Material change for
a better environment

Reference guide

August 2010

The Designing out Waste Tool for Civil Engineering Projects

Guide to Reference Data, Version 1.0

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Front cover photography: Home page of the Designing out Waste Tool for Civil Engineering

Executive summary

This report outlines the key sources of background data assembled for use in WRAP's Designing out Waste Tool for Civil Engineering projects (DoWT-CE, freely accessible at http://dowtce.wrap.org.uk). This web-based tool has been developed to help design teams forecast the amount of waste generated by their projects, identify actions to prevent waste, and calculate the combined impact of design solutions.

The DoWT-CE uses the same database as WRAP's Net Waste Tool (the Net Waste reference dataset). The Net Waste Tool was developed for use by construction teams (from the detailed design stage onwards) to provide a detailed forecast of waste arisings and identify opportunities to reduce, reuse and recover construction waste. Users are required to enter quantities data and choose components from a list of over 1000 components.

The DoWT-CE provides an **indicative** waste forecast and can be used at option preparation and design stages. The tool only requires users to enter high-level project data (e.g. approximate duration of works, basic dimensions).

The Net Waste reference dataset was developed in 2008 and updated in 2009. This report describes the data collection method used and comments upon the quality of the data gathered, in terms of availability and limitations of the data, assumptions made in applying the information gathered and results of the data validation work. This report covers only the data relevant to the DoWT-CE. A separate report covering the full Net Waste reference database can be found at http://nwtool.wrap.org.uk.

The reference dataset contains eight categories of data:

- Component Dimensions and Densities;
- Wastage Rates;
- Wastage Rates associated with Modern Methods of Construction (MMC) (where applicable);
- Mass of Packaging (where applicable);
- Recovery Rates;
- Bulking Factors;
- Embodied Carbon of Primary Materials and Carbon Savings from Reduction of Waste; and
- Cost of Waste Disposal and Take-Back Schemes.

The reference dataset has been compiled using a mix of primary and secondary sources of information. A desk-based study has been undertaken to identify pre-existing data in published sources of information, including previous WRAP research projects, articles from academic journals and online information from component manufacturers and industry associations. This proved valuable in collating information for all data categories, but particularly for wastage rates, MMC wastage rates, recovery rates and carbon emission factors. Additional primary research has also been undertaken for volume to mass factors, container costs and take-back costs due to a lack, or absence, of available secondary information. Materials recycling facility (MRF) operators and construction companies have been approached to provide information.

The datasets were assembled by Arup and Cyril Sweett (on behalf of WRAP), with input from Responsible Solutions Ltd (who provided packaging data on behalf of Envirowise). All data have been compared against pre-existing information from the Building Research Establishment (BRE) and WRAP Net Waste Trials and data gathered as part of the WRAP Net Waste Tool Consultation Group. Actual project information has also been received in response to a questionnaire sent out to various contractors and other members of the Net Waste Tool Consultation Group. TRL was commissioned by WRAP to update the data relating to civil engineering components in November 2009.

The information used in the reference dataset does contain a number of limitations and these are described according to each data category. As a result of these limitations and the varying availability of data, options for further research are suggested. These recommendations are particularly important in light of the need to refine the data as standard waste management practices improve and better data become available. Net Waste Tool users are also invited to submit relevant data from their own projects, or otherwise, that could be used to help refine the reference dataset.

The DoWT-CE and the Net Waste Tool do not aim to forecast waste with complete accuracy – rather they are designed to help design teams and project teams quickly identify their major sources of waste and the most significant opportunities to take action. For this purpose, Net Waste Tool users are able to over-write data with project-specific information such as wastage rates. The DoWT-CE provides indicative information only and does not allow users to over-write component data. The reference data aim to be representative, but will inevitably not be correct for individual projects.

Contents

1.0 Introduction

This report outlines the key sources of background data (the Net Waste reference dataset) assembled for use in the Designing out Waste Tool for Civil Engineering projects (DoWT-CE). This is a web-based tool that has been developed to help design teams (including engineers, developers and clients) measure the amount of waste generated by their projects, and identify opportunities to make cost and resource efficiency savings by preventing waste, reducing the quantity of materials specified, or reusing reclaimed materials. The DoWT-CE also helps users quantify the impact of design changes, on project costs, waste to landfill, and embodied carbon.

The DoWT-CE allows users to:

- generate an indicative project waste forecast by entering high-level project details;
- highlight potential areas for improvement to help focus attention on opportunities to design out waste; and
- record design-stage solutions for reducing waste and calculate their impact on the project.

Users	Design team – engineer
When	Option preparation and design development stages
Inputs	**For waste forecast**: ▪ basic project details (approximation duration of works, basic dimensions etc) **For impact calculation:** ▪ decisions taken to design out waste ▪ calculated impacts e.g. proposed quantity of reclaimed materials used
Outputs	▪ Material consumption and waste arisings by element ▪ The combined impact of design solutions ▪ Detailed project reports and project comparison reports
Cost	▪ 10 – 20 minutes needed for an indicative waste forecast ▪ The Tool is free to use
Benefits	▪ Identify areas of opportunity for designing out waste ▪ Calculate the combined impact of design solutions, including cost savings ▪ Produce a waste forecast for an outline Site Waste Management Plan ▪ Compare the relative waste forecasts of two or more specifications

The DoWT-CE uses the same dataset as WRAP's Net Waste Tool (the Net Waste reference dataset). The Net Waste Tool was developed for use by construction teams (from the detailed design stage onwards) to provide a detailed forecast of waste arisings and identify opportunities to reduce, reuse and recover construction waste. The Net Waste Tool requires the user to enter quantities data and choose from components from a list of over 1000 components.

The Net Waste reference dataset was developed in 2008 and updated in 2009. This report describes the data collection method used and comments upon the quality of the data gathered, in terms of availability and limitations of the data, assumptions made in applying the information gathered and results of the data validation work. This report focuses on the data relevant to the DoWT-CE. A separate report covering the full reference database can be downloaded from the Net Waste Tool: http://nwtool.wrap.org.uk.

The purpose of this report is to describe the data collection method used and to comment upon the quality of the data, in terms of availability and limitations of the data, assumptions made in applying the information gathered and results of data validation exercises.

For more information:

- The Designing out Waste Tool for Civil Engineering projects - http://dowtce.wrap.org.uk
- Quick Start Guide - http://dowtce.wrap.org.uk/Documents/DoWT-CE%20Quick%20Start%20Guide.pdf
- Full User Guide - http://dowtce.wrap.org.uk/Documents/DoWT-CE%20User%20Guide.pdf
- Designing out Waste: a design team guide for Civil Engineering Projects - http://www.wrap.org.uk/construction/tools_and_guidance/designing_out_waste/dow_civil_eng.html

2.0 The Designing out Waste Tool for Civil Engineering projects

The practical benefit of the DoWT-CE lies in its ability to make a strong business case for waste prevention through design. The Tool then provides decision-making guidance that helps designers identify design options that will have an impact on wastage. The DoWT-CE draws from the same database as the Net Waste Tool, but does not require the input of detailed quantities data to produce a waste forecast. The Tool can therefore be used at early design stages before a detailed design/masterplan is available.

The specific benefits of the DoWT-CE are that it:

- provides a quick method for generating an indicative waste forecast;
- provides outputs based on limited input data, to inform design team decisions;
- contributes useful information to the Designing out Waste process;
- provides a business case for waste prevention (value of materials saved and reduced disposal costs); and
- helps designers assess the combined impact of their design solutions on wastage

The DoWT-CE is a decision making tool, not a design tool. It can help the user identify opportunities to prevent waste through the application of design solutions, and calculate the combined impact of the chosen design solutions. The Tool does not tell the user which design solutions to pursue, or the impact individual solutions will have on wastage.

