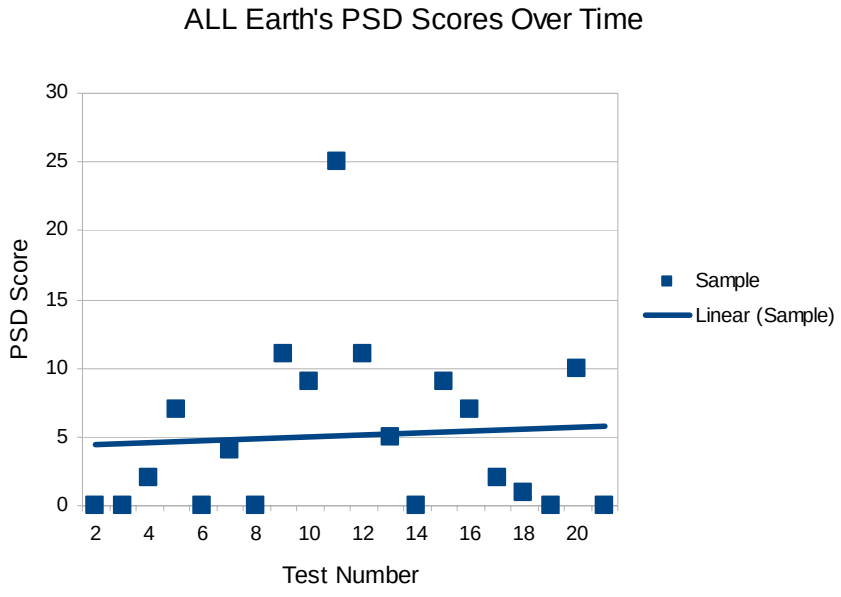

Figure 5: Scatter Plot of All Earth's PSD Scores With a Linear Regression Line

Nineteen of the 21 samples from All Earth's facility were tested for liquid limit and linear shrinkage. As shown in Figure 6 below, All Earth met the liquid limit specification of less than 35% every time, the only facility to do so. A linear trend line was added to graph the trend over time, which is level over the 19 tests. The trend line also gives an approximate average of the liquid limit which for All Earth is less than 30%. All Earth also met the linear shrinkage specification of less than 3% for each sample.

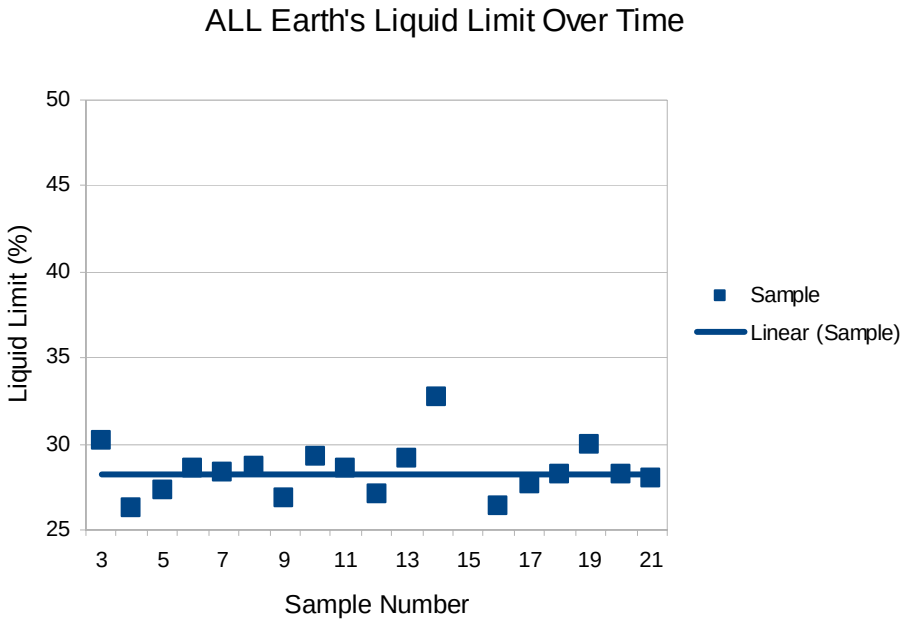

Figure 6: Scatter plot of All Earth's Liquid Limit With a Linear Regression Line

Four of the 21 samples were tested for LA abrasion. One of those samples did not meet the specification for LA abrasion of less than 40%.

Six of the 21 samples were tested for maximum compressive strength and California Bearing Ratio (CBR). None of those samples met the specification for maximum compressive strength of greater than 1.7 MPa. All but one of the samples met the CBR specification of greater than 100%.

Nineteen of the 21 samples were tested for optimum moisture content (OMC). Only two of those samples met the OMC specification of between 95% and 110%. OMC was not considered important under this project as moisture content is normally adjusted prior to material placement.

8.3. C&D RECYCLING

C&D Recycling's facility was sampled 25 times over the 31 week period. Figure 7, below, shows C&D Recycling's PSD scores for the 25 samples, 2 of which made the specification. A linear regression line was fitted to the graph to illustrate the trend in scores, which is moderately up over the 25 tests.

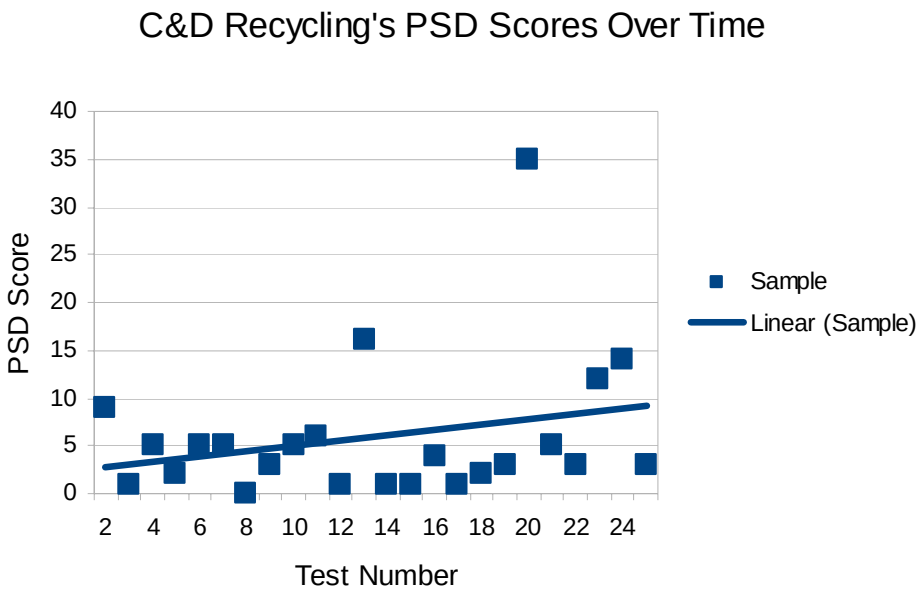

Figure 7: Scatter Plot of C&D Recycling's PSD Scores With a Linear Regression Line

