Sustainable use of new and recycled materials in coastal and fluvial construction

A guidance manual

Neal Masters

Thomas Telford

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The photograph on the front cover shows the range of materials used in the construction works at Felpham (courtesy of Arun District Council).

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Preface

Interest in sustainable development and environmental issues is intensifying. The environmental performance of the construction industry and the impact that construction materials have on the environment throughout their life cycle is increasingly under the scrutiny of local, national and international environmental pressure groups and consequently the general public.

Traditionally, the selection of materials for coastal and fluvial construction has been based solely on economic, durability and hydraulic performance criteria. Some consideration has been given to the environmental impacts of materials on local surroundings (e.g. visual and safety aspects), however, no clear mechanism is in place for assessing project options on the basis of the sustainability of the use of those materials.

Primary materials such as rock, timber, aggregate, concrete and steel are used extensively in coastal and fluvial construction projects and there can be significant environmental impacts from their extraction, processing, transportation, use and disposal. There is currently very limited practical guidance available to those involved with coastal and fluvial construction on how to assess these impacts. There is also very little information available to engineering designers on the potential uses, durability and environmental impacts of reclaimed and recycled materials.

This manual provides detailed information, including a software tool, to enable those involved with engineering projects to increase the sustainability of construction by minimising the environmental impacts of the materials used. It also describes opportunities to incorporate reclaimed and recycled materials into coastal and fluvial structures by integrating the consideration of these materials into each stage of the design process. It will prove invaluable to those involved in civil engineering and contracting industries, including consultants, contractors, government agencies, material suppliers, environmental bodies, academics and others interested in the environmental aspects of coastal and fluvial construction.

The manual is divided into three main parts. The predominant issues covered in each part are outlined below:

Part A

- Defining sustainable development.
- European and national strategies for sustainable development and sustainable construction.
- Sustainable development policy of the Environment Agency and the Ministry of Agriculture, Fisheries and Food.
- International sustainability standards (e.g. ISO 14000).

- Summary of Life Cycle Assessment, Embodied Energy Analysis and Design for the Environment.
- Inter-relationship between environmental impact assessment techniques.

Part B
- Integrating sustainable thinking into the design process.
- Identifying system design units, options and quantities.
- Taking account of available material types and dimensions.
- Using locally available reclaimed or recycled materials over first use and distantly sourced materials.
- The significance of transport in the overall environmental impact.
- Reduction, reuse, recovery and disposal to be preferred in that order.
- Examples of reuse and recycling.
- Comparison techniques are given, including integration into existing techniques (e.g. multi-criteria, benefit cost).
- New Ecopoints estimator approach described and software package included.

Part C
- The importance of transport in the overall environmental impact of construction materials.
- Case examples describing reuse and recycling.
- Environmental impacts throughout the life cycles of rock, timber, aggregate, concrete, steel, recycled plastic and recycled rubber.

Neal Masters *is a graduate environmental engineer who joined HR Wallingford in 1997. He has managed and worked on a number of large research projects. He has also been responsible for generating wave climates and design wave conditions using numerical modelling techniques and he has developed a software package for conducting wave and wind data analysis.*

Jonathan Simm *is a chartered civil engineer who worked with consulting engineers for 14 years on the design and construction of port and coastal defences before joining HR Wallingford in 1992. Since then he has been manager of the Engineering Support Section, where he has been responsible for consultations and research studies aimed at bridging the gap between theory and practice.*

Acknowledgements

This manual has been produced as a result of an HR Wallingford research project, carried out under the Department of the Environment, Transport and the Regions' Partners in Technology Scheme, and constitutes HR Wallingford Report SR 535. The objective of the project was to draw together existing knowledge, experience and research, including that gained from case studies, to produce detailed guidance on the environmental impacts of construction materials and to identify possibilities for recycling and re-using materials in coastal and fluvial engineering projects.

This manual was prepared by HR Wallingford (HR) and was published on behalf of the Department of the Environment, Transport and the Regions (DETR) and the Environment Agency. The views and information presented in the guide are those of HR Wallingford and while they reflect the views of the advisory committee they are not necessarily those of the funding organisations. The project was managed by Neal Masters and Jonathan Simm of HR Wallingford.