The Tool should be used in conjunction with WRAP's Designing out Waste: a design team guide for Civil Engineering Projects (available from WRAP's website:
http://www.wrap.org.uk/construction/tools_and_guidance/designing_out_waste/dow_civil_eng.html.

The Tool and the guide together provide the necessary processes and applications. Refer to the DoWT-CE User Guide for guidance on using the tool, and information on the designer's role in the waste management process.

The DoWT-CE can facilitate the workshop process and the selection of design solutions, by providing useful information including an indicative waste forecast. Once the design team has selected particular design solutions to prevent waste, these can be entered into the tool to calculate the impact on project cost, waste to landfill and embodied carbon.

Waste forecast

The DoWT-CE requires the following input to generate an indicative waste forecast:

- Approximate construction value
- Project start/end date
- Duration of the different construction elements within the project (i.e. earthworks would be defined as an 'element').
- Basic dimensional data for the sub elements selected (i.e. length/width/height/depth/etc)

The tool contains a range of civil engineering construction 'elements'; these include items such as 'earthworks' or 'foundations' (see Appendix for a complete list). Under each element is a number of 'sub elements'. Each sub element is a design option for the element in questions i.e. under the element 'earthworks' sub elements include 'embankments with precast concrete retaining walls' or 'embankments with soil nails'.

The user builds their project by selecting the sub elements present in their design. Each sub element comprises a number of components. The tool has default components for each sub element. As part of the Designing out Waste process the user can select alternative components to investigate how a change in design specification can improve Material Resource Efficiency.

The tool uses this information to calculate the following data which can be downloaded as a performance report:

- Indicative waste forecast and quantity of materials specified (by sub element)
- Potential to improve (based on the difference between standard and good practice wastage rates) including:
  - potential improvement in waste arisings, cost of waste and CO_2
  - demolition and excavation materials available for reuse
  - quantity of materials consumed (by element/sub element)

- potential reduction in waste arisings (by element/sub element)
- potential increase in recycled content (by element/sub element)
- potential reduction in CO_2 emissions from transportation

To calculate these forecasts, the tool draws on data in the Net Waste reference dataset including rates (£/unit) and wastage rates. The performance report compares elements/sub elements in order to focus the design team's attention on those that provide the greatest opportunities to prevent waste.

Design solutions and impacts

Table 1 (see over) explains the impacts calculated by the tool and the assumptions made. The Net Waste reference dataset is used in the calculation of all the savings listed.

Table 1 DoWT-CE project savings and future savings

Saving	Description	Assumptions
Project savings		
Material saving (£)	Value of material saved through reduced quantity specified, reuse of reclaimed materials and/or lower wastage allowances	■ Does not include the cost of processing materials for reuse. ■ Assumes reuse of reclaimed materials offsets the need to purchase new materials. ■ Assumes lower wastage rates will result in lower wastage allowances in bill of quantities.
Material saving (t)	Mass of material saved through reduced quantity specified, reuse of reclaimed materials and/or lower wastage allowances.	■ Assumes reuse of reclaimed materials offsets the need to purchase new materials. ■ Assumes lower wastage rates will result in lower wastage allowances in bill of quantities.
Disposal cost saving (£)	Disposal cost saving through waste reduction.	■ Assumes there is a cost for disposing of materials. ■ The number and cost of skips is calculated using the volume of waste and the cost of using 40 yrd^3 $30.6m^3$ waste containers with a disposal cost of £555 per container. ■ Assumes a reduction in wastage will result in a fewer mixed waste skips being used, at the same cost per skip. ■ Assumes there is no cost of disposal for in-situ material
Total cost saving (£)	Value of materials saved plus disposal cost saving.	
Materials avoiding landfill (t)	Reduction in waste to landfill as a result of lower wastage.	■ A standard practice recovery rate for mixed waste skips (currently 50%) is applied to the quantity of waste. Therefore, 50% of waste produced goes to landfill. ■ Assumes the recovery rate is not changed if less waste is produced, therefore less waste produced means less waste goes to landfill. ■ Assumes site won material will remain on site as far as practical
CO_2 saved through avoided extraction (t CO_2 eq)	Reduction in embodied CO_2 as a result of reduced quantity specified, reuse of reclaimed materials and/or lower wastage allowances.	
CO_2 saved through transporting less materials (t CO_2)	The total CO_2 from transportation is calculated on the basis of total mass of material multiplied by distance multiplied by an emission factor. Reducing the importation of new material to site through the reuse of site-won material cuts down on the overall mass of material transported (hence reduces the CO_2 associated with transportation)	■ Uses an emission factor of 0.0003174 tCO_2/km (see section 10 for more information) ■ This is a generic emission factor hence doesn't take into consideration factors such as speed, hot/cold start, age of vehicle ■ The calculation does not account for the distance the site won material has to be transported on site in the reuse process

3.0 The Net Waste Reference Dataset

3.1 Arrangement of data

The basis of the Net Waste reference dataset is a list of more than 1,000 building components. Components represent the most basic level of the reference dataset and include a mixture of materials and pre-assembled components.

Each component within the reference dataset is assigned a primary material type and, depending upon its composition, up to a maximum of four material types. This enables the DoWT-CE to link the 'waste' from each component to a specific waste stream. For example, a component comprised of pre-cast concrete would be classified as inert and a timber component (i.e. timber railway sleepers) as timber. Materials are allocated from a pre-defined list which is further refined into a series of headline waste streams, as illustrated by Figure 1.

The material types to which components are allocated, has recently been updated to reflect the material types used in WRAP's Site Waste Management Plan Template[1] (based on LoW codes). These types are similar to those previously in the reference dataset, but are more specific. Figure 1 shows the arrangement of data in the Net Waste dataset (the mapping of components to material types to waste streams), based on the original material types.