23 of the 25 samples from C&D Recycling's facility were tested for the liquid limit and the linear shrinkage. As shown in Figure 8 below, C&D Recycling's samples failed to meet the liquid limit specification of less than 35% on 16 occasions. A linear trend line was added to graph the trend over time, which is moderately down over the 23 tests. The trend line also gives an approximate average of the liquid limit, which for C&D Recycling is around 38%. C&D Recycling also met the linear shrinkage specification of less than 3% every time.

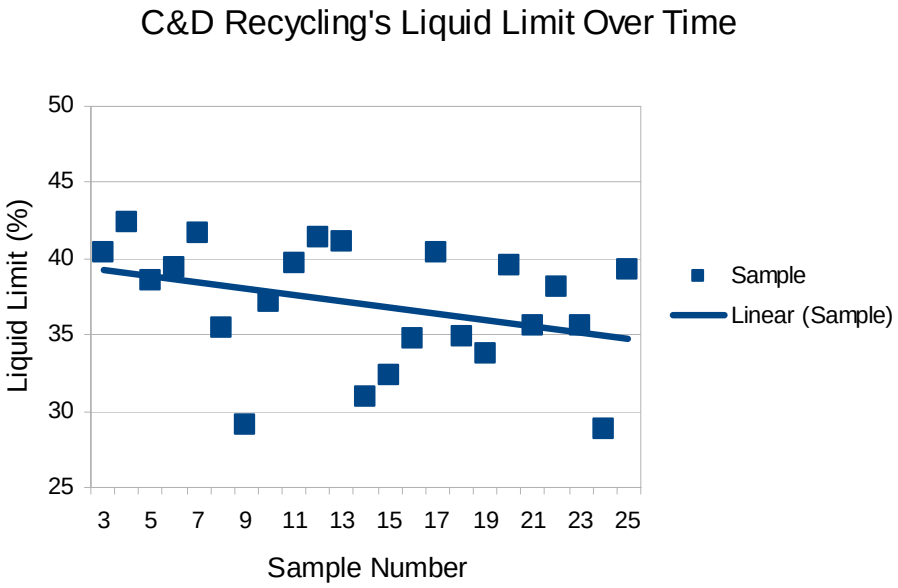

Figure 8: Scatter Plot of C&D Recycling's Liquid Limit With a Linear Regression Line

Five of the 25 samples were tested for LA abrasion. Four of those samples did not meet the specification for LA abrasion of less than 40%.

Eight of the 25 samples were tested for maximum compressive strength and California Bearing Ratio (CBR). None of those samples met the specification for maximum compressive strength of greater than 1.7 MPa. All but two of those samples met the CBR specification of greater than 100%.

All 25 samples were tested for optimum moisture content (OMC). Only one sample met the OMC specification of between 95% and 110%.

8.4. CAPITAL DEMOLITION AND EARTHWORKS

Capital's facility was sampled 25 times over the 31 week period, however one sample was of the wrong material so was not included in the results. Figure 9, below, shows Capital's PSD scores for the 24 samples, 11 of which made the specification. A linear trend line was fitted to the graph to the trend in scores, which is down over the 24 tests.

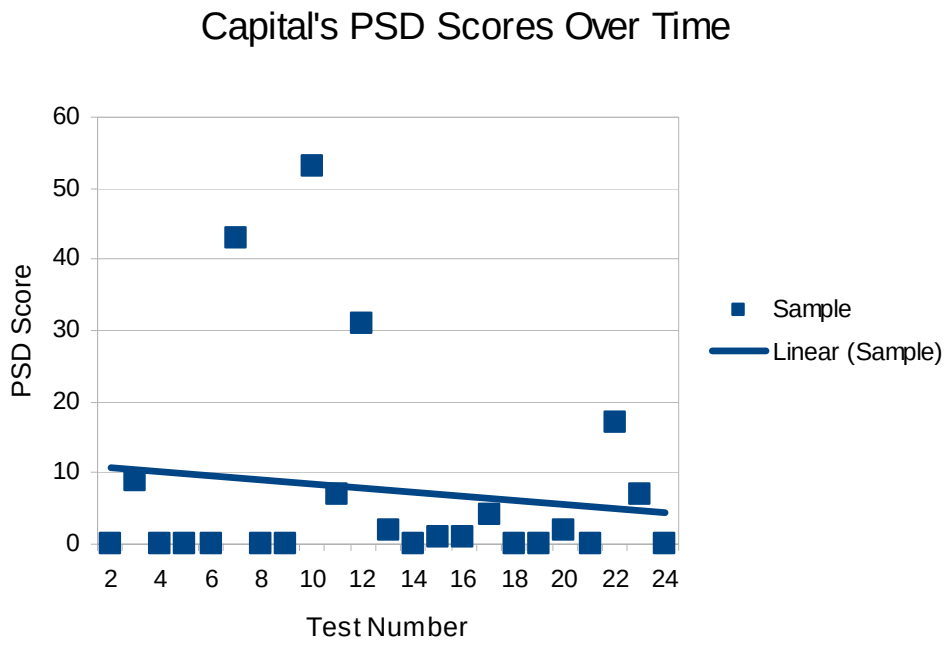

Figure 9: Capital's PSD Scores Over Time

Twenty-two of the 24 samples from Capital's facility were tested for the liquid limit and the linear shrinkage. As shown in Figure 10 below, Capital's samples failed to meet the liquid limit specification of less than 35% on 13 occasions. A linear trend line was added to graph the trend over time, which is very slightly down over the 22 tests. The trend line also gives an approximate average of the liquid limit, which for Capital is around 37%. Capital also met the linear shrinkage specification of less than 3% every time.

