Transport Research Laboratory

Recycled Aggregates for Minor Schemes

Logistics Study

by M Lamb, S Reeves, B Cordell

RPN1569

FINAL PROJECT REPORT

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by M Lamb, S Reeves, B Cordell (TRL)

Prepared for: Project Record: **Recycled Aggregates for Minor Schemes**

Client: **Constructing Excellence in Wales (Paul Jennings)**

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Contents

List of Figures

List of Tables

Executive summary

Constructing Excellence in Wales commissioned TRL to undertake a logistics study to build on the previous work carried out by TRL and Tarmac on Recycled Aggregates for Minor Schemes (RAMS) in 2009. High quality aggregate is often used in minor schemes, where lower grade material could be utilised. The lack of a suitable specification and detailed information on the properties of lower quality material has resulted in significant quantities of lower quality material being sent to landfill. Significant quantities of lower grade recycled aggregates are produced in Wales, mostly by small producers, who do not always work to national standards or follow the WRAP Quality Protocol. These recycled aggregates are not suitable for use in high grade applications such as those covered by the Specification for Highway Works, but may be suitable for use in low risk applications. The RAMS project is looking at how this material could be used more effectively. The test results so far indicate that lower grade material could be suitable for some minor works schemes.

In order to fulfil this potential increase in use, the material needs to be readily available, cost-effective and, ideally, have lower carbon emissions than primary aggregates. This related project focused on these issues. It involved an assessment of the availability of recycled aggregates in Wales, looking at the location of producers and the area they served. The project also looked at the economic costs and carbon emissions associated with using lower grade recycled aggregates where suitable applications arise, comparing it to virgin aggregates and Type 1 recycled aggregate. Information for the study was gathered from telephone interviews and questionnaires with recycled aggregate producers in Wales and a site visit to a producer near Cardiff.

Aggregates are a low value, high volume product which makes transport costs a high proportion of their price. In order for their use to be cost-effective, aggregates cannot be transported by road over large distances; the source needs to be close to the point of use, especially for low value applications such as those being investigated in the RAMS project. The study found that the average distance of recycled aggregate customers from the producer was 14 miles. The majority of construction activity is carried out in urban areas and this is also where recycled aggregate producers are normally situated; close to sources of feedstock and customers. The locations of recycled aggregate producers in Wales were obtained and plotted on a map with a radius of 30 minutes travel time marked out. This showed that there is a good coverage, with sufficient producers to serve all the major urban areas where the majority of construction work occurs.

The study also found that where lower grade recycled aggregate can be used (i.e. it meets the performance requirements of an application) it generally was cost-effective to do so. The price of recycled aggregates varied widely, but is normally cheaper than virgin aggregates; the lower grade recycled aggregate was on average £3 per tonne cheaper than Type 1 recycled aggregate. In addition recycled aggregate tends to be less dense than virgin aggregate, so a greater volume is obtained for the same weight. Similarly, the lower grade recycled aggregate was found to be less dense than Type 1 recycled aggregate. In addition to the difference in material cost, recycled aggregate sources are more likely to be close to urban areas where much of construction work takes place, whereas quarries for virgin aggregates tend to be in more rural areas. The average transport distance by road for virgin aggregates is 29 miles (UK average in 2006)[1] compared to the average of 14 miles that lower grade recycled aggregate travels. In Wales, the large number of quarries is such that the average distance to be travelled is shorter. However, in many cases the transport distances for lower grade recycled aggregates will still be less than for virgin aggregate,

[1] Aggregate Levy Sustainability Fund, Reducing the environmental effect of transporting aggregate

hence reducing transport costs. This also reduces transport emissions feeding into the Life Cycle Assessment (LCA) carried out as part of the study.

The Life Cycle Analysis has shown that there is a significant carbon saving in the production of lower grade recycled aggregates compared to that of virgin aggregate. The results indicate, that the use of lower grade materials would emit less carbon even if transported up to nine miles further than virgin aggregate.

The project has thus shown that, where it is suitable for the proposed application, lower grade recycled aggregates are likely to be readily available and cost effective compared to virgin and higher quality recycled aggregates and will yield benefits in reduced carbon emission compared to these alternatives.

The applications for which the lower grade recycled aggregate are suitable are considered in the main RAMS project, which is reported separately from this study.

1 Introduction

The Constructing Excellence in Wales (CEW) Waste Programme is undertaking a number of projects to improve the management of construction waste in Wales, and to increase the use of recycled aggregates. One of these projects is the Recycled Aggregates for Minor Schemes (RAMS) project. High quality primary and recycled aggregate is often used in minor schemes, such as cycle paths, car parks and minor estate roads, where lower grade material could be used. At the same time, significant quantities of lower quality material are being sent to landfill. The RAMS project is looking at how this material could be used more effectively. The project aims to produce a Technical Specification for adoption in Wales to:

- Maximise the use of lower utility recycled aggregates in low grade engineering pavements e.g. footpaths and car parks,
- Reduce engineers risk through the production of a nationally recognised specification for inclusion of such aggregates in low grade, low risk schemes,
- Make recycled aggregate the aggregate of choice,
- Reduce landfill by 500,000 tonnes per year in Wales

The first phase of the project was carried out by Tarmac, Birmingham University and TRL in 2009. It involved testing lower grade recycled aggregates produced by a selected group of producers against various standards. The material was then trialled under loading at a testing pit in Birmingham University. During the trials, assessments were made on the strength and durability of the material. A further phase of testing from producers around Wales has been instigated, and the results from the Phase 1 testing undertaken by Tarmac, and testing under the TRAMS project, indicate that there is significant potential for the material to be used for the minor schemes envisaged.

The market for recycled material in Wales suffers due to the presence of significant number of virgin quarries producing crushed rock at a competitive price. The cost differential between virgin and recycled aggregate is minimal and therefore transport cost becomes a major factor. For a lower grade recycled aggregate, the situation is more acute.

In order to overcome this challenge, it is necessary firstly to prove fitness for purpose. The lower grade recycled aggregate is not intended to be used in major schemes, due to the potential risk, and in any case, the quantities available would be insufficient. The balance of evidence suggests that this material could be better used in low risk applications in minor road schemes. It was therefore considered important to improve understanding of the locations where the material is produced in Wales, and to suggest measures for improving the infrastructure if necessary. This study aims to help identify:

- the locations of producers of lower grade recycled aggregate in Wales;
- the price compared to virgin and higher quality (Type 1) recycled aggregate;
- transport costs compared to virgin and higher quality (Type 1) recycled aggregate; and
- environmental implications of the use of lower grade recycled aggregates.

The report describes the results of this study.