The manual was edited by Neal Masters and Jonathan Simm from text compiled by the following.

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The manual also complies with the Environment Agency's R&D Technical Report W240. The work was part funded as part of the Environment Agency's National R&D Programme under Project W5-049.

In-kind contributions

In-kind contributions, in terms of data on historic projects and staff time committed to the project, were provided by the following organisations.

- Environment Agency.
- Arun District Council.
- Aitken & Howard Ltd.
- British Cement Association.
- Steel Construction Institute.
- Mackley Construction.
- Posford Duvivier.
- Poole Harbour Commissioners.
- Commercial Marine & Piling Ltd.

Steering group

The research was guided by an advisory committee which was comprised of the following members.

Brian Holland	Arun District Council
Les Parrott	British Cement Association
Katharine Clarke	Environment Agency — Thames Region
Mike Pomfrett	Environment Agency — Thames Region
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Glossary

Aggregate	Crushed stone, sand or gravel
Alternative materials	Materials, such as recycled plastic and rubber, that are not normally considered as traditional construction materials
Armour layer	A protective layer of armour units
Armour stone	Large quarried stone used as primary protection against wave attack
Armour units	Large quarried stone or specially shaped concrete block used as primary protection against wave action
BCA	Benefit cost analysis
Beach profile	A cross-section taken perpendicular to a given beach contour
Beach renourishment	Supplementing the natural volume of sediment on a beach, using imported material (also known as beach recharge/nourishment/feeding)
BRE	Building Research Establishment
Breakwater	A structure to break the force of waves, typically a wall constructed out into the sea to protect a natural or artificial harbour
Breastwork	A timber structure generally built parallel to the coast
Caisson	Concrete box-type structure
Camel	Floating fender usually made from rubber or plastic filled with pressurised air or plastic foam
Coir rolls	Coir fibre compressed into a roll and contained by an exterior netting of synthetic cord — used for toe protection along rivers in low energy environments (reed growth usually replaces coir fibre with a root matrix once established)
Culvert	A covered conduit for taking a watercourse, drain or sewer under a railway, road or embankment
CIRIA	Construction Industry Research and Information Association
DETR	Department of the Environment, Transport and the Regions
Dolphin	An island structure either piled or a gravity construction that can carry mooring bollards or fenders to absorb berthing energy

Dredging	The excavation and removal of material from the bed of a river, lake, harbour or sea by dredger, dragline or scoop
Durability	The ability of a material to resist degradation and retain its physical and mechanical properties
EIA	Environmental Impact Assessment
Fenders	Shock absorbing objects hung over the side of vessels or attached to berths (usually piers or quays) in order to prevent damage to the vessel or berth
Gabion	A rectangular box made of wire mesh and filled with stone
Geotextile	A synthetic fabric used as a filter (can be woven or unwoven)
ggbs	Ground granulated blastfurnace slag
Groyne	A structure, generally perpendicular to the shoreline, built to control the movement of beach material
LCA	Life Cycle Assessment
Leachate	The liquid generated after a liquid comes into contact with a solid
Lumber	Recycled plastic timber
MAFF	Ministry of Agriculture, Fisheries and Food
Maintenance	Repair or replacement of part of a structure in order to prevent failure of the structure
MCA	Multi-criteria analysis
Offshore breakwater	A breakwater, generally parallel to the shore, built towards the seaward limit of the surf zone
pfa	Pulverised fuel ash
Piling	Timber, concrete, steel or plastic posts or sheets driven into the ground to carry a vertical or horizontal load
Primary materials	Materials whose production has involved extraction from virgin natural reserves
Pyrolysis	Decomposition of rubber by heat in an oxygen free atmosphere
Quarry	A site from which natural rock is extracted
Reclaimed material	A material that has been recovered from the waste stream and can be used again without further processing
Recycling	The collection and separation of materials from waste and their further processing so that they can be used again
Recycled material	A material that has been collected and separated from the waste stream and that has undergone some form of processing (can also be used to describe a material that incorporates a recycled material within it, i.e. not all materials referred to as being recycled