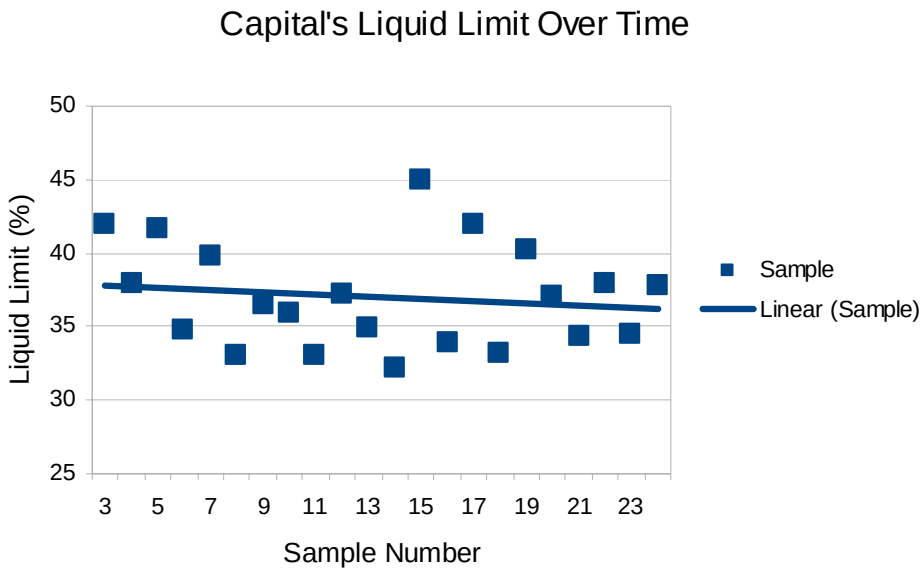

Figure 10: Scatter Plot of Capital's Liquid Limit With a Linear Regression Line

Four of the 24 samples were tested for the LA abrasion. One of those samples did not meet the specification for LA abrasion of less than 40%.

Seven of the 24 samples were tested for maximum compressive strength and California Bearing Ratio (CBR). None of those samples met the specification for maximum compressive strength of greater than 1.7 MPa. All of those samples met the CBR specification of greater than 100%.

All 24 samples were tested for optimum moisture content (OMC). Only one sample met the OMC specification of between 95% and 110%.

8.5. VEOLIA ENVIRONMENTAL SERVICES

Veolia's facility was sampled 25 times over the 31 week period. Figure 11, below, illustrates Veolia's PSD scores for the 25 samples, 6 of which made the specification. A linear trend line was fitted to the graph to outline the trend in scores, which is moderately up over the 25 tests.

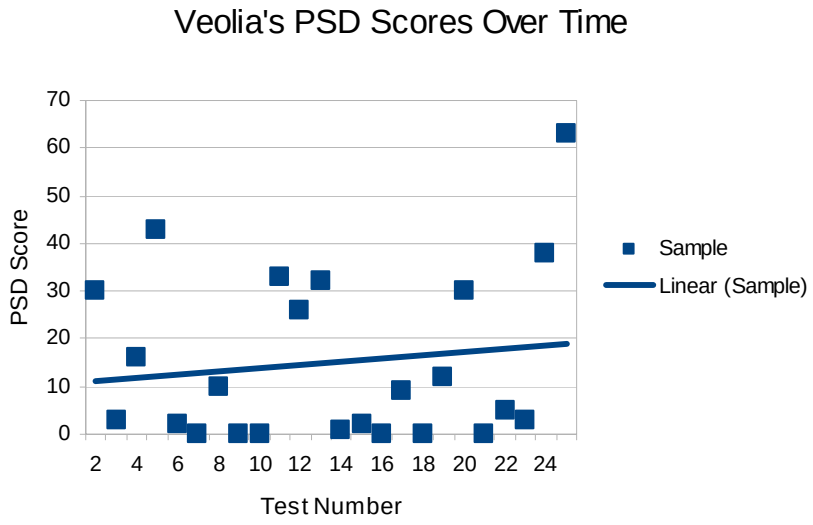

Figure 11: Scatter Plot of Veolia's PSD Scores With a Linear Regression Line

Twenty-three of the 25 samples from Veolia's facility were tested for liquid limit and linear shrinkage. As shown in Figure 12 below, Veolia's samples failed to meet the liquid limit specification of less than 35% on 2 occasions. A linear trend line was added to graph the trend over time, which is moderately down over the 23 tests. The trend line also gives an approximate average of the liquid limit, which for Veolia is around 33%. Veolia also met the linear shrinkage specification of less than 3% every time.

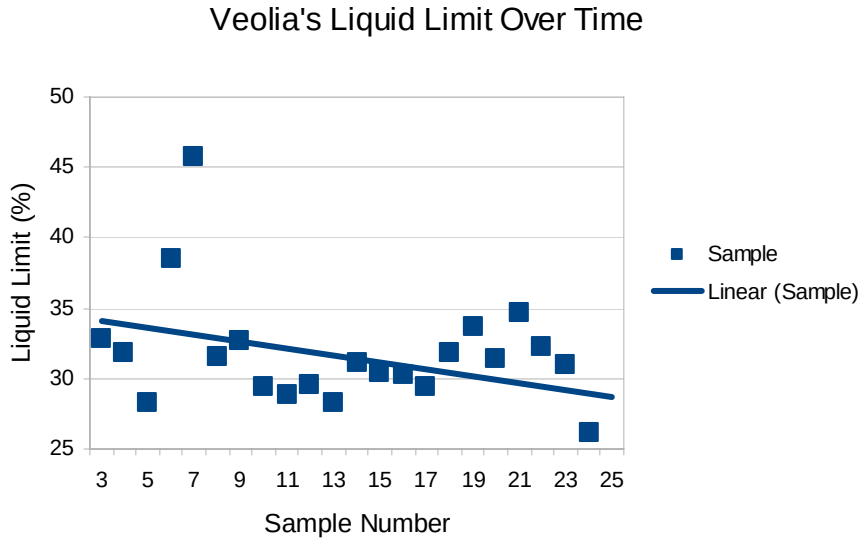

Figure 12: Scatter Plot of Veolia's Liquid Limit With a Linear Regression Line

Five of the 25 samples were tested for LA abrasion. Four of those samples did not meet the specification for LA abrasion of less than 40%.