2 Methodology for data collection

In order to carry out the study, information was required on the number and location of recycled aggregate producers in Wales, the typical distance products are transported, product and transport costs and the types of plant used in processing. This information was gathered using three methods:

- A short questionnaire (given in Appendix A) was developed. The names and address of recycled aggregate producers were extracted from the Environment Agency, Wales Environment Trust and WRAP websites and the questionnaire was sent to the approximately 100 recycled aggregate producers throughout Wales.
- In-depth telephone interviews were carried out with the producers involved in the first phase of the project.
- One of the project team visited a recycled aggregate production site to gather more detailed data on plant fuel consumption for the embodied carbon calculation.

Twelve questionnaires were returned to the product team, and out of the 12 producers involved in the initial project, seven were available for interview during the project time frame.

3 Data collection findings

A summary of the information collected from the returned questionnaires and interviews is provided in this section; further details are given in the appendices. This section provides general background information on recycled aggregate producers in Wales as well as specific information for the cost and carbon analysis.

3.1 Organisations

The types of organisations that produce recycled aggregates are:

- Specialist recycled aggregate producers.
- Skip hire companies that also process and sell the material they collect;
- Mobile operators which take the crusher to the construction site, where the majority of the material is processed and reused on site. Any excess is sold;
- Waste transfer stations which accept a variety of types of waste, process it and sell on the products;
- Quarries which produce recycled aggregate in addition to virgin material;
- Demolition companies that process and sell the demolition waste they produce;
- Plant hire and haulage companies.

Of these, only the quarries and specialist producers are likely to produce high quality recycled aggregate in accordance with national standards and the WRAP Quality Protocol. Many of the other categories of producer are likely to produce lower grade recycled aggregates, which are the focus of the RAMS project.

3.2 Products produced

Most organisations produce two or three types of aggregate. The most commonly produced materials are given as Type 1 (unbound sub base), 6F2 (or 6F5, coarse grained capping) and non-standard aggregates (e.g. hardcore, general fill, crushed concrete). A minority of larger producers sell a greater range of higher value aggregates such as pipe bedding and singe size clean material. The lower grade recycled aggregate is sold as hardcore, general fill, landfill, crusher run, crush, infill and general gravel fill. Many producers also sell topsoil or other recycled materials such as wood chippings.

The amount of recycled aggregate produced at each site ranges from less than 5,000 tonnes per annum to one organisation who produced over 200,000 tonnes per annum. The majority of producers (68% of respondents) produce less than 10,000 tonnes per annum. Selling recycled aggregates is often combined with another business (e.g. skip hire) rather than being the sole source of income.

3.3 Feedstock for recycled aggregates

Sources of feedstock for recycled aggregates include:

- skips from demolition and construction projects;,
- utility arisings;
- local builders;
- local authority highway departments;
- soils that contain a large amount of stones; and
- waste transfer stations.

Reports on the reliability of the source varied. Some people stated that the source was reliable and steady throughout the year, while others reported a drop in the volume available during the winter and autumn or variability depending on the number of construction projects being carried out locally. One interviewee reported that wet weather impeded production of the aggregates and they kept a stockpile for the winter months. Others said they had been hit by the recession and the decrease in construction work being carried out.

3.4 Processing and testing

Most organisations carried out crushing, screening and grading on the feedstock before selling it. The majority of the plant used is basic jaw crushers and screeners. One manufacturer listed higher quality plant including a finger screen, but this was probably as he also hired out equipment as part of his business. Some organisations hire in the plant, so the plant manufacturer can vary. Table 4 in Appendix D provides a list of the types of plant used in processing recycled aggregate.

The producers were not always explicit about testing regimes. A few replied they carried out testing as per the WRAP Quality Protocol, that Constructing Excellence is carrying out testing or that testing was provided by an independent laboratory. Those that did give more detailed indicated that basic tests such as grading, particle shape and density and material composition were carried out. Tests such as Los Angeles, $MgSO_4$ durability and frost heave that are normally carried out for Type 1 were not mentioned. This confirms that the majority of producers are probably not working to national standards and the WRAP Quality Protocol. Thus some products that are sold as Type 1 or 6F2/6F5 may not comply with all the requirements for these applications in the Specification for Highway Works.

3.5 Market for recycled aggregates

The customers for recycled aggregates include local builders, local authority highway departments, utility companies, farmers, local outlet sales and occasionally private individuals. The types of applications the products are used for are mostly low level such as landfill cover, access roads and general fill in building works. However some higher level applications such as sub base, pipe bedding and under floor slabs were also mentioned.

3.6 Transporting aggregates

Aggregates are expensive to transport due to their volume and weight, therefore the feedstock source and the purchasers of the product tend to be local to the recycling site. Feedstock comes on average from within a 12 miles radius of the site, travelling a maximum of around 25 miles. The feedstock is normally transported in eight-wheel tipper trucks or skips with a capacity of up to 20 tonnes.

The recycled aggregate products are sold to clients within a similar range of the production site. The product may be collected by the client or delivered by the producer. The average distance the product travels is around 14 miles and the maximum 23 miles. The vehicles used for collection/delivery are usually similar to those used for the feedstock.

3.7 Aggregate costs

Recycled aggregate ranges in price from £2 to £12 per tonne depending on the product and supplier. Lower grade recycled aggregate is sold for around £5 per tonne, whereas Type 1 or other higher quality products are normally sold for around £8 per tonne. If clients are unable to collect the aggregate, transport is provided by the producer at extra cost. The cost is usually based on distance and tonnage using a zone system. In some cases transport is charged per hour travelled, or by load. The average transport cost was found to be around £3.10 per tonne within a radius of 15 miles equivalent to £0.21 per mile per tonne.

3.8 General comments on the recycled aggregate market in Wales

Several people commented on the reluctance of local authorities to use recycled aggregates. One person felt that this was not due to price or quality, but a reflection of the preconceptions and reluctance to change found within organisations. Conversely another interviewee felt things were becoming more positive and clients were more aware of recycled aggregates. He felt that blue chip companies were more open to using them than they had been in the past and tenders often included the option for both virgin and recycled aggregate with a decision made on price.

Several people commented on the impact of the recession on the construction industry and therefore the amount of recycled aggregates produced and sold.

4 Analysis and discussion

While there are widely acknowledged environmental and economic benefits from using recycled aggregates in place of virgin material, provided they are suitable for the proposed application, it is important when promoting their use to first examine the aggregate market specific to an area. In order to achieve the benefits of using recycled aggregates they need to be:

- Readily available – with reliable sources close to the point of use.
- Cost-effective – cost the same or less than the alternatives.
- Sustainable – produce less carbon emissions than the alternatives.

This section analyses the data collected in order to address these three points and discusses the implications for the use of lower grade recycled aggregates in Wales.

4.1 Availability

Figure 1 shows the identified locations of C&D processing facilities in Wales (in blue) and transfer facilities (in red).