	materials in this manual are necessarily composed of 100% recycled material)
Reuse	The use of materials recovered from the waste stream without further processing
Revetment	One or more layers of stone, concrete or other material used to protect the sloping surface of an embankment, natural coast or shoreline against erosion
Rip-rap	Wide-graded quarry stone normally used as a protective layer in revetments or in bank protection to prevent erosion
Rubble-mound structure	A mound of randomly shaped and randomly placed stone
Secondary materials	Materials used in construction that have already been used or are recovered from the waste stream of other activities
SETAC	Society of Environmental Toxicology and Chemistry
Spiling	Fluvial bank protection using fresh willow withies (small branches) woven around willow sticks to form a dense fence that will sprout and grow if backfilled with dredgings
Spoil	Soil, rock or other earth material arising from excavation, dredging or other ground engineering work
Toe	The lowest part of a coastal or fluvial defence structure or river bank
Toe boarding	Timber or plastic boarding placed at the lower part of a river bank to protect it from erosion by wave action or water flow
TTF	Timber Trade Federation
Waste	Something that 'the producer or holder discards or intends to or is required to discard' (Waste Management Licensing Regulations, 1994)
Waste hierarchy	For definition see Box 4.5

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Background and use of the manual

1. Background and use of the manual

There is currently very limited practical guidance available to coastal and fluvial engineers on identifying and assessing the overall environmental impact of different project options. Environmental Impact Assessment takes account of the effects that a structure has on its local environment but there is a need to also consider the environmental impact from the creation of the structure itself. This needs to be assessed throughout its life cycle, from the extraction of the raw materials used to build it, the processing and transport of these materials and the ultimate disposal or reuse of the structure or its components. By taking a whole life view, the total environmental impact of creating the structure can be understood better and areas can be identified where this impact can be decreased. In this way, the sustainability of coastal and fluvial construction is increased.

This manual aims to provide details of methods for identifying and assessing the overall environmental impact of coastal and fluvial construction. The use of reclaimed and recycled materials and the benefits that this brings to the environment are also discussed. A large number of case examples and photographs are included in the manual to illustrate the text.

The following sections outline the aims, scope, readership, structure and use of the manual. A brief description of relevant legislation and an overview of the role and responsibilities of the organisations involved in flood and coastal defence and construction in the UK can be found in Appendix 1.

1.1. THE NEED FOR ENVIRONMENTAL SUSTAINABILITY IN MATERIAL SELECTION

Sustainable development is about choosing a development path that will not adversely affect the environment or disadvantage the social or economic well being of present or future populations. Environmental, social and economic issues are not opposing forces but are ultimately linked, e.g. we may currently experience economic well being at the expense of the environment — in the future the damaged environment may hinder economic development.

The most widely used concise definition is the ‘Brundtland’ definition which refers to ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (Brundtland, 1987).

There is an increasing emphasis on sustainable development within the construction industry. This has sparked an awareness of the high level of use of primary materials and the excessive production of construction waste. Flood defence works, both coastal and fluvial, utilise significant quantities of primary materials.

The aim of this manual is to provide information and practical advice on the environmental implications of material selection in order to decrease the negative impacts on the environment and increase the sustainability of coastal and fluvial construction. This means reducing the use of non-renewable materials, overall energy consumption, and other negative environmental impacts over the life cycle of a particular scheme.

1.2. THE ROLE OF THE UK GOVERNMENT IN IMPROVING THE SUSTAINABILITY OF CONSTRUCTION

1.2.1. Department of the Environment, Transport and the Regions

The aim of the Construction Directorate at the DETR is to improve the quality of life by promoting sustainable development at home and abroad, fostering economic prosperity and supporting local democracy. One of the DETR's main objectives is to secure an efficient market in the construction industry with innovative and successful UK firms that meet the needs of clients and society and that are competitive at home and abroad.

1.2.2. Environment Agency

The Environment Agency has a statutory obligation to supervise and carry out land drainage and flood defence functions, a statutory duty to maintain, improve and develop fisheries and a duty to promote conservation, enhancement and recreational use of inland and coastal waters in England and Wales.