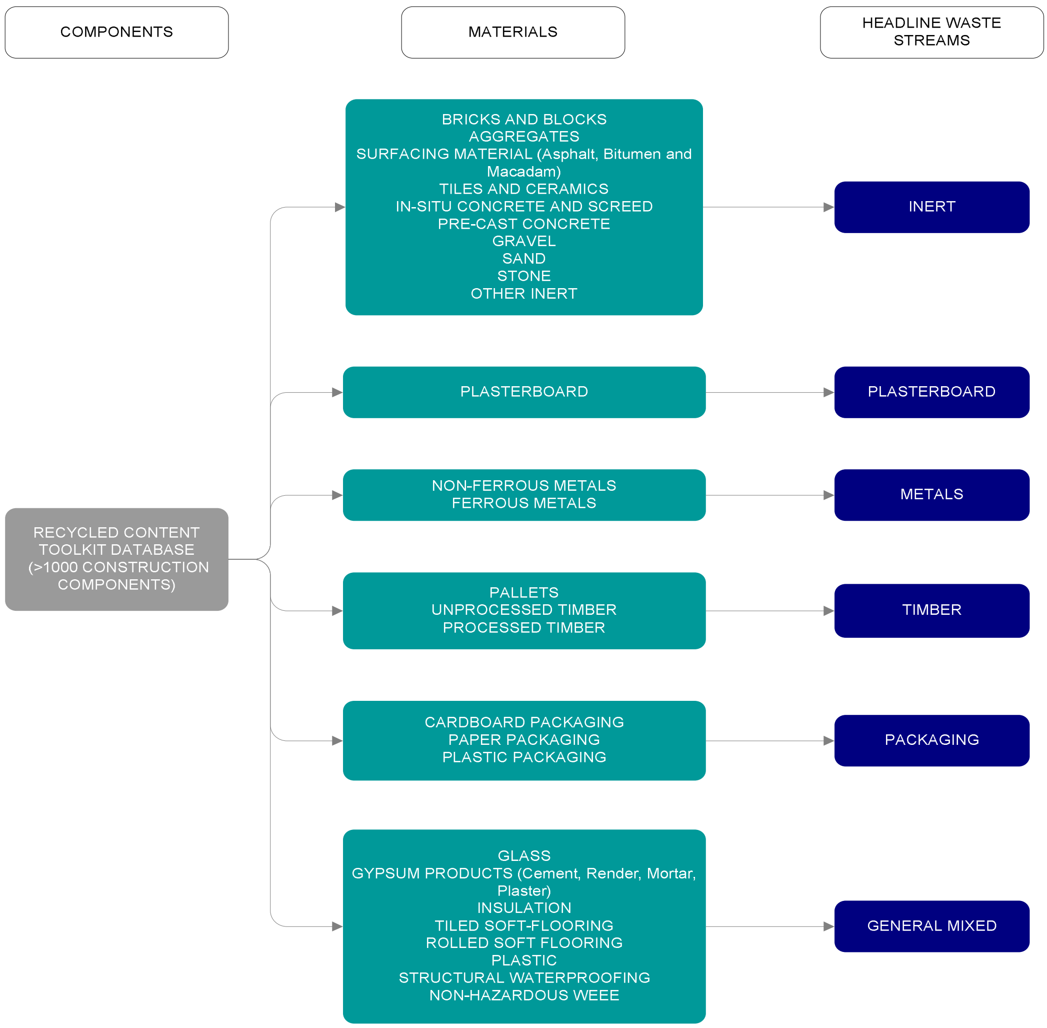

Figure 1 Arrangement of data in the Net Waste Reference dataset

[1] *Available at www.wrap.org.uk/swmp*

Materials default to the headline waste stream to which they have been assigned, unless otherwise specified. For example, waste from a composite component containing materials that can be easily separated will be assigned to several waste streams. All materials that make up composite components which cannot easily be separated are selected to default to mixed waste.

3.2 The DoWT-CE data sub-set

The DoWT-CE uses only a pre-selected number of components and building elements from the Net Waste Reference Dataset. The DoWT-CE utilises the data behind each component (e.g. rate, wastage rate, material type, density, waste stream) in much the same way as the Net Waste Tool. However, the DoWT-CE does not provide detailed results at the component level, nor does it allow users access to view or edit the data behind each component. The DoWT-CE uses component data but aggregates the results which are reported at the sub element level. Sub element level results relate to:

- The quantity and cost of material specified (quantity multiplied by rate or density)
- The quantity and value of material wasted (wastage rates applied to quantity of material specified)
- Disposal cost (assigns waste to waste streams, then calculates the number of waste containers required)

A list of the element categories that appear in the Net Waste Tool are set out in Table 2 below.

Table 2 List of Elements in the DoWT-CE data sub-set

Elements in the DoWT-CE data sub-set
Foundations
Earthworks
Drainage
Pavements
Streetworks
Track
Temporary Works
Structures
Platforms

Please see Appendix 1 for a full list of Elements and Sub elements present within the tool dataset.

4.0 Data requirements

The Net Waste reference dataset contains eight categories of data, each of which applies at either the component, material, or headline waste stream level. Both the Net Waste Tool and the DoWT-CE use the reference data to calculate wastage information for each component selected by the user. Table 3 lists the data categories and summarises whether and how these are utilised by the DoWT-CE.

Table 3 Net Waste reference dataset categories and the DoWT-CE

Component level	**DoWT-CE**
Dimensions and densities	Included
Wastage rates	Included
Wastage rates associated with Modern Methods of Construction (MMC)	Included
Mass of packaging	Included
Material level	
Recovery rates	Recovery rate for mixed waste stream (50%) only
Mass to volume conversion factors	Included
Carbon:	
■ Embodied carbon of primary materials	Included
■ Carbon savings from reduction of waste	Included
■ Carbon savings from recycling	Not included
Headline waste stream level	
Disposal costs:	
■ Cost of waste disposal	Cost of waste disposal for 40 yrd^3 30.6m^3 waste containers with a disposal cost of £555 per container.
■ Cost of take-back schemes	Not included
Other	
■ Carbon savings from transportation	Based on emission factor of 0.0003174 tCO_2/km

4.1.1 Dimensions and Densities

Dimension and density data are required for each component in order to convert dimensional metrics (item, m, m^2 or m^3) to mass (kg). Some dimensions also require conversion factors from linear or square metres to volume (m^3).

4.1.2 Wastage Rates

Wastage rates account for the proportion of a component that ends up as waste during the installation and/or construction process. Wastage rates are treated like wastage allowances, i.e. the waste allowance is added to the quantity of materials specified. Wastage rates apply to all components in the reference dataset and exist in two forms, baseline and good practice. Allowance has been made to accommodate best practice wastage rates in future versions of the Net Waste reference dataset.

Wastage rates are expressed as a percentage by volume of construction materials ordered which becomes waste and are used to calculate the likely or actual proportion of each component wasted. This is a key dataset as wastage rates inform a number of functions, including the site waste management plan screen, skip selector and waste management costs, and the final Net Waste metric calculation.[2]

Wastage rates are referred to as 'default' wastage rates when described in comparison to wastage rates associated with Modern Methods of Construction (MMC); see Section 2.2.3 for details.

[2] *WRAP (2008) The Net Waste Method: Testing a New Standard for Measuring Waste Neutrality,* *http://www.wrap.org.uk/construction/tools_and_guidance/the_net_waste.html*

4.1.3 Wastage Rates Associated with Modern Methods of Construction

The role of Modern Methods of Construction (MMC) is more applicable to buildings than civil engineering projects. As such, the MMC rates provided within the DoWT-CE tool are identical to the 'default' wastage rates. Albeit the user can set these accordingly if they feel that the values provided are not representative.

4.1.4 Packaging

The reference dataset contains information relating to the amount of packaging associated with each component. This is expressed in terms of kilograms per component and is split across four types of packaging material: wooden pallets, timber, cardboard/paper and plastic. The purpose of this is to allow the total mass of packaging associated with these components to be calculated.

Whilst a packaging waste stream has been identified, only cardboard, paper and plastic packaging default to this waste stream. Metal packaging is assigned to the metal waste stream and timber packaging and wooden pallets to the timber waste stream. This distinction applies to the Net Waste Tool, but does not affect the DoWT-CE which is not designed to provide detailed outputs on waste streams and the potential for recovery. Instead, the DoWT-CE calculates waste to landfill by assuming only mixed waste skips are used.

4.1.5 Recovery Rates

Recovery rates are applied at the material level and represent the proportion of each material within a component that is likely to be recovered through a materials recycling or processing facility. This information is required to calculate the amount of waste associated with each component that will be diverted from landfill.

There are two categories of recovery rates within the reference dataset:

- Recovery rates of materials from segregated containers; and
- Recovery rates of materials from mixed waste containers.

Both sets of data include baseline and good recovery rates; allowance has been made to accommodate best practice recovery rates in future versions of the dataset.

The DoWT-CE calculates waste to landfill by assuming a recovery rate of 50%.

4.1.6 Mass to Volume Conversion Factors

Mass to Volume conversion factors refer to the amount of void space within a waste container and are required to calculate the actual volume of space taken up by a particular material. These are described in section 9.

4.1.7 Cost of Waste Disposal and Take-Back Schemes

Cost data are used to demonstrate the cost of disposal and the savings that could be made by segregating waste and reducing waste to landfill. The reference dataset contains cost data for a variety of container sizes for each headline waste stream. Together with the value of waste, these savings provide the business case for waste minimisation and management.

The DoWT-CE calculates waste to landfill by assuming only segregated containers will be used. Users can obtain a more detailed waste forecast, including a skip segregation strategy, from the Net Waste Tool.