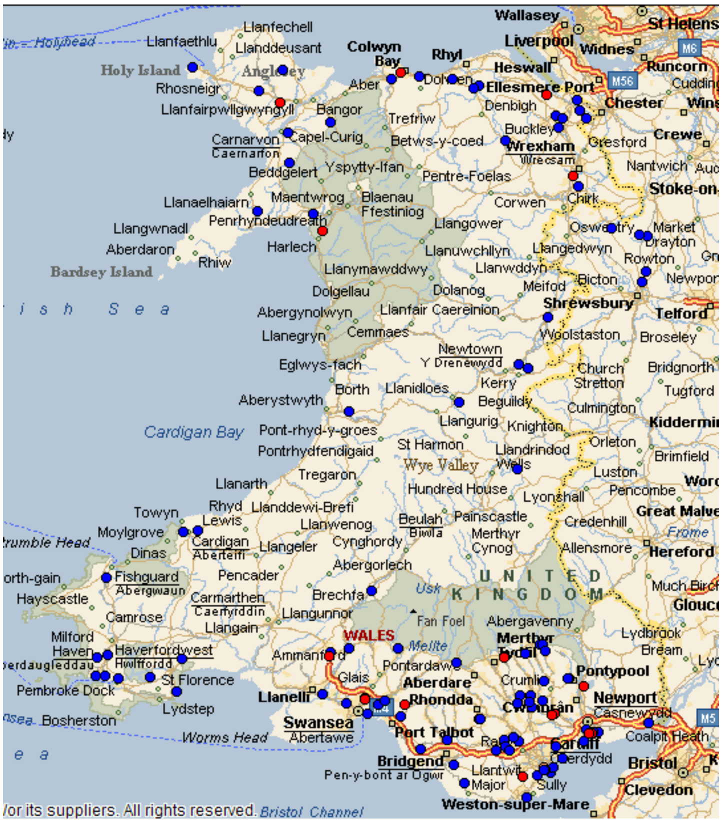

Figure 1 Locations of identified waste processing facilities and transfer facilities in Wales

TRL considered that the likely transport distances for recycled aggregates to be in the order of 15 miles or around 30 minutes, and this is backed up by the average of 14 miles found in the responses to the questionnaire and interviews (Section 3.6). This average distance needs to be considered in the context of population, geography and transport links. Aggregates might travel further in more rural areas where there are fewer sources of supply. The transport links running east-west in both the north and south, along the A55 and M4 corridors respectively are very good, whilst some of the north-south links do not meet the same standards. Conversely, the narrow South Wales valleys run more or less north-south, and transport links to neighbouring valleys are sometimes limited, despite the short distances as the crow flies.

Maps were prepared showing both 15 mile radii and 30 minute travel time from the C&D processing facilities shown on Figure 1 (see Appendix B for details). Neither option is perfect, but travel time maps (Figure 2) offer a better indication, as they take account of both where the roads are, and set average speeds for certain types of road. Taken together, the distance and travel time maps give a good indication of the overall infrastructure in Wales.

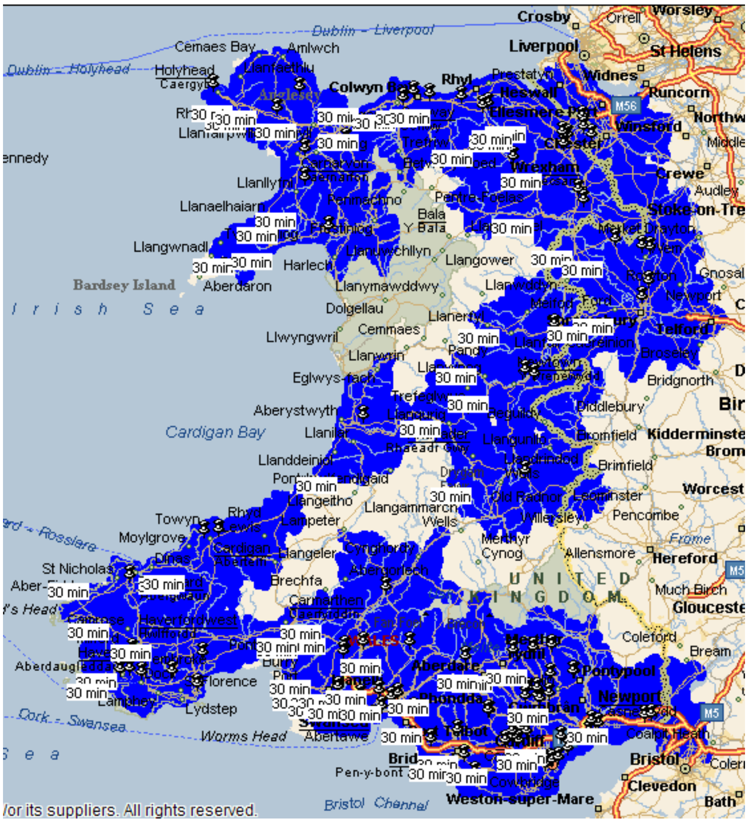

Figure 2 Approximate 30 minute drive times around facilities

The travel time plot shows that the majority of locations in Wales are within 30 minutes of at least one recycled aggregate producer. There are a few gaps in North West Wales and above the South Wales coalfield area shown in green on the map (Figure 2). However two of the major gaps represent the Snowdonia and Brecon Beacons National Parks. Whilst there are housing and businesses within the parks, the scale and control of developments is limited, i.e. there is likely to be very limited generation of, and requirement for recycled aggregates in the first place, and even if there were, the likelihood of gaining planning consent for a recycling facility or transfer site would be slim.

There are gaps in southern Ceredigion and on the Pembrokeshire / Carmarthenshire border. The potential for the development of a storage or bulking site could be explored, although it should be recognised that Ceredigion (42 people per square kilometre) has the second lowest population density in Wales, and Pembrokeshire (71 people per square kilometre) and Carmarthenshire (73 people per square kilometre) the fourth and fifth lowest respectively, compared to a Wales average of 140 people per square kilometre and typically a range of 300 – 700 in the South Wales Valleys and around 2,200 in Cardiff, based on 2001 figures from the office for National Statistics[2]. Hence, demand for aggregates is likely to be much lower in these areas, so the gaps are not significant in terms of the overall supply and demand picture for Wales.

When considering areas with higher population centres, the coverage of facilities is far denser, as presented in Figure 6 and Figure 7 in Appendix B.1, which show the identified facilities in North and South Wales respectively, with a 5 mile radius. Clearly, not all facilities are equal in terms of the volume, source or quality of materials; there are some large facilities specifically set up to deal with C&D waste, with very sophisticated

[2] http://www.statistics.gov.uk/statbase/Product.asp?vlnk=9550&More=Y

crushing, screening and in one case washing plant, whilst others may operate on a very limited scale, as part of a wider business.

Nonetheless, there is clearly an opportunity to establish a network of facilities, which would serve the majority of the population centres in Wales, with recycled aggregates, including lower grade recycled aggregate material. It is suggested that this could be combined with the ongoing roll-out of Green Compass accredited facilities, and also with a design guide and/or specification produced as a result of the RAMS project testing and possible future site trial.