Seven of the 25 samples were tested for maximum compressive strength and 8 of the 25 samples were tested for California Bearing Ratio (CBR). None of those samples met the

specification for maximum compressive strength of greater than 1.7 MPa. Four samples met the CBR specification of greater than 100%.

All 25 samples were tested for optimum moisture content (OMC). None of those samples met the OMC specification of between 95% and 110%.

Veolia's sample data was also tested against the Main Roads 501 Specification for recycled crushed concrete for use as sub-base. Twenty-four of the 25 samples made the PSD specification for sub-base. When compared against the liquid limit specification of less than 45%, 22 out of 23 samples met the specification. Four out of 5 samples met the specification for LA abrasion of less than 45%. All of the eight samples compared against the CBR specification of greater than 50% passed.

9. DISCUSSION

9.1. LIQUID LIMIT

The liquid limit (LL) is defined as the minimum moisture content at which 25 blows in the standard test apparatus will just close a groove in a sample of soil. In other words it is a measure of how plastic a material is. Plasticity is required in road base to allow good cohesion, compaction and pavement flexibility. However, when road base is made from recycled concrete the plasticity of the RCRB behaves differently to road base made from virgin quarry materials. The main reason is that the reactivated cement fines in the RCRB take up moisture through hydration. This moisture shows up as part of the total moisture in the material when oven dried as part of the test procedure but is not free moisture within the colloidal matrix of the material.

This is further characterised by the optimum moisture content (OMC) of RCRB which typically is in the range of 13 -16% whereas road base made from virgin rock has an OMC in the order of 6.5 – 7.5%. Understanding the different behavioural characteristics of RCRB is crucial for the acceptance of these materials as quality construction products.

All facilities tested had difficulty in meeting the liquid limit requirements with the cleaner higher grade concrete feedstock displaying the highest liquid limits. The acknowledgement of this characteristic has lead to a paradox shift in thinking amongst the project stakeholders as it was clear that to meet the liquid limit of the 501 Specification other requirements of the Specification would have to be compromised, this being the percent of heavy foreign material and clay or another form of plasticiser would have to be used to control plasticity. Manufacturers of road base using virgin quarry materials use clay as plasticisers to meet plasticity requirements as part of normal operations.

9.2. HIGH DENSITY MATERIALS

In order to control plasticity, foreign materials such as brick, clay or sand would be required. The 501 Specification has a limit of 5% on high density foreign material and with 5 -15% of foreign material required to meet the liquid limit this acceptance criteria of the Specification cannot be met.

9.3. MAXIMUM DRY COMPRESSIVE STRENGTH

Maximum dry compressive strength is an indication of the cohesive strength of the material. Road base made from virgin materials characteristically has more cohesion and displays higher unconfined compressive strength characteristics than RCRB. This is due to the higher strength of individual particles, the angular nature of the particles and the cohesiveness of the clayey matrix. Due to the inherent nature of RCRB low compressive strength was recorded suggesting that the maximum dry compressive strength of 1.7Mpa as specified in the Specification is unachievable using RCRB.

9.4. FEEDSTOCK VARIABILITY

Although the four recycling facilities that participated in this investigation are Perth based, their individual business models have a dramatic effect on the characteristics of their respective feedstocks which accounts for the differences in results at each facility.

9.4.1. All Earth

All Earth's facility operates from its waste transfer station site in Maddington. The majority of the C&D waste comes from the company's own construction and earthmoving business operations allowing for greater attention to source separation of C&D materials. The result is a high level of quality control over the feedstock and the recycled products produced and minimal residual to landfill.

All Earth was the only facility to produce material on a consistent basis that complied with the liquid limit requirements. This was achieved by using source separated crushed brick rubble as a plasticiser, All Earth was the only company to use crushed bricks to meet liquid limit requirement. As brick rubble is listed as a foreign material within the MRWA 501 Specification its use is currently restricted to a maximum of 5%.

9.4.2. C&D Recycling

C&D Recycling's facility is established on Federal Airport land in Hazelmere adjacent to a large pile of demolition waste. C&D Recycling processes the stockpile of concrete, sand and rubble along with incoming C&D waste from building and demolition sites. The nature of the feed stock produces recycled building materials with noticeable organic content. Large quantities of fill sand are screened and road base products have high liquid limits due the separation of fill sand from the feedstock prior to crushing. The facility experiences around 5% residual to landfill consisting mainly of wood and plastic.

9.4.3. Capital Demolition

Capital Demolition's facility is vertically integrated into the company's demolition activities resulting in very clean structural concrete used as feedstock. The structural concrete allows high CBR (granular strength) values but with the higher cement content displays higher than specified liquid limits. Capital Demolition reports around 2% residual to landfill.

9.4.4. Veolia Environmental Services

The Jandakot recycling facility processes C&D waste collected by the company's waste collection fleet and waste received from commercial operators. The nature of the waste is commingled building waste containing large quantities of dirt, sand, timber, light metals and plastic.

Initially VES did not wish to be assessed against the base course specification preferring to be assessed on the sub-base specification. The reason being that the "business as usual" operation the Jandakot facility is to process co-mingled C&D waste and produce fill sand and low grade road base for use as select fill. The facility has around 20-30% residual to landfill.

As the trials progressed, VES, through increased understanding of the results of the testing program started to produce higher quality products. VES has been assessed against the road base specification in direct comparison to the other three facilities.

9.5. OBSERVATIONS FROM THE TEST RESULTS

From the above results and the data attached in the Appendix, the following conclusions were made:

- Facilities can meet the specified PSD grading for base course;
- More work is required for all of these facilities to be able to consistently produce product that meets the PSD grading specification;

- Making the PSD specification depends on raw feed selection, production procedures and equipment (screens) used;
- Making the liquid limit specification depends heavily upon material selection;
- All facilities improved the liquid limit results for their RCRB products over the testing period;
- Two facilities had difficulty achieving the specified liquid limit of less than 35%, as it was noted that the cleaner the feedstock the higher the liquid limit;
- Facilities are capable of making the specification for LA abrasion;
- The specification for maximum compressive strength is too high and currently unachievable;
- The specification for CBR is achievable;
- Further studies into foreign material and unconfirmed compressive strength of RCRB products are required;
- Further work should be carried out to find an achievable specification for maximum compressive strength;
- None of the four facilities can produce RCRB products that meet Main Roads 501 Specification for base course as the Specification stands at present; and
- All four facilities can consistently produce a RCRB product that meets the specification for sub-base.