The reference dataset also contains information on the cost of applicable take-back schemes for certain materials, which the user is able to select where applicable. The DoWT-CE does not utilise this data.

4.1.8 Embodied Carbon Impact Factors

The reference dataset contains two sets of carbon factors which allow the user to calculate the net carbon dioxide benefits of a) diverting waste from landfill by recycling (relative to landfill) and b) saving embodied energy of construction products through further waste reduction. The resulting units are a mass (kg) of carbon dioxide saved per kilogram of material that will be recycled and per kilogram of material that is not wasted.

The DoWT-CE calculates the reduction in embodied carbon as a result of reduced quantity specified, reuse of reclaimed materials and/or waste reduction (i.e. application of lower wastage allowances). It does not calculate carbon benefit from diverting waste from landfill by recycling, however this can be done using the Net Waste Tool.

4.1.9 Carbon emissions associated with transportation

The DoWT-CE enables the user to input the distance the virgin materials used within each sub element have been transported to site. The tool takes the input distance and multiplies it by an emission factor (tCO_2/km) to quantify the total CO_2 emissions. As the user specifies the reuse of materials on-site, the overall CO_2 emissions associated with transportation will decrease.

4.2 Data Gathering

Arup collated information for all categories of data except dimensions and densities (undertaken by Cyril Sweett) and packaging, which was provided directly by Responsible Solutions, a consultant to Envirowise. This report does not currently provide any further information on these two datasets except to comment on the quality of the packaging data provided; the densities dataset is contained in Appendix 2.

The reference dataset has been compiled using a mix of primary and secondary sources of information. A desk-based study was undertaken to identify pre-existing data in published sources of information, including previous WRAP research projects, articles from academic journals and online information from component manufacturers and industry associations.

Additional primary research was undertaken for bulking factors, container costs and take-back costs due to a lack, or absence of, available secondary information. Bulking factors have since been replaced with mass to volume conversion factors to create consistency with the WRAP Reporting Portal and the Major Contractor Group's conversion factors. Materials recycling facilities (MRFs) and construction companies have been approached to provide information as well as some industry organisations, such as British Gypsum, which has provided information on the cost of plasterboard take-back schemes in particular.

Research was also undertaken to help allocate material categories to composite components. This involved consultation with Arup internal specialists and component manufacturers, including Kingspan, Bison, Kirk Natural Stone, Levolux, Alumasc Exterior Building Products, Tensys, Demountable Partitions Ltd, and Mitchellson, among others.

Information contained within the reference dataset is based on new build projects where possible. The sources of available data for each data category are described further in Section 5 of this report.

4.3 Data Benchmarking and Validation

Benchmarking and validation of the reference dataset was undertaken at various stages during January to March 2008. It has been possible to provide some degree of validation for all categories of data, which is further described in section 3 of this report. A variety of key sources were identified to undertake this exercise as follows:

- Building Research Establishment (BRE): has detailed information available on wastage rates and recovery rates of components and building materials. This is based on a range of sources and dates from 2005. This information is confidential and cannot be used specifically or described in this report, but has been used to test if research data are within a range to be expected.

- WRAP Net Waste Trial (Net Waste Trial): In 2007, the Net Waste Method was trialled on eight construction waste projects across the UK, involving the collection of wastage rate data for a variety of Net Waste reference dataset components based on the various construction contractors' experience.[3] This data was checked against the existing BRE data (as described above) and has since been provided for use as part of the data validation exercise for the Net Waste reference dataset.

[3] http://www.wrap.org.uk/wrap_corporate/news/wrap_launches_pilot.html

- Net Waste Tool Consultation Group (Net Waste Consultation Group): set up as part of Phase One of the Net Waste project to test functionality of the Net Waste Tool. This comprised members of the construction industry who were familiar with the project and who were willing to participate in the scoping phase of the Net Waste Tool. A workshop meeting was held on the 4th February 2008 and the opportunity used to present research data requiring further validation.

4.4 Data Entry and Data Update Process

The WRAP Data Controller is a software data management tool developed to facilitate the data gathering exercise and capture the information recorded. This incorporates the full reference database, against which values for wastage rates, MMC wastage rates, packaging, and component dimensions and densities can be input. It also enables materials to be allocated to components and provides the mechanism by which components can be assigned to the mixed waste category, if this is not the default waste stream.

The Data Controller will be used to update the reference dataset as future versions of the Net Waste Tool and DoWT-CE are developed. This is particularly important for data categories such as wastage rates, which will be affected, for example, by developments in construction methods and price of secondary materials such as metals. This report also states a number of limitations in relation to each category within the initial reference dataset and a number of areas for further research have been identified.

In relation to this process, users of the tool are invited to submit relevant data from their own projects, or otherwise, that could be used to help refine the reference dataset.

5.0 Wastage Rates and Materials Allocation

5.1 Sources of Available Information

There is a relatively wide range of data available for both building materials and composite components (see the data report for the DoWT-B accordingly). Following a review conducted by WRAP in 2009 it was evident that the data available was more relative to buildings as opposed to civil engineering projects. Therefore, WRAP commissioned work to update the information for civil engineering components in November 2009. Please see Appendix 2 for information relating to each component.

5.2 Limitations of Data and Options for Further Research

The DoWT-CE requires wastage rate data at baseline and good practice. However, the sources of information consulted generally provide just one figure and it is often not stated as to whether this is considered to be baseline, good or best practice. Baseline and good practice wastage rates are, therefore, assumed based upon the range and type of information provided by the various sources. Some sources provide a range of values between which wastage rates are expected to fall and these have been interpreted as providing a 'baseline' and 'good' practice wastage rate.

Despite the level of research undertaken with component manufacturers in relation to component-specific wastage rates, it has sometimes been necessary to apply a wastage rate based on the performance of the materials contained within a certain component. In other cases, where it was felt incorrect to do this, professional judgement has been applied, particularly for some off-site manufactured components for which little wastage is assumed but for which there is no actual reference data in support of the assumption made.

As future versions of the DoWT-CE and Net Waste Tool develop, it will be necessary to undertake further research on best practice wastage rates. Some of this information does already exist as secondary information from previous WRAP research, although to a more limited extent than for baseline and good practice wastage rates. One of the challenges will be to find best practice wastage rates for composite components, where most of the baseline and good practice wastage rates have been obtained from manufacturers or are based on professional judgement according to the nature of the materials used and application within the construction process.

5.3 Data Benchmarking and Validation

Wastage rate data has been benchmarked against existing information from BRE, Waste Aware Construction, the WRAP Net Waste Trial, Net Waste Consultation Group and Net Waste Contractor Questionnaires.

It has been possible only to benchmark wastage rates for materials against Waste Aware Construction Data, which applies to fifteen main types of materials generated as waste during construction. In some cases, the data are too generic to be useful; for example a wastage rate of 6% is specified for 'concrete' but it is currently unknown as to whether this applies to in-situ or pre-cast concrete, although this figure would fall within the ranges specified for both types of concrete. Where the data can be used for comparison, the results are varied; wastage rates of 16% for drywall plasterboard and 10% for general inert support the good and baseline wastage rates identified respectively for these two material types. The wastage rate for timber (15%) is a third higher than the baseline wastage rate for both unprocessed and processed timber, whilst wastage rates for bricks (7.5%), glass (1%) and non-ferrous metal (1%) are much lower than the good wastage rates identified for these materials.

Information provided by BRE is generally in line with the baseline wastage rates identified for the Net Waste reference dataset. Only one respondent to the contractor questionnaire provided percentage waste rate data for an actual project and this was shown to be more in line with the good practice wastage rates identified.

Where available from published information, use has also been made of best practice wastage rates which validate that baseline and good practice wastage rates are in the correct range.