The potential for a network of Green Compass sites could be explored, and presented on a map. TRL understands that an accreditation scheme is underway following the initial pathfinder scheme.

The study has thus shown that the lower grade recycled aggregates meet the first criterion, namely that they are readily available, with reliable sources close to the point of use.

As a means of comparison, the Mineral Products Associate (MPA) website[3] states that its members have fifty four quarries in Wales, although contact details are not provided, which is assumed to comprise the bulk of the major quarries. TRL undertook a search of the five main quarry companies (Tarmac, Cemex, Lafarge, Aggregate Industries and Hanson) and found forty two locations where crushed rock was produced from four companies (Aggregate Industries website indicated no such facilities in Wales).

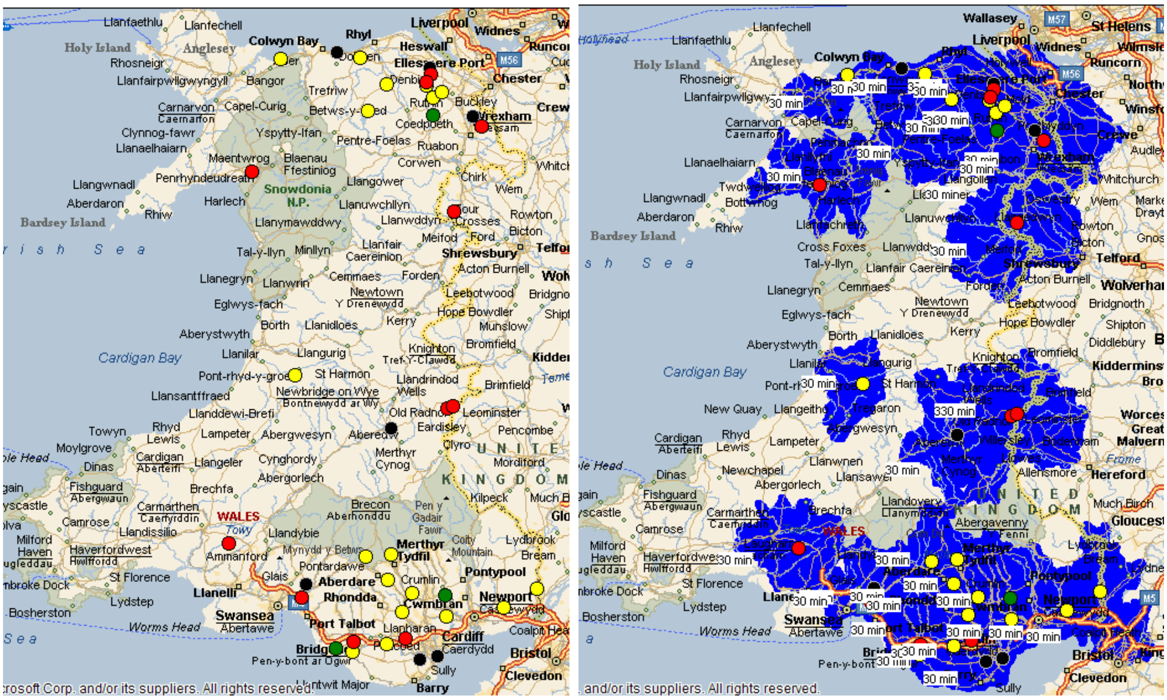

Figure 3 Virgin Quarry Location and 30 minute drive time

The figures above, suggest that the quarry network has more gaps than the recycled aggregate network, although it still covers the main population centres. It should also be recognised that there may be other quarries that were not identified that would extend the network, and that unlike some producers of recycled aggregate such as skip hire companies, all of the quarries have the production of aggregate as their sole business.

What the maps show overall however, is that there is a supply of virgin and recycled aggregate in the main population centres of Wales, and that there should be opportunities for the producers of lower grade materials to supply minor schemes,

[3] http://www.mineralproducts.org/qua_yourarea02.htm

whereas the major producers would be more likely to supply major schemes where the standards and quantities required are significantly higher.

4.2 Cost-effectiveness

The costs involved in purchasing aggregates are a combination of the cost of the material and the cost of transportation. The large weight and bulk of aggregates means that transportation costs are high, whereas production costs are relatively low making transport a major part of the cost associated with aggregates.

4.2.1 Material costs

The material cost of aggregates is normally given by tonne, but may be quoted by load. The cost will depend on the quality of the material required, with products with tighter grading and performance specifications being sold at a higher price due to the additional processing and testing required. There may be a minimum amount that can be purchased, e.g. 10 tonnes. The material cost also varies according to the producer, reflecting the local market. In this project we found significant variations in aggregate prices for apparently similar products.

From the questionnaire and interviews carried out, the cost of recycled aggregate was found to range from £2 to £12 per tonne, with an average of £5 for lower grade recycled aggregates and £8 for Type 1. Information obtained from quarries suggests that the cost of virgin Type 1 is around £1.50 per tonne greater than recycled Type 1. In part the difference in price between virgin and recycled aggregate is due to the Aggregates Levy[4], which currently adds £2 per tonne to the cost of virgin aggregate (it will increase to £2.10 per tonne on 1 April 2011).

A further factor to consider is that although aggregates are normally purchased by weight (tonne), in practice it is usually the compacted volume (m^3) of aggregates that is the important aspect during construction; aggregates are specified by volume in Bills of Quantities. Virgin aggregate such as the sandstone and limestone that is found in Wales has a particle density[5] of around 2.7 Mg/m^3. High quality recycled aggregate tends to be less dense, typically around 2.3 Mg/m^3, due to the inclusion of lighter materials such as brick and mortar. This means recycled aggregate can have around 15% more volume than the same weight of virgin aggregate. Consequently, less tonnage of recycled aggregate would be required for the same application. Lower grade recycled aggregate tends to be lighter than higher grade recycled aggregate increasing this difference in price. For example, in Phase I of this project the tests gave a compacted bulk density at optimum moisture content of around 1.95Mg/m^3 for lower grade recycled aggregate compared to a typical value for limestone Type 1 of 2.45Mg/m^3.[6] On projects where large volumes of aggregates are required, this could make a significant difference to the overall cost.

4.2.2 Transport costs

Transport cost does not depend on the product type, but tonnage and distance. Transport is a large component of aggregate costs. The responses from the questionnaires and interviews suggest that 30 - 45% of aggregate cost is for transportation, consequently the distance from the source of materials an important influence on cost. Realistically, road transport of aggregates is not competitive beyond 30 miles from the aggregate source and recycled aggregates are unlikely to be

[4] http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageImport_ShowContent&propertyType=document&columns=1&id=HMCE_CL_001169
[5] Particle density is defined as the ratio of dry mass and volume.
[6] ALT-MAT Deliverable D4 European Project under the 4th Framework Programme, 1999.

transported more than half this distance. There are certain exceptions such as the transport of high friction Pennant sandstone, from South Wales, that has specific qualities required for road surfacing, which will allow it to be transported further.