Many works carried out by the Environment Agency involve the construction of fluvial and coastal structures, using a broad range of materials. The Environment Agency has a remit to promote sustainable practices and to take due account of the environmental impacts of any works that it carries out as part of its powers or duties. The Environment Agency is therefore working to develop mechanisms for assessing environmental impacts of fluvial and coastal schemes beyond the 'on site' impacts, which are already taken into account.

1.3. MATERIALS COVERED IN THE MANUAL

Coastal engineering works are normally constructed either to assist in maritime trade, to protect the coastline or for leisure. Works to prevent the erosion of existing coastlines are commonly called coast protection works in the UK and works to protect low-lying areas from flooding are commonly called sea defence works. Commonly occurring coastal engineering structures and their associated main construction materials are summarised in Table 1.1.

Table 1.1. Common materials used in coastal engineering

Main construction material	Common structure type
Rock	Shore parallel revetments, groynes, shore connected breakwaters, detached breakwaters and reefs (both below and above low water mark), scour protection
Timber	Groynes, breastwork, timber piles, wavescreens
Aggregate (other than that used in concrete)	Beach renourishment
Concrete	Mass and reinforced concrete structures, such as seawalls, jetties, revetments, groynes and concrete armour units, as an alternative to rock in breakwater structures or in pipe outfalls
Steel	Sheet-piled walls, tubular/H piles for jetties, concrete reinforcement, pipe outfalls
Plastics (new)	Sheet piles, geotextiles, pipe outfalls
Plastics (recycled)	Sheet piles, piles, lumber, railing
Rubber (reused tyres)	Fenders, revetments

Table 1.2. Common materials used in fluvial engineering

Main construction material	Common engineering application
Rock/masonry	Rip-rap bank protection, scour protection, gabions, masonry gravity walls, blockwork walls
Timber	Toe boarding, timber piling, willow mattresses/fascines, angling platforms
Aggregate (other than that used in concrete)	Reinstating river beds
Concrete	Mass and reinforced concrete structures, such as weirs and spillways, gravity walls, locks, bank protection
Steel	Toe boarding, sheet piling, gabion baskets/mattresses, concrete reinforcement
Plastics (new)	Sheet piles, geotextiles, gabion baskets/mattresses
Plastics (recycled)	Sheet piles, piles, toe boarding, decking
Rubber (reused tyres)	Bank protection

Fluvial construction is concerned mainly with preventing or reducing the risk of flooding to low-lying land and in the provision of river control structures, such as weirs and spillways. It is also concerned with river diversions for road or other development schemes and leisure interests, such as canal or lock restoration. River protection work (i.e. erosion protection) tends to be on a much smaller scale than corresponding coast protection works. Commonly occurring fluvial structures and their associated main construction materials are summarised in Table 1.2.

The principal materials covered in this manual include: rock, timber, concrete, steel, aggregates, recycled plastic and rubber.

1.4. OBJECTIVES OF THE MANUAL

The principal objectives of this manual are as follows.

1. *Provide guidance to the UK coastal and fluvial construction industry on the sources of information to allow assessment of the relative total impact on the environment of 'first-use' material selection.*

   The manual aims to heighten awareness of the range of issues to be considered when selecting construction materials. The manual also draws together existing knowledge, experience and research to produce both guidance and future protocol on the decision-making process with regard to material selection for coastal and fluvial construction works.

2. *To provide a recommended comparative analysis mechanism for assessing the environmental impacts of 'first-use' material selection.*

   A wide range of techniques has been developed to assess the total environmental impacts of materials and construction. These include Life Cycle Assessment and Embodied Energy Analysis. These techniques have traditionally been applied to buildings.

   This manual summarises available information sources, best practice techniques and assesses whether these techniques are applicable to coastal and fluvial construction. Methods such as the calculation of Ecopoints as developed by the BRE are investigated and a spreadsheet tool utilising Ecopoints for comparing the environmental impacts of different design options at the project appraisal stage has been developed.

3. *To assess the current use of recycled and recyclable materials, the potential for using recycled and recyclable materials and compare these (in terms of the overall impact to the environment) to their 'first-use' alternatives.*

   The manual reviews the opportunities to use recyclable and recycled materials in coastal and fluvial construction and particularly emphasises alternatives to 'first-use' unsustainable materials.