The following limitations for this project were identified:

- only conducting the testing program for a 31 week period;
- not testing for foreign materials or the unconfined compressive strength;
- not being able to provide good feedback to recyclers due to the lag in receiving results from the lab; and
- a few short term difficulties that led to one or two weeks of poor results.

9.6. RELIABILITY OF PRODUCT

None of the four facilities can currently make RCRB products that meet all of the acceptance criteria in the 501 Specification for base course. However, it is probable that all four facilities will be able to consistently produce RCRB material that meets the PSD grading and liquid limit specification in the future. This can only be achieved through diligent work, careful raw feed selection, plant operation, production procedures, maintaining equipment in good working order and the use of “foreign materials” such as clay, crushed brick and sand to correct liquid limits.

All facilities have shown that they can consistently produce RCRB material that meets the Specification for sub-base.

9.7. ACHIEVED OUTCOMES

9.7.1. C&D Working Group

Establishing a C&D Working Group of the WMAA WA Division was a key outcome for this project. A C&D Working Group was established and played an important role in the successful completion of this project. The C&D Working Group will continue to operate

and work to further the goals of the construction and demolition waste recycling industry. The working group meets every three months and has now met on at least six occasions. Minutes from the meetings are available from the member's portal of the WMAA website.

To date the C&D Working Group has thirty persons included on the communication list. The working group has secured further SWIS funding for C&D projects, represented the C&D recycling industry in forums involving State and Local Governments and presented papers at conferences and workshops around Perth. The working group through its affiliation with the WMAA National C&D Working Group has been involved in the development of national guidelines for the management of asbestos in C&D waste and facility management guidelines. Through consultation with the Toxicology Branch of the WA Department of Health the C&D Working Group has provided comment on State asbestos management policies developed by the Department of Health.

The C&D Working group continues its work to develop industry acceptance for recycled concrete construction materials and without the support of the Waste Authority's SWIS funding for this project the C&D Working Group would most likely not have eventuated.

9.7.2. Market Confidence

The project in itself and the results obtained from the testing program, including a range and variability in PSD grading scores, the variability in liquid limits, and being unable to meet all the current Specification parameters have created engagement and discussion from RCRB stakeholders.

Although the outcomes of the testing program are unlikely to promote immediate market confidence with prospective users in RCRB, the escalation of the development of the recycling market will lead to future confidence.

There should not be a shortage of market confidence in using RCRB products for sub-base and other lower end uses. The construction and demolition waste recycling industry can reliably, consistently, and sustainably supply RCRB products for use as sub-base in roads and base material in footpaths, driveways, and parking lots. Suggested reasons for the limited uptake of RCRB materials include: cost, lack of knowledge about reliability, lack of knowledge about benefits, unwillingness to try something new, and agreements and relationships with crushed rock suppliers. Most of these can be overcome by greater marketing of the benefits and successes of recycled construction and demolition waste products.

9.7.3. C&D Recycling Industry

Prior to the commencement of this project, knowledge of the characteristics and resulting performance of road base manufactured from recycled concrete within the participating recycling companies was limited. The four participating recycling companies came from land development, demolition and waste collection backgrounds.

Throughout the 31 weeks of testing, the knowledge and understanding of the performance of RCRB increased among facility staff, the result of which can be see in the improvements in test result consistency.

All Earth, assisted by its experience in road construction, was able to produce quality road base over a continual period to a standard satisfactory to the MRWA.

9.7.4. Perth to Bunbury Highway Trial Pavement

Through the stakeholder contacts made throughout this project and the confidence gained by the C&D recycling companies to be able to make quality base course materials, Bowman & Associates on behalf of the C&D Working Group secured SWIS funding to subsidise the delivery of recycled concrete base course to a trial pavement in the Perth to Bunbury Highway. All Earth is the nominated supplier of recycled concrete base course for a trial pavement due to the company's ability to produce a quality product on a continual basis and to a standard acceptable to MRWA. The trial pavement is due to be constructed in February 2009 and will be reported as an outcome report for SWIS Project No. 5805.

9.8. NEXT STEPS FOR INDUSTRY

Further steps for industry to take include:

- Working with MRWA to develop a specification that is consistently achievable and functional (short to medium term);
- Continuing to work on developing a consistent RCRB product that reliably makes the specification (long term);
- Experimenting with raw feed selection, screen sizes, and plant operation to find the best procedures that will produce a consistent RCRB product (short to medium term);
- Regularly testing RCRB products against the Specification (short to medium term);
- Working towards increasing the quality of supplied material (medium to long term);
- Working to increase the market demand for, and market share of, RCRB products for the higher end use base course materials (short to medium term);
- Developing, in partnership with Local Government, more test road sections that use RCRB as road base similar to the City of Canning's Welshpool Rd upgrade (short to medium term); and
- Greater marketing of the environmental and economic benefits of RCRB products to buyers in industry and government (short to medium term).

9.9. ACHIEVING FURTHER USE IN INFRASTUCTURE

The goal for construction and demolition waste recyclers and proponents of sustainability is to have widespread use of recycled C&D waste products in all civil construction sectors. Replacing virgin material with RCRB products in road construction is an integral part of reaching this goal. To achieve this, RCRB products must meet achievable specifications and be permitted for use; local governments must take the initiative and be the first to adopt RCRB products; industry and MRWA must follow the lead of local governments; and the costs of virgin materials must reflect the true environmental and social costs of quarrying.