Transport may be provided by the producer or purchaser, but regardless the cost is borne by the purchaser making sources of aggregate closer to the construction site more cost effective. Transport costs are usually charged at cost per tonne within a radius of the site, e.g. 10 or 15 miles. From the questionnaire and interviews, transport costs were found to be around £3.10 per tonne within a radius of 15 miles equivalent to £0.21 per mile per tonne.

Typical vehicles for virgin aggregate transport are 32 tonne, rigid chassis tippers. Recycled aggregates are normally transported by smaller vehicles such as 20 tonne tippers. The transport price charged appears to be similar for both types of vehicle.

As discussed in Section 4.1, recycled aggregate producers tend to be located close to urban centres near the source of the feedstock meaning that these materials are generally available near the point of use. The locations of the virgin quarries may be marginally further away from the centres of population, than recycled producers, but nonetheless, there is a plentiful supply of virgin aggregates within a close distance of the majority of the population centres in Wales.

4.2.3 Cost comparison

Using these average material and transport costs, and assuming that the lower grade recycled aggregate is suitable for the application, the following comparisons can be made. If sources of virgin, recycled type 1 and lower grade recycled aggregate are all within 15 miles of the construction site, around £45 (36%) could be saved on purchasing 10 tonnes of aggregate by using lower grade recycled aggregate instead of virgin and £30 (27%) instead of Recycled Type 1 (see Table 1).

Table 1 Comparison of the costs for purchasing 10 tonnes of aggregate

	Virgin aggregate	Recycled aggregate Type 1	Lower grade recycled aggregate
Product price per 10 tonnes (£)	£95	£80	£50
Transport cost for 15 miles (£)	£31	£31	£31
Total cost (£)	£126	£111	£81

The costs fluctuate significantly between producers, so that the range of prices for recycled aggregates overlaps with the range for virgin material. Consequently, in some cases recycled aggregates may be closer in price to virgin aggregates. However, this does not take into account the likely locations and travel distances. Construction sites are usually situated within urban areas where the population density is highest. Recycled aggregate producers also tend to be located in urban areas close to the sources of feedstock. However quarries are more likely to be in rural locations. Even if the prices of lower grade recycled aggregate and virgin aggregate were identical, if the source of virgin aggregate was located only slightly further away it is likely to be sufficient enough to make it more cost effective to purchase lower grade recycled aggregate. There is also the difference in density to take into account. If $10m^3$ of aggregates were specified, this would equate to 24 tonnes of virgin aggregate and 20 tonnes of lower grade recycled aggregate – requiring an extra four tonnes of material to be purchased.

The lower grade recycled aggregates thus satisfy the second criterion for use, namely that they are cost-effective, i.e. they cost the same or less than the alternatives.

4.3 Life Cycle Assessment

A life cycle assessment was undertaken, which focused on measuring the contribution to climate change of low quality recycled aggregate and comparative virgin aggregate scenarios: the "carbon footprint". Life cycle assessment (LCA) is a method by which environmental impacts associated with a product or service can be calculated. A carbon footprint uses LCA methodology and is limited to only investigating the carbon dioxide (CO_2) emissions. With increasing pressure on all areas of UK industry to improve energy efficiency and reduce CO_2 emissions through their activities and supply chain, a measurement of the carbon footprint of their product is an essential starting point for emissions reduction strategies.

A site visit was conducted to allow familiarisation with the processes involved and to initiate data collection on resource use and energy consumption. Despite the site visit, very limited primary data on fuel consumption was forthcoming to form the basis of the assessment. Instead, various data and estimations were used to make a preliminary assessment. Since the data is not firsthand nor specific, the assessment should be regarded as indicative rather than an accurate portrayal of the situation at any particular quarry or recycling centre. Figure 4 shows the lifecycle considered for the production of a lower quality recycled aggregate. There is a large variety of processes and equipment available which can be used to recycle construction and demolition waste into a useful construction material; the simple setup investigated is only one possibility of many.

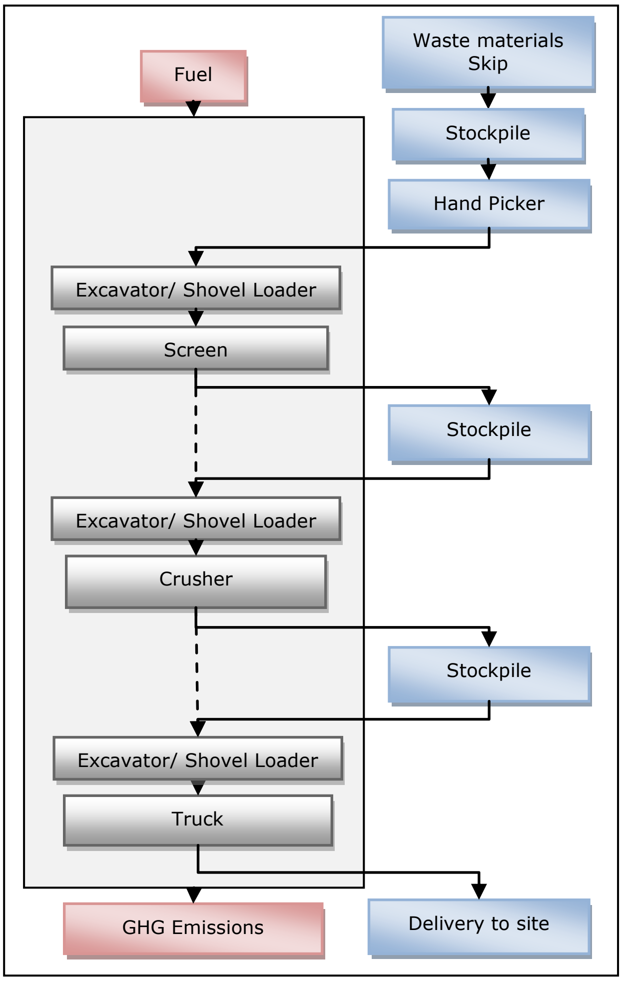

Figure 4 Modelled system for production of recycled aggregate

The selected virgin aggregate carbon footprint figure for production used is 4.32 $kgCO_2$/tonne, as taken from the Mineral Product Association's (MPA) 2009 Sustainability Report[7].

The approach used to calculate the recycled aggregate carbon footprint figure was to consider the list of commonly used machinery in the production of recycled aggregates, presented in Table 4, in the configuration shown in Figure 4. Average fuel consumption for this equipment was calculated using the method devised by the United Nations for engine work rates[8], see Equation 1 displayed below. Litres of fuel used per machine hour (LMPH) is calculated by multiplying together the mass of fuel needed to create 1 brake horsepower (K), the gross horsepower (GHP) of the engine being used and the load factor (LF) on the engine. This is then divided by the mass per litre of the fuel. Table 2 gives the standard data designated for use with Equation 1.