Some of the wastage rate data presented to the Net Waste Consultation Group resulted in the following amendments:

- **Bricks and blocks:** it was considered that the baseline practice wastage rate of 3-4% was too low, especially for bricks, and more representative of a best practice scenario. It was estimated that up to 16% wastage would typically occur on delivery to site, with perhaps a further 5% wastage occurring on site. For this reason, a 20% baseline wastage rate has been input for both bricks and blocks, with a 10% good wastage rate for bricks and a 5% wastage rate for blocks. The good practice wastage rate for blocks is less than for bricks based on information provided by the Net Waste Trials, where four projects reported a wastage rate of 5% for blocks.

- **Packaging:** it was agreed that baseline wastage for construction packaging would be close to, if not 100%. This would apply to all materials since it was confirmed that the industry, generally, does not segregate packaging waste streams, although some are trialling reusable packaging on specific projects.

5.4 Wastage and MMC Wastage Rate Dataset and Assumptions

Due to the large number of components in the Net Waste reference dataset, a full set of wastage rate data and assumptions is available in the Net Waste Tool data report, available from http://nwtool.wrap.org.uk. The majority of components in the reference dataset are assigned either with a general material or component-specific wastage and these are detailed in Tables 2 and 3 respectively.

Materials allocation is important because it is sometimes used to inform the wastage rate where it cannot be identified from other sources; i.e. the wastage rates of the constituent materials are used to produce an aggregate figure, e.g. as for pre-cast beam and block used in ground slabs and in-situ reinforced concrete, where the steel element is determined to be more than 3%.

Materials allocation also determines the waste stream to which waste from the component will be assigned. All components which are comprised of more than one material are automatically selected to default to mixed waste. There are two exceptions to this:

- Components which contain only materials from the same waste stream; e.g. 'porous concrete pipe with type A bed and type A fill', which contains pre-cast concrete and aggregate materials, both of which are categorised as inert materials. Also, waste from most door components, which are comprised of processed and unprocessed timber, will continue to be categorised within the timber waste stream rather than mixed waste.

- Any component containing in-situ concrete in addition to one other material, i.e. usually reinforced concrete. The in-situ nature of construction means that any concrete waste will be separate to steel waste and vice-versa.

Appendix 2 shows the wastage rates (mainly based on primary materials) for which there is much published information available and which is well supported by other sources.

6.0 Packaging

6.1 Sources of Available Information

The DoWT-CE includes packaging waste in waste forecasts. Each component in the Net Waste reference dataset includes data on the packaging type and quantity of packaging per unit.

WRAP identified that the most reliable source of construction packaging waste data currently available is the Envirowise Construction Packaging Waste Estimator Version 1.0.[4] This is an online tool designed to help identify packaging waste streams and provide information to help users improve management of waste generated in the construction sector; it is designed to accompany the Envirowise Good Practice Guide - Managing Packaging Waste on Your Construction Site (GG606).[5]

The Packaging Waste Estimator contains a reference dataset that enables the weight of packaging in kilograms per component to be specified. Estimates can be obtained on the levels of packaging waste produced throughout the duration of a project, currently categorised as building, fit out and external works.

The current version of the Packaging Waste Estimator is based upon an initial set of data collected through onsite visits to builder's merchants and construction site audits. As such, reference data within the tool is based on actual packaging quantities, but where this has not been possible it is based on visual observations of how packaging is generally managed on construction sites.

A data mapping exercise was undertaken to match the existing packaging waste factors to the component list in the Net Waste reference dataset. This process has identified packaging data for approximately 75% of the components within the reference dataset, including:

- Components for which packaging data already exists;
- Components for which existing data could be used with further calculation; and
- Components for which no data currently exists.

6.2 Limitations of Data and Options for Further Research

Envirowise recommend that outputs from the current version of the tool should be used as a guide to decision making only and specify a number of key limitations associated with its dataset. In terms of its use within the DoWT-CE, these limitations are as follows:

- Packaging with a formal collection and return procedure is included;
- The Envirowise dataset is based upon packaging associated with a traditional building construction project and common work activities. Packaging data may not be available for components that are required for more specialised construction;
- There is no reference to components that generate very little, if any, packaging, e.g. concrete;
- It has not been possible to account for every method and amount of packaging that would be used by suppliers to package their products. As such, packaging waste outputs should be used as an estimate in the absence of better information being available; and

The Packaging Waste Estimator is in the process of being updated, which will entail the collection of data based on detailed analyses of bill of quantities and information gathered during site audits.

6.3 Results of Validation Exercise

Since the Packaging Waste Estimator has been identified as the most reliable source of data available, opportunities for benchmarking and validation are currently limited.

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[4] http://www.envirowise.gov.uk/gg606

[5] http://www.envirowise.gov.uk/gg606

6.4 Packaging Dataset and Assumptions

The packaging waste element of the reference dataset is not currently included in this report as it is based on a pre-existing dataset taken from the Envirowise Packaging Waste Estimator.

7.0 Recovery Rates

The availability of recovery rate data is somewhat more limited compared to that for wastage rates. Mixed wastes that are taken to a Materials Recovery Facility/Waste Transfer Station are allocated at a 50% recovery rate. WRAP is currently undertaking a review of this data.

Further information on research and validation into recovery rates is included in the Net Waste Tool data report available at: http://nwtool.wrap.org.uk.

8.0 Volume to Mass Conversion Factors

8.1 Sources of Available Information

The Net Waste reference dataset includes the Environment Agency's volume to mass conversion factors. The DoWT-CE uses the Environment Agency's volume to mass conversion factors to calculate volume of waste from mass of waste (calculated mass/conversion factor = volume). The EA's volume to mass conversion factors were created to take waste data reported in volume (bulked not absolute) and convert to mass for reporting purposes. These factors (applied to material types) have recently been added to the Net Waste reference dataset and are used by the DoWT-CE and WRAP's Reporting Portal[6].

The DoWT-CE uses the standard Environment Agency conversion factors (as used by the EA). However, where the EA Wales waste analysis provides updated factors these are used in preference. Early versions of the UKCG waste data reporting method (January 2009) used the standard EA conversion factors, however these have since been updated as a result of the EA Wales analysis.

For example, the factor for bricks is 1.2 ($1m^3$ x 1.2 = 1.2 tonnes). These are applied to the mass of waste in the DoWT-CE to find the volume of waste (e.g. for bricks, 1.2 tonne of waste is divided by a factor of 1.2 to give $1m^3$). The calculated volumes are based on the space in the skip (i.e. bulked not absolute).

[6] *More information is available at* *http://www.wrap.org.uk/document.rm?id=6932*

9.0 Cost of Waste Disposal

9.1 Sources of Available Information

Container Costs
The DoWT-CE calculates a 'baseline' quantity of waste to landfill using the mixed waste stream recovery rate (50%) assuming the use of 40 yrd^3 $30.6m^3$ waste containers with a disposal cost of £555 per container. Any reduction in wastage is shown as an improvement in waste to landfill relative to this baseline.

With the exception of timber and metals, containers costs used in the Net Waste reference dataset are provided by Hippowaste and have been validated using construction-specific container cost data from a materials recycling facility. Information is also available online from various container companies operating throughout the UK but these tend to be aimed at the household waste market, in which case prices may not reflective of those charged to the construction industry, although this cannot be confirmed without further research.

A MRF operator in the West Midlands has provided cost data. This was used for benchmarking purposes only since the MRF does not provide the full range of container sizes pre-defined by the Net Waste reference dataset, and thus not all of the container sizes and waste streams are included.

The sources of information used show that container costs are highly variable and are dependent on a number of factors, including:

- Transportation costs;
- Labour costs;
- Market for materials (especially for metals);
- Region of the UK; and
- Effect of increasing Landfill Tax.