10. APPENDIX

Bowman & Associates Pty Ltd

SWIS #4003 RCRB Testing Summary

Particle Size Distribution		Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date
Test Method	MRWA: 115.1	31.10.07	12.11.07	29.11.07	9.1.08	16.1.08	23.1.08	30.1.08	22.02.08	28.02.08	7.03.08	13.03.08	19.03.08	27.03.08	2.04.08	23.04.08	30.04.08	07.05.08	14.05.08	21.05.08	28.05.08	04.06.08
Specification	MRWA Table 501.23	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**
75.0mm Sieve	100% Passing	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
37.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
26.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
19.0	95 -100	100	99	100	99	99	99	99	98	99	99	100	99	98	99	99	99	93	94	96	98	95
13.2		93	90	86	89	90	85	86	84	89	88	95	90	89	86	87	86	76	81	85	86	83
9.5	59 - 80	82	75	72	76	78	72	73	70	77	76	84	77	77	74	77	74	63	69	72	75	69
6.7		69	64	61	65	67	60	62	58	66	65	73	67	67	62	67	63	52	59	60	66	58
4.75	41 - 60	59	55	53	55	57	52	54	49	57	57	63	57	57	53	58	55	44	51	52	58	49
2.36	29 - 45	46	43	42	44	46	41	43	39	47	46	50	47	46	42	47	44	35	41	42	47	40
1.18	20 - 35	37	35	35	36	38	35	37	31	39	39	42	39	37	33	39	38	29	34	34	39	32
0.600	13 - 27	28	26	27	28	30	27	29	25	31	31	32	31	29	26	30	31	23	26	27	31	25
0.425	10 - 23	20	20	20	21	22	20	22	19	24	23	24	24	21	19	22	23	17	20	21	23	19
0.300	8 - 20	13	13	13	14	15	14	15	13	16	16	15	16	14	13	15	16	12	14	15	15	13
0.150	5 - 14	6	7	6	6	8	7	8	7	8	8	7	9	7	6	8	6	6	7	8	8	6
0.075	3 - 11	4	4	4	4	5	4	5	5	5	5	5	6	4	4	5	5	4	5	5	5	4
0.0135		1	2	2	1	3	1	2	2	2	2	3	2	1	1	3	3	2	2	3	2	2
Consistancy Limits																						
Test Method	MRWA: 120.2, 123.1, 220.1, 140.1, 141.1, 110.1, 110.2, 133.1, 133.2																					
Specification	MRWA 501.94																					
Liquid Limit (%)	<35.0%			30.2	26.3	27.3	28.6	28.3	28.7	26.8	29.3	28.6	27.1	29.2	32.7	24.7	26.4	27.6	28.2	30	28.2	28
Linear Shrinkage (%)	<3.0%			0.0	0.0	0.0	0.0	1.2	0.4	0.4	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0
LA Abrasion	<40%				36.8						39.3				39			40.5				
Max Comp Strength	>1.7Mpa		1.010	0.830	0.960										0.84			0.8				1.06
CBR	>100%		240	160	150										45			120				130
Unconf. Comp. Strength	0.6 - 1.0 MPa																					
SMDD t/m³		1.932	1.930	1.964	1.964	2.004	1.972	1.936	1.976	1.962	1.958	1.92	1.98	1.95	1.896	1.976	1.952	1.904	1.948	1.919	1.92	1.92
OMC %	95% - 110%	74.2%	88.1%	92.6%	77.9%	93.6%	110.5%	93.5%	95.0%	92.5%	143.5%	92.7%	90.3%	not done	not done	126.1%	125.5%	78.4%	92.6%	99.9%	92.1%	71.4%
Foreign Material High Density	<5%																					
Foreign Material Low Density	<2%																					
Foreign Material - Wood	<0.5%																					
Foreign Material - Asbestos	0%																					

Moisture content	8.83%	11.10%	11.20%	9.04%	9.73%	12.26%	11.41%	11.49%	10.54%	15.78%	12.23%	10.66%	not done	not done	13.62%	14.18%	10.11%	11.39%	12.19%	12.16%	10.28%
Optimum Moisture content	11.90%	12.60%	12.10%	11.60%	10.40%	11.10%	12.20%	12.10%	11.40%	11.00%	13.20%	11.80%	12.00%	14.20%	10.80%	11.30%	12.90%	12.30%	12.20%	13.20%	14.40%

Bowman & Associates Pty Ltd

SWIS #4003 RCRB Testing Summary

Particle Size Distribution		Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date
Test Method	MRWA: 115.1	31.10.07	12.11.07	29.11.07	9.1.08	17.1.08	24.1.08	30.1.08	7.2.08	13.2.08	22.02.08	28.02.08	07.03.08	13.03.08	19.03.08	27.03.08	02.04.08	10.04.08	16.04.08	23.04.08	30.04.08	07.05.08	14.05.08	21.05.08	28.05.08	04.06.08
Specification	MRWA Table 501.23	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing
75.0mm Sieve	100% Passing	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
37.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
26.5	100	100	97	100	100	100	100	100	100	99	100	99	100	100	99	99	100	99	99	99	97	99	99	98	99	99
19.0	95 -100	95	89	94	90	93	92	90	99	93	90	92	94	97	95	96	91	96	94	93	84	91	93	87	93	93
13.2		86	74	81	77	81	77	75	86	77	78	81	80	88	84	87	80	85	82	84	67	79	85	70	78	84
9.5	59 - 80	76	63	69	66	68	61	62	68	62	64	70	67	79	73	77	67	71	70	73	54	67	75	58	63	74
6.7		66	53	58	57	55	48	51	54	52	52	57	55	69	61	67	55	56	60	63	41	57	65	48	57	64
4.75	41 - 60	57	46	49	50	45	39	43	43	45	41	47	46	61	51	57	46	44	52	54	32	49	56	40	51	54
2.36	29 - 45	44	37	36	39	32	29	32	31	37	29	34	35	49	38	43	34	31	42	41	23	38	43	30	44	42
1.18	20 - 35	34	29	28	30	25	21	25	24	32	22	24	24	40	27	34	26	23	34	31	19	30	32	24	39	32
0.600	13 - 27	26	22	21	22	18	16	19	18	26	16	16	17	31	20	24	18	18	26	22	14	22	23	19	32	23
0.425	10 - 23	20	17	16	17	14	13	14	14	22	13	11	13	25	16	19	14	14	21	16	11	17	18	15	25	18
0.300	8 - 20	14	12	11	12	10	10	10	10	17	9	7	10	18	12	13	10	10	15	11	8	12	13	11	19	13
0.150	5 - 14	7	7	5	6	5	6	5	6	10	5	4	6	10	7	7	6	6	8	6	5	6	7	6	10	7
0.075	3 - 11	4	4	3	3	3	3	3	4	6	3	3	4	7	5	4	3	4	5	4	3	4	4	4	6	4
0.0135		1	2	1	1	1	1	1	1	2	1	3	1	5	2	2	1	1	2	2	1	1	1	1	3	1
Consistancy Limits																										
Test Method	MRWA: 120.2, 123.1, 220.1, 140.1, 141.1, 110.1, 110.2, 133.1, 133.2																									
Specification	MRWA 501.94																									
Liquid Limit (%)	<35.0%			40.4	42.4	38.5	39.4	41.6	35.5	29.1	37.1	39.7	41.4	41.1	30.9	32.3	34.8	40.4	34.9	33.8	39.5	35.6	38.1	35.6	28.8	39.3
Linear Shrinkage (%)	<3.0%			0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.0	1.6	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4
LA Abrasion	<40%				46.2				46				35.7				43.3					40.7				
Max Comp Strength	>1.7Mpa		0.770	0.780	0.890				1.220				0.37				0.59					1.16				0.71
CBR	>100%		160	200	180				210				190				80					110				70
Unconf. Comp. Strength	0.6 - 1.0 MPa																									
SMDD t/m³		1.886	1.826	1.906	1.86	1.892	1.852	1.906	1.926	2.014	1.894	1.9	1.876	1.794	1.912	1.85	1.88	1.834	1.848	1.86	1.888	1.868	1.844	1.852	1.98	1.848
OMC %	95% - 110%	68.4%	68.4%	80.8%	37.7%	55.6%	47.1%	36.7%	76.5%	57.8%	67.6%	72.3%	58.9%	86.6%	61.0%	45.9%	37.5%	56.3%	49.6%	57.0%	47.5%	59.1%	95.0%	69.5%	61.5%	54.0%
Foreign Material High Density	<5%																									
Foreign Material Low Density	<2%																									
Foreign Material - Wood	<0.5%																									
Foreign Material - Asbestos	0%																									