Equation 1 United Nations equation for estimate of fuel consumption

$$\boxed{LMPH = \frac{K \times GHP \times LF}{KPL}}$$

Table 2 Standard data for use with Equation 1

Engine	Weight (KPL) kg/litre	Fuel Consumption (K) kg/brake hp-hour	Load Factor (LF)		
			Low	Med	High
Gasoline	0.72	0.21	0.38	0.54	0.70
Diesel	0.84	0.17	0.38	0.54	0.70

The 2010 Defra carbon dioxide conversion factor[9] for diesel fuel was then applied to these average figures. There are several options available regarding the "scope" of emissions represented in the emissions factor. In order to ensure direct comparability with the MPA figure, the figure which included only "direct" CO_2 emissions was used; no consideration was given to "pre-combustion" emissions associated with fuel supply, nor the other greenhouse gases that contribute to climate change.

In the model it was assumed that each piece of equipment operated with a high level of engine loading. The site visit highlighted that aggregate recycling was often done in batches, thus allowing a high level of equipment loading. The average fuel consumptions for the different pieces of equipment were calculated based on sample sizes of 2 loaders, 10 screens and 11 crushers. Data was compiled for engine output and potential material throughput. The fuel consumptions of each type of equipment were equated to CO_2 emissions and compiled into the model.

The recycled aggregate carbon footprint figure for production was calculated at 1.33$kgCO_2$/tonne. This shows that a saving of approximately 2.99$kgCO_2$/tonne is possible when considering only the production processes. The MPA CO_2 figure for the production of virgin aggregate is much greater than the recycled aggregate figure. The lifecycle for the production of virgin aggregate includes a number of operations and

[7] http://www.mineralproducts.org/documents/MPA_SD_Report_2009.pdf
[8] http://www.fao.org/docrep/t0579e/t0579e05.htm
[9] http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm (Annex 1 Table 1b)

stages which are not required when recycling aggregate. This includes overburden removal, drilling, blasting and additional crushing, transportation, washing and screening, in order to produce a higher quality aggregate. The MPA figure was generated from member companies providing energy use data and allocating it to a product. There is a variation in quality and accuracy of the data provided to the MPA so this should be considered an approximate figure. Work is continuing to produce a more accurate figure; this will be available in the first half of 2011.

Emissions due to transport were calculated from the 2010 Defra GHG conversion factors[10] for freight vehicles. The 'Rigid >17t' vehicle value was used on a tonne kilometre basis, for the distances for each material transport was the same as used for the cost comparison, namely 15 miles. Utilisation of the vehicle was based on the UK average for a vehicle of that size, which is 53%. Due to the potential CO_2 saving associated with using the recycled aggregates obtained from the system considered, extra transport could be undertaken up to the breakeven point and some benefit would still be realised. Extrapolating the results allows the added distance that recycled aggregate could be transported to be calculated. This was calculated to be 9 miles, thus there is a potential environmental argument for transporting recycled aggregate up to 24 miles from the site where it is produced in the scenario considered.

Table 3 Potential kgCO_2/tonne saving and transport distance increase

Material	Production (kgCO_2/t)	Transport (kgCO_2/t)	Total (kgCO_2/t)	Potential saving (kgCO_2/t)	Potential transport increase (miles)
Virgin Aggregate	4.32	4.83	9.15	-	-
RAMS	1.33	4.83	6.16	2.99	9

It should be considered therefore that the carbon footprint conducted shows a further benefit of lower quality recycled aggregate over virgin aggregates in terms of sustainability; they are responsible for the production of less CO_2 than virgin aggregates.

5 Conclusions

Tests carried out as part of the previous work for the Constructing Excellence in Wales Recycled Aggregates in Minor Schemes project indicate that lower grade recycled aggregates could be suitable for some minor works schemes. In order for the use of this type of material to be expanded it needs not just to meet performance specifications, but also to be readily available throughout Wales, cost-effective to use and help towards meeting sustainability targets by reducing carbon emissions. This project looked at these points.

The majority of construction work takes place in urban centres, where there is the highest population, e.g. in the South Wales Valleys. Therefore the greatest demand for aggregates is within these areas, rather than for example around Snowdonia or the Brecon Beacons. In addition to generating the demand for aggregates, construction work also produces the feedstock for recycled aggregates. Consequently recycled aggregate producers tend to be located near urban areas where the feedstock sources and demand is found. This study found that there was a good coverage of recycled aggregate

[10] http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm (Annex 7 Table 7e)

producers throughout Wales and that the urban areas, where the majority of aggregates are used, are well served with a number of recycled aggregate producers. In general there are sufficient producers throughout the populated areas of Wales for a source of recycled aggregate to be less than 30 minutes drive from a construction site, which is usually closer than sources of virgin aggregates. From the information gathered it appears that although, in some cases, the amount of material available can fluctuate with season and the amount of local construction activity, these sources are generally reliable. There has been some impact on the amount of material available from the reduction of construction work due to the recession, but there is still sufficient material to meet demand.

The project also demonstrated that there are substantial cost savings to be achieved from using lower grade recycled aggregates, where suitable, instead of virgin aggregates and less but still significant savings compared to using recycled Type 1 aggregate. The price of aggregates can vary widely, but lower grade recycled aggregate can cost £4.50 per tonne less than virgin aggregate and £3 per tonne less than recycled aggregate Type 1. In addition, lower grade recycled aggregate is less dense than virgin aggregate, which means fewer tonnes need to be purchased to obtain the same volume of material. Construction sites are normally located close to urban centres, as are recycled aggregate producers, whereas quarries are usually in more rural locations. Transport costs are a large component of aggregate costs and shorter transport distances can mean that recycled aggregates are significantly cheaper than virgin material.

Shorter transport distance also reduces the carbon emissions associated with using aggregates. The Life Cycle Assessment also indicates that the production of lower grade recycled aggregates produces far less CO_2 than the production of virgin aggregates.

The study has thus shown that, where it is suitable for the proposed application, lower grade recycled aggregates are likely to be readily available, cost effective compared to virgin and higher quality recycled aggregates and will yield benefits in reduced carbon emission compared to these alternatives.

The applications for which the lower grade recycled aggregate are suitable are considered in the main RAMS project, which is reported separately from this study.