Variability in container costs makes it extremely difficult to suggest a one-size-fits-all approach and the costs used in the reference dataset should be used as a guide only.

For further information on container costs in the Net Waste reference dataset, refer to the Net Waste Tool data report, available from http://nwtool.wrap.org.uk.

10.0 Carbon Factors

10.1 Sources of Available Information

The quoted emission factors come from a number of published sources which either undertake a life cycle inventory analysis, or report on the findings of other life cycle based studies that have undertaken a life cycle inventory analysis. Life cycle inventory analysis represents part of the process of life cycle assessment (LCA), which is enshrined in international standards (ISO 14040-44).

Figures for the embodied carbon of the primary material (used in both the DoWT-CE and the Net Waste Tool) are sourced from the University of Bath's Inventory of Carbon and Energy (ICE), Version 1.5a beta and Version 1.6a, which provides values of embodied energy and carbon co-efficients collected from secondary resources assessed for reliability by the author.[7]

The Net Waste Tool also utilises factors relating to carbon dioxide emissions arising from recycling. More information on this can be found in the Net Waste Tool data report, available from http://nwtool.wrap.org.uk.

Data are also available from a range of other sources, which have not been used at this stage either due to copyright permissions or because further study is required to establish their LCA boundaries; these sources include:

- GaBi 4 life-cycle assessment tool;[8]
- The Environment Agency's Waste and Resources Assessment Tool for the Environment (WRATE);[9]
- The Environment Agency's online Carbon Footprint Calculator;[10]
- CSERGE Working Paper: A Life Cycle Assessment and Evaluation of Construction and Demolition Waste; [11]
- Defra (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions;[12]
- EcoInvent Centre (also known as the Swiss Centre for Life Cycle Inventories) Version 2.0 LCA tool;[13]
- Edinburgh Centre for Carbon Management Carbon Self-Assessment Tool;[14]

10.2 Limitations of Data and Options for Further Research

Each of the LCA studies used to assemble carbon factors in the reference dataset have different boundaries, assumptions and data, for example, in terms of age and of geographical and technical scope, some of which may be reported and some of which may not. As a result, there will be some variation in the actual values included in the Net Waste reference dataset. It is advised, therefore, that values should be considered as a guide only rather than a definitive carbon saving.

The data gathered applies specifically to materials rather than components, which means that carbon factors are applied to composite components based on the apportionment of materials, which may not necessarily reflect the carbon dioxide saving associated with recycling a particular component. There are also a large number of data

[7] *Hammond G & Jones C (2006) Inventory of Carbon & Energy Version 1.5 Beta, University of Bath.*

[8] *http://www.gabi-software.com*

[9] *http://www.environment-agency.gov.uk/wtd/1396237*

[10] *http://www.environment-agency.gov.uk/business/444304/502508/1506471/1506565/1508048/1883907/?lang=_e*

[11] *Craighill A & Powell JC (1999) A Life Cycle Assessment and Evaluation of Construction and Demolition Waste. CSERGE Working Paper WM 99-03.*

[12] *Defra (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, http://www.defra.gov.uk/science/project_data/DocumentLibrary/WR0609/WR0609_5737_FRP.pdf*

[13] *http://www.ecoinvent.org*

[14] *http://www.eccm.uk.com/httpdocs/index.htm*

gaps, including items such as electrical and electronic equipment and M&E plant, and for some materials themselves; values for bricks and blocks and tiles and ceramics are based on those for aggregates.

As the Net Waste reference dataset is refined, further work will be required to obtain carbon factors for these components and materials.

10.3 Data Validation and Benchmarking

As demonstrated, there are a number of other sources of data available that provide alternative figures to those suggested. However, it has not been possible to use these in a benchmarking exercise due to the different LCA system boundaries. Further work would be required to determine these system boundaries and the LCA studies that would be appropriate to the Net Waste reference dataset.

11.0 Conclusion

This report outlines the key sources of background data (reference dataset) assembled for the Net Waste reference dataset. The data it contains is based on a variety of relevant sources and in some cases professional judgment has been applied in making assumptions associated with the components and materials in the database. As such, the reference dataset exists to guide the user as to the appropriate values that are assumed to be typical for the relevant data categories included.

The reference dataset will be refined by WRAP over time and a number of suggestions have been made for further research that would assist this process. It is also important that DoWT-CE users have an opportunity to influence this process e.g. comments on appropriateness of the existing data that could be used to help refine the reference dataset over time. Furthermore, where the Net Waste Tool is used on a project, actual project waste data can be uploaded to the Net Waste Tool. This will assist WRAP in interrogating and updating wastage rates.

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Appendix 1

List of elements and sub elements within the tool

Table A1 List of elements and sub elements within the tool

Element	Sub element category	Sub elements available for selection
Foundations	Piling	in situ RC CFA
		precast concrete
	Ground improvement	in situ stabilisation/ improvement
		ex situ HBM production
	Strip foundations	geosynthetics and granular material
		unreinforced concrete
Earthworks	Embankments	soil nailing
		shallow embankments
		precast concrete retaining walls
		gabion basket retaining walls
		steel sheet retaining walls
		in situ stabilisation/ improvement
		ex situ HBM production
		geosynthetics and granular material
	Cuttings	soil nailing
		shallow embankments
		precast concrete retaining walls
		gabion basket retaining walls
		steel sheet retaining walls
		in situ stabilisation/ improvement
		ex situ HBM production
		geosynthetics and granular material
		geosynthetics and granular material
Drainage	Filter and perforated drain	Type G filter drain with Type V (topsoil) top to filter drain
		Type G filter drain with Type Y (lightweight aggregate) top to filter drain
		Type G filter drain with Type X or W (subbase) top to filter drain
		Type J filter drain with Type V (topsoil) top to filter drain
		Type J filter drain with Type Y (lightweight aggregate) top to filter drain
		Type J filter drain with Type X or W (subbase) top to filter drain
		Type H filter drain with Type V (topsoil) top to filter drain
		Type H filter drain with Type Y (lightweight aggregate) top to filter drain
		Type H filter drain with Type X or W (subbase) top to filter drain
		Type I filter drain with Type V (topsoil) top to filter drain

Element	Sub element category	Sub elements available for selection
		Type I filter drain with Type Y (lightweight aggregate) top to filter drain
		Type I filter drain with Type X or W (subbase) top to filter drain
		Type K filter drain with Type V (topsoil) top to filter drain
		Type K filter drain with Type Y (lightweight aggregate) top to filter drain
		Type K filter drain with Type X or W (subbase) top to filter drain
	Pipes and gullies	Gullies connected by vitrified clay pipe carrier drains using Type A trench and bedding
		Gullies connected by vitrified clay pipe carrier drains using Type S trench and bedding
		Gullies connected by vitrified clay pipe carrier drains using Type B trench and bedding
		Gullies connected by vitrified clay pipe carrier drains using Type F trench and bedding
		Gullies connected by vitrified clay pipe carrier drains using Type N trench and bedding
		Gullies connected by uPVC flexible pipe carrier drains using Type T trench and bedding
		Gullies connected by uPVC flexible pipe carrier drains using Type S trench and bedding
Pavements	Full pavement	in situ stabilisation/ improvement for subbase under reinforced concrete pavement
		in situ stabilisation/ improvement for subbase under HBM base and flexible surfacing for pavement
		in situ stabilisation/ improvement for subbase under fully flexible pavement
		ex situ HBM production for subbase under reinforced concrete pavement
		ex situ HBM production for subbase under HBM base and flexible surfacing for pavement
		ex situ HBM production for subbase under fully flexible pavement
		geosystems and granular material for subbase under reinforced concrete pavement

geosystems and granular material

Element	Sub element category	Sub elements available for selection
		for subbase under fully flexible pavement
		granular subbase under fully flexible pavement
Streetworks	Backfill	graded granular fill
		stabilised material for fill
	Subbase	granular subbase
		HBM (BS EN specified)
	Pavements	fully flexible
		HBM (BS EN specified) base and flexible surfacing
Track	Track	Track with steel sleepers
		Track with concrete sleepers
		Track with wooden sleepers
Temporary works	Haul roads	granular
		in situ stabilisation/ improvement
		ex situ HBM production
		geosynthetics and granular material
	Working platforms	granular
		in situ stabilisation/ improvement
		ex situ HBM production
		geosynthetics and granular material
Structures	Concrete	structural concrete
		reinforcing steel
	Steel	construction steel (per tonne)
	Masonry	lightweight block walls
		dense block walls
Platforms	Platforms	Type 1 crosswall platform
		Type 2 crosswall platform
		Traditional front wall platform