Moisture content	9.65%	10.47%	9.62%	5.39%	8.06%	7.30%	4.59%	10.02%	5.66%	9.93%	9.62%	9.19%	13.68%	8.90%	6.65%	6.12%	8.61%	6.70%	9.40%	5.94%	8.51%	13.40%	9.04%	8.37%	9.02%
Optimum Moisture content	14.10%	15.30%	11.90%	14.30%	14.50%	15.50%	12.50%	13.10%	9.80%	14.70%	13.30%	15.60%	15.80%	14.60%	14.50%	16.30%	15.30%	13.50%	16.50%	12.50%	14.40%	14.10%	13.00%	13.60%	16.70%

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SWIS #4003 RCRB Testing Summary

Particle Size Distribution		Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date	Sample Date
Test Method	MRWA: 115.1	31.10.07	12.11.07	29.11.07	9.1.08	17.1.08	24.1.08	30.1.08	7.02.08	13.02.08	22.02.08	28.02.08	07.03.08	13.03.08	19.03.08	27.03.08	02.04.08	10.04.08	16.04.08	23.04.08	30.04.08	07.05.08	14.05.08	21.05.08	28.05.08	04.06.08
Specification	MRWA Table 501.23	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing	% Passing
75.0mm Sieve	100% Passing	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
37.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
26.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	100	100
19.0	95 -100	100	100	99	100	99	99	100	98	99	100	96	100	99	97	99	98	98	99	98	99	100	98	95	100	99
13.2		91	89	88	90	91	86	93	84	88	95	75	96	92	81	86	85	84	88	85	87	93	85	87	92	88
9.5	59 - 80	81	72	77	76	77	73	83	66	72	88	56	89	81	64	68	70	68	75	72	71	84	67	78	82	74
6.7		70	59	67	62	63	61	72	54	59	78	44	79	70	53	54	57	54	63	60	59	75	54	69	71	62
4.75	41 - 60	61	49	57	50	51	49	64	46	47	68	37	69	59	45	43	46	43	52	49	49	65	45	60	61	52
2.36	29 - 45	48	37	45	36	36	36	54	36	34	55	29	55	45	36	31	34	31	40	36	37	54	35	49	47	39
1.18	20 - 35	39	29	40	27	26	27	47	29	27	47	24	38	36	29	23	26	21	30	28	26	45	27	41	37	26
0.600	13 - 27	30	22	31	20	19	20	37	21	20	37	20	27	27	22	16	19	15	22	20	18	36	21	32	27	18
0.425	10 - 23	22	16	22	15	15	15	28	16	15	28	15	20	20	18	12	14	10	16	15	13	27	16	24	20	14
0.300	8 - 20	15	11	15	11	10	11	19	12	11	19	11	14	13	13	9	10	7	11	10	9	18	12	18	14	9
0.150	5 - 14	8	6	8	6	5	6	10	7	6	10	6	8	7	7	4	4	3	5	5	4	9	6	11	7	5
0.075	3 - 11	6	4	6	4	3	4	8	5	4	8	4	5	5	5	3	3	2	3	3	2	7	4	8	4	3
0.0135		0	1	0	0	1	1	2	1	1	0	2	2	4	2	1	1	1	2	2	1	4	1	5	3	1
Consistancy Limits																										
Test Method	MRWA: 120.2, 123.1, 220.1, 140.1, 141.1, 110.1, 110.2, 133.1, 133.2																									
Specification	MRWA 501.94																									
Liquid Limit (%)	<35.0%			41.9	37.9	41.6	34.7	39.8	33.1	36.5	35.9	33	37.2	34.9	32.2	45	33.9	41.9	33.2	40.2	37.1	38.8	34.4	38	34.5	37.8
Linear Shrinkage (%)	<3.0%			0.0	0.0	0.0	0.0	0.0	0.4	1.2	1.6	0.4	0.4	0.8	0.4	0.0	0.0	0.4	0.0	0.0	0.0	1.6	0.4	1.6	0.0	0.0
LA Abrasion	<40%				33.1				45.9				38.3				36.4					28.9					
Max Comp Strength	>1.7Mpa		0.800	0.860	0.940				0.740				0.42				0.79					1.07				0.92
CBR	>100%		150	150	240				140				180				170					40				100
Unconf. Comp. Strength	0.6 - 1.0 MPa																									
SMDD t/m³		1.902	1.856	1.838	1.842	1.900	1.932	1.880	1.896	1.908	1.932	1.910	1.865	1.896	1.900	1.884	1.916	1.856	1.800	1.864	1.884	1.855	1.988	1.864	1.820	1.824
OMC %	95% - 110%	111.6%	64.1%	123.6%	67.7%	61.0%	80.6%	87.9%	66.4%	66.9%	104.3%	64.2%	69.6%	74.1%	59.7%	41.7%	71.9%	52.1%	56.4%	58.5%	54.2%	89.1%	86.5%	93.9%	62.0%	71.8%
Foreign Material High Density	<5%																									
Foreign Material Low Density	<2%																									
Foreign Material - Wood	<0.5%																									
Foreign Material - Asbestos	0%																									