4. *To summarise a range of case studies where environmental issues relating to material selection have been considered.*
   Case studies are presented throughout the manual illustrating where a sustainable policy in the selection of materials has been adopted or where materials have been recycled or reused.

5. *To provide a draft policy statement for use by the Environment Agency or Maritime Local Authority.*
   A generic draft policy statement, which could be used or adapted by flood defence and coast protection authorities, on material selection is included in Box 1.1.

Box 1.1. Draft policy statement on material selection for use by flood defence and coast protection authorities

The Environment Agency/Local Council will adopt an approach to material selection that:

- promotes sustainable practices and takes due account of environmental impacts
- will be applied in a consistent manner
- will have regard to costs and benefits in relation to the environmental impacts identified
- is as clear, simple and transparent as possible, to the designer, contractor and material supplier
- is appropriate for the businesses involved, harnessing the profit objective of each business but serving environmental and sustainable development objectives
- sets a clear framework of objectives for the designer, contractor and material supplier to meet
- is delivered by competent staff with an understanding of the issues involved.

1.5. READERSHIP OF THE MANUAL

This manual is aimed at a wide readership. It is designed to serve and inform the needs of clients, project funders (e.g. MAFF, Environment Agency, local authorities and internal drainage boards), consulting engineers, contractors, material suppliers, environmental bodies, environmental staff and others interested in coastal and fluvial construction. It is intended that the manual be suitable for both the specialist and non-specialist and, as such, a certain amount of general information is included. It does not consider fluvial structures, such as bridges or dams, although many of the concepts and practices detailed within this manual are equally applicable to the construction of such structures.

Clients and project funders will find useful information included on how to:

- assess design options, starting at the feasibility stage, to minimise the total environmental impact
- encourage the reduction of resource wastage and increase the use of recycled and secondary materials.

Contractors will find useful information included on how to:

- minimise resource wastage within fluvial and coastal construction
- increase knowledge on the availability and suitability of recycled and secondary use materials within fluvial and coastal construction.

Designers will find useful information included on how to:

- assess design options at the feasibility stage
- identify and eliminate high environmental impact material elements of the design
- identify alternative material options to the use of 'first-use' materials
- optimise the reduction, reuse and recycling potential of 'first-use' and non-sustainable materials.

Environmental consultees (EIA teams) will find useful information on:

- environmental impacts throughout the life cycles of the materials used in coastal and fluvial construction
- methods for comparing the environmental impacts of different project options that compliment the environmental impact assessment (EIA) process.

Environmental bodies will find useful information on:

- the challenges facing the coastal or fluvial engineer when trying to manage construction in a sustainable way.

Most of the issues discussed and the current practice and policy described in this manual relate to practice within the United Kingdom. However, a large amount of the information is also likely to be applicable to coastal and fluvial construction internationally.

1.6. STRUCTURE AND USE OF THE MANUAL

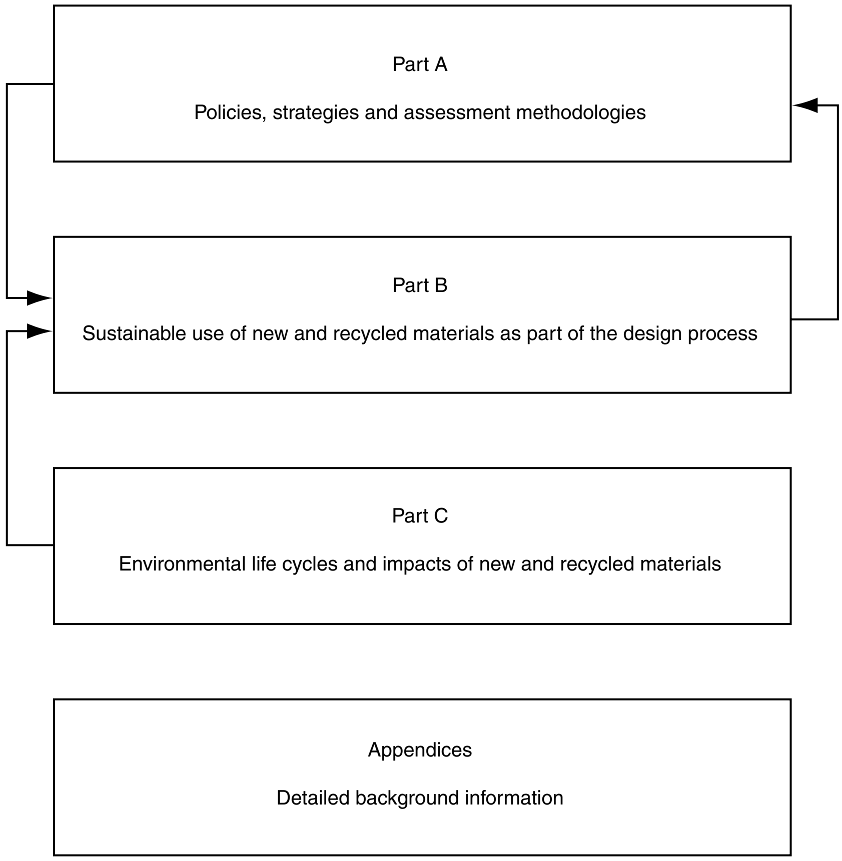
The manual is structured into four main sections. The basic elements of each section are outlined in Box 1.2.