Appendix 2

Overview of component data

Table A2 Overview of component data

Component description	Recycled content		Density ($kgCO_2/m^3$)	Wastage rate		Embodied CO_2 (tCO_2/t)
	Standard	Good		Standard	Good	
Concrete Strip, Strength C25 or lower, 1000 deep, (up to and inc. DPC) no reinforcing	0	4	2.4	4	2	0.088
Concrete Strip, Strength C25 or lower, 600 deep, (up to and inc.DPC) no reinforcing	0	4	2.4	4	2	0.088
Concrete Strip, Strength C25 or lower, 1000 deep, (up to and inc. DPC) with reinforcing	12	15	2.7	4	2	0.088
Concrete Strip, Strength C25 or lower, 600 deep, (up to and inc.DPC) with reinforcing	12	15	2.7	4	2	0.088
General Fill, SHW Class 1A,B,C	0	50	1.9	10	5	0.005
Structural screed min 75mm thick to concrete and smooth trowelled finish; mesh reinforcement	13	14	1.5	5	2.5	0.088
Concrete Strip, Strength C30 or higher, 1000 deep (up to and inc. DPC) no reinforcing	0	5	2.4	4	2	0.088
Concrete Strip, Strength C30 or higher, 600 deep (up to and inc. DPC) no reinforcing	0	5	2.4	4	2	0.088
Concrete Strip, Strength C30 or higher, 1000 deep (up to and inc. DPC) with reinforcing	12	15	2.7	4	2	0.088
Concrete Strip, Strength C30 or higher, 600 deep (up to and inc. DPC) with reinforcing	12	15	2.7	4	2	0.088
Reinforced in-situ concrete 600mm, C30 or higher	15	20	2.7	4	2	0.088
Sand	0	25	1.8	10	5	0.005
Cast in-situ RC CFA bored pile dia. 300, C25 or lower	12	15	2.1	5	2.5	0.088
Cast in-situ RC CFA bored pile dia. 350, C25 or lower	12	15	2.1	5	2.5	0.088
Cast in-situ RC CFA bored pile dia. 450, C25 or lower	12	15	2.7	5	2.5	0.088
Cast in-situ RC CFA bored pile dia. 450, C30 or higher	11	16	2.7	5	2.5	0.088
Cast in-situ RC CFA bored pile dia. 300, C30 or higher	11	16	2.7	5	2.5	0.088
Precast concrete - 300mm dia, driven	20	22	2.1	1	0	0.088
Precast concrete - 400mm dia, driven	20	22	2.1	1	0	0.088
Precast concrete - 450mm dia,	20	22	2.1	1	0	0.088

Component description	Recycled content		Density	Wastage rate		Embodied CO_2 (tCO_2/t)
	Standard	Good	($kgCO_2/m^3$)	Standard	Good	
driven						
SHW Class 6F5 coarse graded capping	0	50	1.9	10	5	0.005
Sand	0	25	1.8	10	5	0.005
Topsoil, SHW Class 5B	0	25	1.44	10	5	0.023
Sand	0	25	1.8	10	5	0.005
Pre-cast concrete hollow core plank; 150mm thick - excludes screed	20	22	2.4	13	3	0.088
Clay to BS EN295, polypropylene couplings	0	4	2	10	5	0.55
Perforated uPVC	0	10	1.4	10	5	2.53
Type N sand bed	0	50	1.8	15	7.5	0.005
Type T sand surround	0	50	1.8	15	7.5	0.005
Type F granular bed	0	50	1.8	15	7.5	0.005
Type S granular surround	0	50	1.8	15	7.5	0.005
Type A Concrete bed	0	10	2.4	15	7.5	0.127
Type Z concrete surround	0	10	2.4	15	7.5	0.127
Type A sand bed	0	50	1.8	15	7.5	0.005
Type B granular bed	0	50	1.8	15	7.5	0.005
Pre cast concrete construction 675 diam	20	22	2.7	1	0	0.088
Pre cast concrete construction 900 diam	20	22	2.7	1	0	0.088
Pre cast concrete construction 1200 diam	20	22	2.7	1	0	0.088
Pre cast concrete construction 1800 diam	20	22	2.7	1	0	0.088
Pre cast concrete construction 2400 diam	20	22	2.7	1	0	0.088
Pre cast concrete construction 2700 diam	20	22	2.7	1	0	0.088
Pre cast concrete construction 3000 diam	20	22	2.7	1	0	0.088
Imported granular fill, SHW Class 1 A//B/C	0	50	1.9	10	5	0.005
Imported cohesive fill, SHW Class 2A/B/C/D	0	10	1.8	10	5	0.005
Imported cohesive fill, SHW Class 2E reclaimed pulverised fuel ash	100	100	1.6	10	5	0.005
Site won wet cohesive fill, SHW Class 2A	100	100	1.8	10	5	0
Site won dry cohesive fill, SHW Class 2B	100	100	1.8	10	5	0
Site won stony cohesive fill, SHW Class 2C	100	100	1.8	10	5	0
Site won silty cohesive fill, SHW Class 2D	100	100	1.8	10	5	0
Type 1 unbound subbase, SHW Clause 803	0	50	1.9	10	5	0.005
Sand	0	25	1.8	10	5	0.005
Imported, SHW Class 5B	0	25	1.4	10	5	0.023
Site won selected granular material for capping, fine grading, SHW Class	100	100	1.9	10	5	0

Component description	Recycled content		Density ($kgCO_2/m^3$)	Wastage rate		Embodied CO_2 (tCO_2/t)
	Standard	Good		Standard	Good	
6F1						
Site won selected granular material for capping, coarse grading, SHW Class 6F2	100	100	1.9	10	5	0
Imported selected granular material for capping, recycled asphalt, SHW Class 6F3	100	100	1.9	10	5	0.005
Imported selected granular material for capping, fine grading, SHW Class 6F4	0	50	1.9	10	5	0.005
Imported selected granular material for capping, coarse grading, SHW Class 6F5	0	50	1.9	10	5	0.005
Imported selected granular material, gabion filling, SHW Class 6G	0	25	1.9	10	5	0.005
Imported well graded fill to structures, SHW Class 6N	0	50	1.9	10	5	0.005
Imported fill to structures, SHW Class 6P	0	50	1.9	10	5	0.005
Site won granular material for stabilisation with lime and cement to form capping, SHW Class 6R, to form 9F	95	95	1.8	10	5	0.005
Imported well graded filter layer below subbase, SHW Class 6S	0	25	1.9	10	5	0.005
Imported selective cohesive fill to structures, SHW Class 7A	0	25	1.8	10	5	0.005
Imported fill to structures/reinforced soil - conditioned pfa, SHW Class 7B	100	100	1.6	10	5	0.004
Site won wet fill to reinforced soil, SHW Class 7C	100	100	1.8	10	5	0
Site won stony fill to reinforced soil, SHW Class 7D	100	100	1.8	10	5	0
Capping-stabilisation with lime SHW Class 7E to form Class 9D	95	95	1.8	10	5	0.037
Capping-silty cohesive stabilisation with cement SHW Class 7F to form Class 9B	95	95	1.8	10	5	0.047
Capping-pfa stabilisation with cement SHW Class 7G to form Class 9C	95	95	1.8	10	5	0.047
Capping-stabilisation with lime and cement SHW Class 7I to form Class 9E	95	95	1.8	10	5	0.042
Type 1 unbound subbase, SHW Clause 803	0	50	1.9	10	5	0.005
Type 2 Unbound Mixtures, SHW Clause 804	0	50	1.9	10	5	0.005
Type 3 (open graded) Unbound Mixtures, SHW Clause 805	0	50	1.9	10	5	0.005
Category B (close graded) Unbound Mixtures, SHW Clause 806	0	50	1.9	10	5	0.005
Sand	0	25	1.8	10	5	0.005
Cement bound granular mixtures A	0	90	2.1	10	5	0.051