Acknowledgements

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Appendix A Recycled aggregate producers questionnaire

Company Name:	
Address of production site inc. postcode:	
Contact Name:	
Contact Tel:	
Contact Email:	

1. **What types of product do you produce?**

Natural aggregate ☐ *Recycled aggregate Type 1* ☐ *Recycled aggregate unspecified* ☐

2. **What do you sell unspecified recycled aggregate as?**

   Hardcore ☐ *General fill* ☐ *Other* _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

3. **How much unspecified recycled aggregate do you produce per annum in tonnes?**

   0 to 5,000 ☐ *5,000 to 10,000* ☐ *10,000 to 50,000* ☐ *Over 50,000* ☐

4. **Does this vary with season? How reliable would you say the source is?**

_ _

_ _

5. **What is the source of your recycled aggregate?**

   Local construction skips ☐ *Quarry waste* ☐ *Trench arisings* ☐

   Other _

6. **What processing do you carry out on the unspecified recycled aggregate?**

   None ☐ *Crushing* ☐ *Grading & Screening* ☐ *Washing* ☐

   Other _

7. **What type of plant do you use for processing?** (please list the manufacturer if possible so we can ascertain fuel consumption)

_ _

_ _

8. What tests do you carry out on the unspecified recycled aggregate?

None ☐ *Visual inspection* ☐ *Grading* ☐

Other _

9. What exemptions or waste management permits does the site have?

_ _

10. Who are your main customers and what applications do they use the material for? (e.g. landfill cover, estate roads etc.)

_ _

_ _

11. What is the price per tonne of your product? (if you sell different types of recycled aggregate please list by type, if there is a minimum amount that can be purchased please specify)

_ _

_ _

12. Does this price include transport to the client's site? If not how much is the transport cost?

_ _

13. Please fill in the transport details

	Average distance travelled	**Maximum distance travelled**	**Type of vehicle used inc. capacity**
Incoming feedstock			
Transport of product			

14. Do you have any other comments about the use of recycled aggregates?

_ _

_ _

_ _

_ _

Appendix B Mapping the coverage of recycled aggregates

The location of waste processing facilities was largely obtained from the Environment Agency, Netregs Waste Directory Site, which allows searches to be made under a number of categories and for a given location. The sub-categories of building waste searched for were clay, hardcore, inert waste, rubble, subsoil and topsoil. For each location searched, a number of companies were identified that matched certain criteria, along with their contact details. It was felt that this was the most likely to be the most up to date source of information, as the companies would be registered with the Environment Agency.

In order to set the context of the supply and demand of recycled aggregate in Wales, the existing recycling infrastructure and any gaps, it is useful to consider the population distribution, as there should be a direct correlation between centres of population and density of recycling facilities, i.e. in areas of high population density there will be more construction activity which will both generate waste, and also potentially purchase recycled material. Of the population of approximately 3 million in Wales, around 60% live in the South Wales valleys in the area of the former South Wales coalfield stretching from Swansea in the west to Newport in the east and Merthyr Tydfil in the north, with over 10% living in the Cardiff unitary authority. With the exception of Flintshire and Denbighshire in the north east corner of Wales, the north, centre and western regions of Wales are largely rural with few major centres of population, as reflected in the low population densities. Figure 1 indicates there is a very strong correlation of the location of recycled aggregate producers with population centres.

In considering the requirement for a network of recycled aggregate producers, it should be recognised that a one size fits all approach is unlikely to be suitable or feasible, and that in the more rural areas of Wales, the spacing of the infrastructure might be greater, or the potential for centres for bulking up might be considered.

TRL considered that the likely transport distances to be in the order of 15 miles or around 30 minutes. Maps have been prepared showing both distance and travel time from these locations.

B.1 Production of distance maps

Maps were produced showing 15 mile radii around the location of the recycled aggregate producers. Figure 5 demonstrates extremely good coverage, with very few gaps and only one gap of any size in the Snowdonia area.

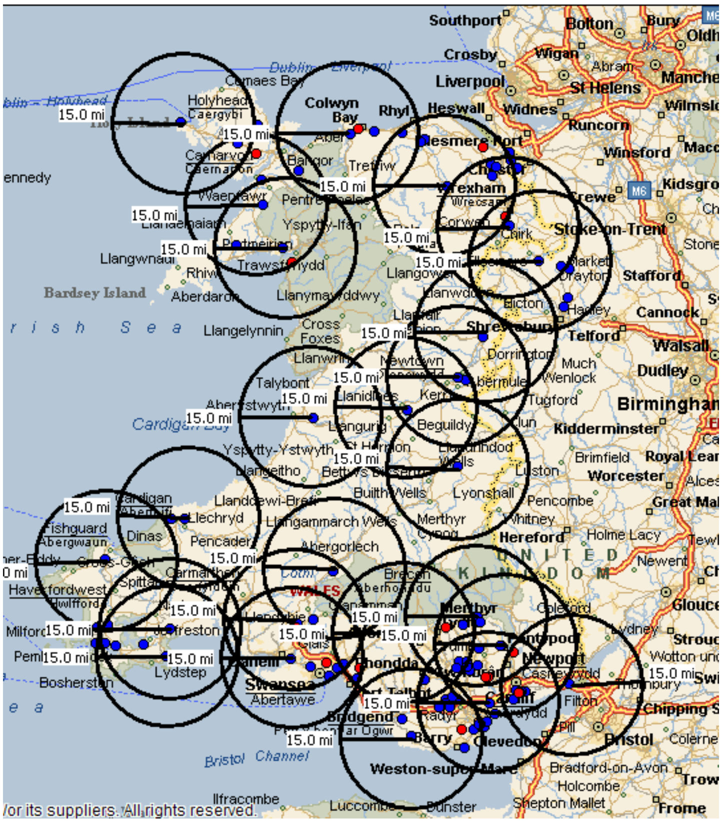

Figure 5 Map showing 15 mile radius around Wales C&D waste facilities

When considering areas with higher population centres, the coverage of facilities is far denser, as presented in Figure 6 and Figure 7, which show the identified facilities in North and South Wales respectively, with a 5 mile radius; even with such a small radius, it can be seen in both cases, and particularly in South Wales, that there is extensive coverage.