Part A

Chapter 2 introduces the environmental policies and strategies in place at the European and national level that influence material selection. The chapter outlines the concept of sustainable development within the context of various current government and industry initiatives within the construction industry. These initiatives are primarily coordinated by the Department of the Environment, Transport and the Regions (DETR).

Chapter 3 introduces the concept of Life Cycle Assessment. It provides a brief introduction to the theory of Life Cycle Assessment and to sources where further

Box 1.2. Structure of the manual



information can be obtained. The chapter also touches on other concepts such as Embodied Energy Analysis and Design for the Environment that may also be of use to the construction industry.

Part B

Chapter 4 describes the design process and discusses ways of incorporating reuse and recycling into that process. Case studies that highlight some of the difficulties associated with reuse and recycling in engineering projects are presented later in the chapter. Chapter 4 also introduces the work of the BRE in developing a methodology for asssessing the environmental impacts of building materials. The methodology used by the BRE to generate Ecopoints is investigated and a spreadsheet for estimating the environmental impacts of different project options, as developed by HR Wallingford and the BRE, is described.

Part C

Chapter 5 summarises the environmental impacts of each stage of the life cycle of the principal materials used, or available for use, in coastal and fluvial construction. The materials looked at in this chapter include rock, timber, aggregate, concrete, steel, recycled plastic and rubber. The life-cycle stages of each material are categorised in the following way: raw materials and extraction, transport to processing facility, production and processing, transport to construction site, construction, use and maintenance, and reuse, recycling and disposal.

Case studies highlighting specific uses for each material are presented with particular emphasis on reuse and recycling.

Appendices

Appendices contain detailed information on the following:

- the role of the organisations responsible for flood and coastal defence
- international standards and initiatives aimed at improving environmental performance and sustainability
- Life Cycle Assessment
- Embodied Energy Analysis
- a description of the simplified tools used within Design for the Environment
- using the Ecopoints estimator spreadsheet.

Part A

Policies, strategies and assessment methodologies

Policies and strategies for achieving sustainable development

2

2. *Policies and strategies for achieving sustainable development*

The growing international concern regarding sustainable development as part of government policy culminated in the UN Conference on Environmental Development (the 'Earth Summit') held in Rio de Janeiro in 1992. At the Earth Summit, 150 states, including the UK, made a commitment to the production of a national strategy on sustainable development.

Information on international standards and initiatives with respect to sustainable development and environmental management issues can be found in Appendix 2. This chapter summarises the concept of sustainable development and describes the policies that have been implemented at both the European and at the national level. This discussion leads to a description of the policies and strategies of the organisations responsible for construction of flood and coastal defence in the UK.