Component description	Recycled content		Density ($kgCO_2/m^3$)	Wastage rate		Embodied CO_2 (tCO_2/t)
	Standard	Good		Standard	Good	
Cement bound granular mixtures B	0	90	2.1	10	5	0.051
Cement bound granular mixtures C	0	90	2.1	10	5	0.051
Cold Recycled Cement Bound Material (in-situ)	0	90	2.1	10	5	0.051
Slag Bound Mixture B1-2, Fly Ash Bound Mixture 1 and Hydraulic Road Binder Bound Mixture 1	5	90	2.1	10	5	0.051
Slag Bound Mixture B2, Fly Ash Bound Mixture 2, Hydraulic Road Binder Bound Mixture 2	5	90	2.1	10	5	0.051
Slag Bound Mixture B3, Fly Ash Bound Mixture 3 and Hydraulic Road Binder Bound Mixture 3	5	90	2.1	10	5	0.051
Fly Ash Bound Mixture 5	5	90	2.0	10	5	0.051
Soil Cement, Soil Treated by Slag, Soil Treated by HRB, and Soil Treated by Fly Ash	90	92	1.8	10	5	0.047
Cold recycled other hydraulic bound material (in-situ)	90	90	2.1	10	5	0.051
Cold recycled hydraulic bound material (ex-situ)	90	90	2.1	10	5	0.051
Recipe Mixtures: Hot Rolled Asphalt Binder Course (SHW Clause 905)	0	25	2.4	5	2.5	0.045
Recipe Mixtures: Dense Base and Binder Course Macadams with Paving Grade Bitumen (SHW Clause 906)	0	25	2.4	5	2.5	0.045
Dense Macadam Surface Course (0/6 mm) (SHW Clause 909)	0	10	2.4	5	2.5	0.045
Rolled Asphalt Surface Course (Recipe Mix)	0	10	2.1	5	2.5	0.045
Recipe Mixtures: Hot Rolled Asphalt Surface Course (SHW Clause 910)	0	10	2.4	5	2.5	0.045
Close Graded Asphalt Concrete Surface Course (SHW Clause 912)	0	10	2.4	5	2.5	0.045
Fine Graded Asphalt Concrete Surface Course (SHW Clause 914)	0	10	2.4	5	2.5	0.045
Open Graded Asphalt Concrete Surface Course (SHW Clause 916)	0	10	2.3	5	2.5	0.045
Design Mixtures: Dense Base and Binder Course Asphalt Concrete (SHW Clause 929)	0	50	2.4	5	2.5	0.045
Recipe Mixtures: Heavy Duty Macadam Base and Binder Course Macadams with Paving Grade Bitumen	0	50	2.4	5	2.5	0.045
Stone Mastic Asphalt (SMA) Binder Course and Regulating Course (SHW Clause 937)	0	50	2.4	5	2.5	0.045
Performance-Related Design Mixtures: Hot Rolled Asphalt Surface Course and Binder Course (SHW Clause 943)	0	10	2.4	5	2.5	0.045
China Clay Sand Asphalt Base	95	95	2.4	5	2.5	0.045

Component description	Recycled content		Density ($kgCO_2/m^3$)	Wastage rate		Embodied CO_2 (tCO_2/t)
	Standard	Good		Standard	Good	
Slate Macadam Base	95	95	2.4	5	2.5	0.045
Paving quality concrete (C30 20mm aggregate)	0	20	2.5	5	2.5	0.127
100mm thick sub-base sand	0	25	1.8	10	5	0.005
Grade C20/25 Bases, footings, pile caps, ground beams, walls, slabs, piers	0	7	2.7	5	2.5	0.088
Grade C25/30 Bases, footings, pile caps, ground beams, walls, slabs, piers	24	30	2.7	5	2.5	0.088
Grade C28/35 Bases, footings, pile caps, ground beams, walls, slabs, piers	24	30	2.7	5	2.5	0.088
Grade C32/40 Bases, footings, pile caps, ground beams, walls, slabs, piers	24	30	2.7	5	2.5	0.088
Steel reinforcing	100	100	1	15	5	1.82
Mortar	3	4	1.75	5	2.5	0.16
Lightweight	50	80	1.4	20	5	0.2
Dense block walls for masonry structures	0	50	2.4	20	5	0.2
Sand	0	25	1.8	10	5	0.005
Site won well graded granular fill, SHW Class 1A	100	100	1.9	10	5	0
Site won uniformly graded granular fill, SHW Class 1B	100	100	1.9	10	5	0
Site won coarse granular material, SHW Class 1C	100	100	1.9	10	5	0
Recipe Mixtures: Hot Rolled Asphalt Surface Course (SHW Clause 910)	0	10	2.4	7.5	4	0.045
Precast reinforced concrete retaining wall	20	22	2.4	0	0	0.385
Geotextile (free draining)	0	0	0.01	0	0	2
Soil nail	0	0	7.85	0	0	2.68
Gabion basket 1000x1000x1000mm	0	0	0.01	0	0	2.94
Gabion basket 1500x1000x1000mm	0	0	0.01	0	0	2.94
Steel sheet pile	0	0	7.85	0	0	2.82
Geogrid	0	0	0.21	0	0	2.82
Type A filter drain material	0	0	2.2	10	5	0.005
Type B filter drain material	0	0	2.2	10	5	0.005
Lightweight aggregate	0	100	1.6	10	5	0.0038
Precast concrete gully 4	20	22	2.7	1	0	0.27
uPVC Pipe	0	10	1.4	10	5	2.5
Steel rails (per metre)	60	60	7.85	0	0	1.77
Railway ballast	0	0	1.8	0	0	0.056
Concrete Railway Sleeper	20	22	2.4	0	0	0.13
Wooden Railway Sleeper	0	0	0.7	0	0	0.46
Steel Railway Sleeper	60	60	7.85	1	0	1.77
Construction steel (per tonne) for steel structures	60	60	0.6	20	5	1.77
440x215x100mm concrete blocks	0	50	0.6	20	5	0.061
ST1 concrete	0	24	2.4	15	7.5	0.096
Precast concrete coper (930mm x	20	22	2.4	0.76	1	0.13

Component description	Recycled content		Density ($kgCO_2/m^3$)	Wastage rate		Embodied CO_2 (tCO_2/t)
	Standard	Good		Standard	Good	
760mm x 100mm)						
Precast concrete tactile slab (400mm x 400mm x 50mm)	20	22	2.4	0.4	0.4	0.13
Precast concrete edging (250mm x 50mm)	20	22	2.4	0.25	1	0.13
Cast in-situ RC CFA bored pile dia. 400, C30 or higher	11	16	2.7	5	2.5	0.088