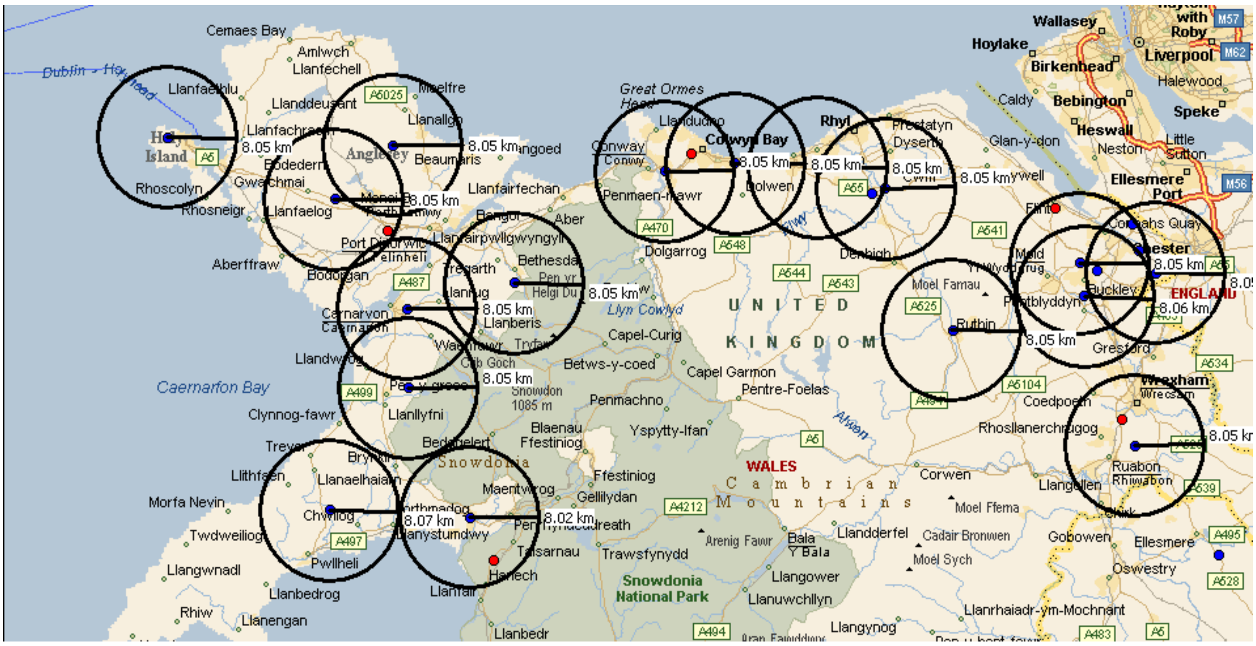

Figure 6 Recycling facilities in North Wales – 5 mile radius

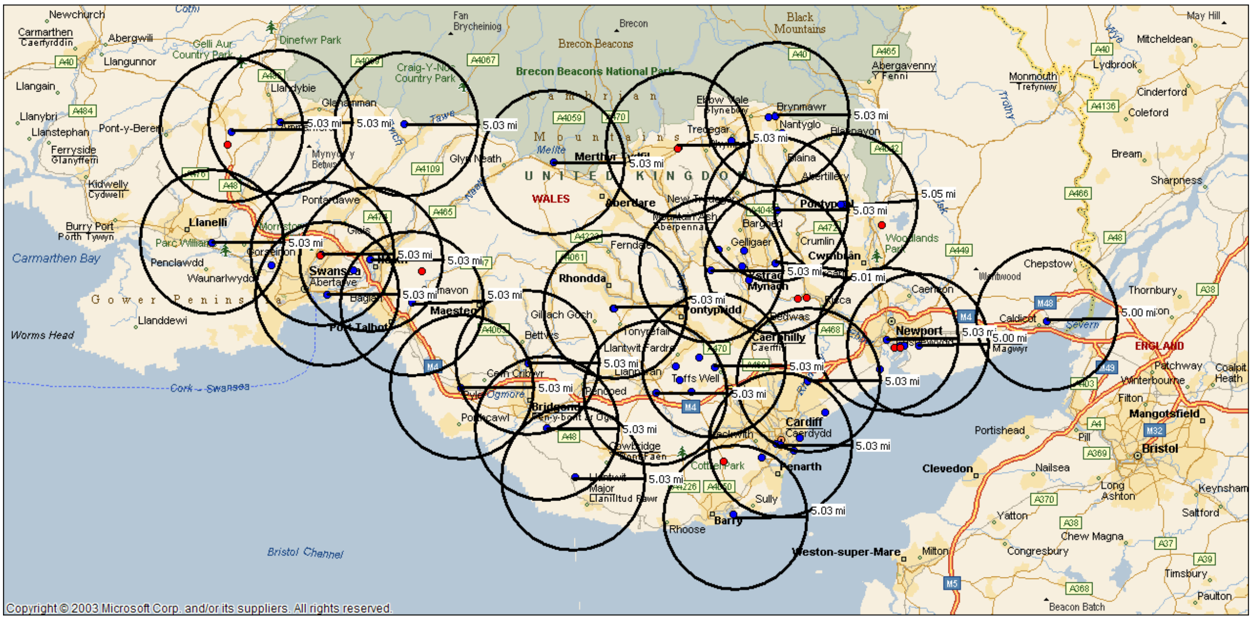

Figure 7 Recycling Facilities in South Wales – 5 mile radius

B.2 Production of travel time maps

Travel time maps might offer a better indication of coverage, as they take account of both where the roads are, and set average speeds for certain types of road. The average speeds chosen for the study are as follows:

Motorways:	50mph
Other limited access roads:	50mph
Major roads:	40 mph
Minor roads:	34 mph
Streets:	19mph

The speeds chosen were based on what would seem reasonable for a vehicle that would be limited to 56mph to achieve on motorways and limited access roads (mainly dual carriageways), and a conservative estimate for other roads. The software is set to always observe local speed limits. It should be noted that for presentation purposes, in areas where there were numerous facilities, not every facility has been shown with a radius, i.e. where radii overlapped, additional points with the radii were not considered.

It should be noted that the software is unable to distinguish between the A470 that runs as a dual carriageway from Cardiff to Merthyr Tydfil, and the A470 which is a single lane, winding road in north west Wales.

As would be expected, the map showing approximate 30 minute drive times around sites (Figure 2) shows a decrease in the coverage of facilities compared to the 15 mile radii distance maps. However, all the major urban areas are adequately covered.

Appendix C Products: results of questionnaire and interviews

The types of aggregate product produced include:

- Type 1
- 6F2
- 6F5
- 6F1
- Hardcore
- General fill
- Pipe bedding
- Planings
- Sandfills
- Single size (clean)
- Crushed concrete
- 40mm clean stone
- 125mm clean
- 4mm grit sand

Appendix D Plant details: results of questionnaire and interviews

Table 4 List of plant used in processing recycled aggregates

Crushers	Screens	Other
Rubbelmaster	Trommel Screens	Komatsu 20 ton excavator
Parker	Extec	jcb 316 loading shovel
Rubble Master- Compact Recycler	Power Grid	
Boxler Screener Crusher		
Extec C10 Jaw Crusher	Extec 53 screen	
Gippo	power screen warrior 1400 finger screen	
OM Apollo	Fintec 640	
Fintec 1107	Extec robotrack	
Extec c12	Extec E7	
Parker Crusher	Power screen Trommel 600 and picking belt with blower	
Hartl jaw crusher	Svedala Trommel screen - ALLU Screening Bucket	
Pegson 830 crusher	Finlay 883/593 screens	
Pegson XR400	Extec S3 screen	
Pegson 428	Powerscreen warrior screen	
Extec crusher	Extec 3 way screen	
Terex Pegson	Power Screen	
Extec T2 crusher	Rubbelmaster	
	Warrior 1808 screener	
	Robotrac screener	
	Chieftain 1400 screener	