Moisture content	14.62%	9.49%	18.05%	8.93%	7.50%	9.19%	12.84%	8.96%	8.96%	13.56%	9.05%	9.68%	10.82%	8.12%	6.96%	9.99%	8.23%	7.56%	9.25%	8.45%	13.81%	10.72%	14.09%	8.86%	10.92%
Optimum Moisture content	13.10%	14.80%	14.60%	13.20%	12.30%	11.40%	14.60%	13.50%	13.40%	13.00%	14.10%	13.90%	14.60%	13.60%	16.70%	13.90%	15.80%	13.40%	15.80%	15.60%	15.50%	12.40%	15.00%	14.30%	15.20%

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SWIS #4003 RCRB Testing Summary

Particle Size Distribution		**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**	**Sample Date**
Test Method	MRWA: 115.1	31.10.07	12.11.07	29.11.07	9.1.08	16.1.08	23.1.08	30.1.08	7.02.08	13.02.07	21.02.08	28.02.08	07.03.08	13.03.08	19.03.08	27.03.08	02.04.08	10.04.08	16.04.08	23.04.08	30.04.08	07.05.08	14.05.08	21.05.08	28.05.08	04.06.08
Specification	MRWA Table 501.23	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**	**% Passing**
75.0mm Sieve	100% Passing	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
37.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
26.5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
19.0	95 -100	100	100	100	100	100	100	98	97	99	99	100	100	100	99	99	100	99	99	99	99	99	99	100	99	99
13.2		94	95	94	94	93	84	85	77	84	81	94	94	94	90	89	88	90	83	89	90	88	87	88	92	91
9.5	59 - 80	82	84	80	82	83	69	73	57	68	65	81	82	83	78	74	77	77	68	80	78	74	75	75	81	81
6.7		71	73	68	70	73	56	63	44	53	55	71	70	72	66	62	66	66	57	70	68	62	64	65	72	73
4.75	41 - 60	62	64	58	61	65	46	54	36	43	48	63	61	63	56	53	57	56	48	61	60	52	53	56	65	66
2.36	29 - 45	51	53	46	49	55	35	43	27	33	39	52	50	51	43	42	45	47	38	49	60	39	45	45	56	59
1.18	20 - 35	43	43	37	41	47	25	32	22	26	34	45	43	44	36	36	34	39	31	40	42	32	38	37	45	53
0.600	13 - 27	33	33	27	30	37	18	24	17	20	27	36	34	35	27	28	26	30	24	29	33	23	29	28	35	43
0.425	10 - 23	23	23	19	22	26	13	18	13	15	20	26	26	26	21	21	19	22	18	22	25	17	21	21	26	31
0.300	8 - 20	14	15	13	14	17	8	13	9	10	13	16	16	17	14	14	13	14	12	14	17	12	14	14	17	20
0.150	5 - 14	6	6	5	6	7	4	7	4	5	5	7	7	7	7	7	6	6	7	6	9	5	6	7	7	8
0.075	3 - 11	4	4	3	3	4	2	4	3	3	3	5	4	4	4	4	4	4	5	4	6	3	4	4	5	5
0.0135		1	2	1	1	3	1	2	1	1	1	2	2	2	2	2	2	2	2	2	3	1	2	3	3	2
Consistancy Limits																										
Test Method	MRWA: 120.2, 123.1, 220.1, 140.1, 141.1, 110.1, 110.2, 133.1, 133.2																									
Specification	MRWA 501.94																									
Liquid Limit (%)	<35.0%			32.8	31.8	28.3	38.5	45.8	31.5	32.6	29.4	28.9	29.5	28.3	31.1	30.4	30.2	29.4	31.8	33.7	31.4	34.6	32.3	31	26.2	22.6
Linear Shrinkage (%)	<3.0%			0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LA Abrasion	<40%				37.8				49.7				41				40.7					42.1				
Max Comp Strength	>1.7Mpa		0.840	0.800					0.610				0.76				0.62					0.75				0.55
CBR	>100%		90	90	80				220				140				100					130				90
Unconf. Comp. Strength	0.6 - 1.0 MPa																									
SMDD t/m³		1.904	1.842	1.848	1.85	1.884	1.934	1.884	1.932	1.868	1.88	1.852	1.892	1.884	1.872	1.866	1.864	1.872	1.852	1.824	1.876	1.89	1.88	1.844	1.854	1.964
OMC %	95% - 110%	84.3%	88.3%	65.0%	75.6%	112.3%	72.8%	88.8%	81.0%	47.4%	53.7%	72.3%	78.5%	56.4%	49.7%	71.1%	72.3%	66.0%	73.7%	59.7%	61.0%	61.4%	73.6%	73.4%	64.1%	64.2%
Foreign Material High Density	<5%																									
Foreign Material Low Density	<2%																									
Foreign Material - Wood	<0.5%																									
Foreign Material - Asbestos	0%																									

Moisture content	10.79%	11.74%	9.16%	11.49%	17.30%	9.25%	12.08%	10.86%	6.82%	7.78%	10.12%	9.42%	7.79%	6.61%	9.32%	9.55%	9.18%	11.20%	10.26%	7.87%	7.67%	10.75%	9.54%	9.10%	7.90%
Optimum Moisture content	12.80%	13.30%	14.10%	15.20%	15.40%	12.70%	13.60%	13.40%	14.40%	14.50%	14.00%	12.00%	13.80%	13.30%	13.10%	13.20%	13.90%	15.20%	17.20%	12.90%	12.50%	14.60%	13.00%	14.20%	12.30%