2.1. SUSTAINABLE DEVELOPMENT

In May 1999 the Government published *A better quality of life: a strategy for sustainable development for the United Kingdom* (DETR, 1999). At the heart of sustainable development is the simple idea of ensuring a better quality of life for everyone, now and for generations to come. It means a more inclusive society in which the benefits of increased economic prosperity are widely shared, with less pollution and less wasteful use of natural resources. Sustainable development matters because the need for growth is as great as ever, especially in the developing world. However, the environment is struggling to cope with current levels of consumption. We have to find new ways of meeting people's needs, expectations and aspirations to ensure that our economy, our society and our environment grow and develop in harmony. The construction industry has a huge contribution to make to our quality of life. Construction, building materials and associated professional services account for some 10% of gross domestic product and provide employment for around some 1·5 million people. The economic, social and environmental benefits that can flow from a more efficient and sustainable construction industry are potentially immense.

2.2. THE EUROPEAN UNION STRATEGY FOR SUSTAINABLE DEVELOPMENT

'Towards sustainability', better known as The Fifth EC Environmental Action Programme, was approved by the governments of the Member States on 1 February 1993. The programme sets longer term objectives and focuses on a more global approach with the main features of sustainability identified as:

- to maintain the overall quality of life
- to maintain continuing access to natural resources
- to avoid lasting environmental damage
- to consider as sustainable a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The strategy covers the following areas.

Target sectors
- Industry
- Energy Sector
- Transport
- Agriculture
- Tourism

Themes and targets
- Climatic change
- Acidification and air quality
- Urban environment
- Coastal zones
- Waste management
- Management of water resources
- Protection of nature and bio-diversity

Areas of specific attention with respect to risk management
- Industry-related risks
- Nuclear safety and radiation protection
- Civil protection and environmental emergencies

Policy instruments
- Improvements of environmental data
- Scientific research and technological development
- Sectoral and spatial planning
- The economic approach: getting the prices right
- Public information and education
- Professional education and training
- Financial support mechanisms

2.3. SUSTAINABLE CONSTRUCTION

The DETR will shortly be publishing a strategy for sustainable construction. This strategy aims to provide a catalyst for change in construction through the identification of priority areas for action, and indicators and targets to measure progress. The strategy builds on the framework and priorities for sustainable development as set out in *A better quality of life*. Foremost amongst these priorities were:

- more growth not less investment in people and equipment for a competitive economy
- achieving higher growth while reducing pollution and the use of resources
- sharing the benefits of growth more widely and fairly
- improving our towns and cities and protecting the quality of the countryside
- contributing to sustainable development internationally.

The construction industry can contribute to the achievement of these sustainable development aims by:

- being profitable and competitive
- delivering buildings and structures that provide customer satisfaction and value
- respecting and treating its shareholders fairly
- enhancing and protecting the environment, and
- minimising its impact on the consumption of energy and natural resources.

2.4. THE POLICIES OF THE ORGANISATIONS RESPONSIBLE FOR FLOOD AND COASTAL DEFENCE

The policies of MAFF and the Environment Agency on sustainable development with respect to materials usage are summarised below.

2.4.1. Ministry of Agriculture, Fisheries and Food

MAFF's present policy on sustainable development and the use of natural resources within coastal and fluvial defence is stated in two of their published guidance documents.

Code of practice on environmental procedure for flood defence operating authorities (MAFF, 1996) states:

> The sustainability of the sources of all materials specified for construction and maintenance works should be fully considered when developing design solutions. This will include sources of timber, fill materials (including beach recharge) and rock.

Coast Defence and the environment (MAFF, 1993) states:

> Protection, conservation and enhancement of the coastal environment should form an integral part of the project design and should include more detailed consideration of . . .

choice of sources of materials, in order to avoid environmental damage either at the donor or the receiving site or during transport.

2.4.2. The Environment Agency

The Environment Agency published *An Environmental Strategy for the Millennium and beyond* in September 1997 which described how the Agency intended to promote a long term and integrated approach to the management of the environment. Following this a series of 'functional action plans' were produced including one relating to flood defence. The contribution of flood defence to sustainable development is summarised within the action plan as seen in Box 2.1.

Box 2.1. Flood defence: contribution to sustainable development (information supplied by the Environment Agency from 1998)

- Sustainable flood and coastal defence schemes are those that take account of natural processes (and the influence of human activity on them) and of other defences and developments within a river catchment or coastal sediment cell and which avoid, as far as possible, committing future generations to inappropriate options for defence.
- Develop and promote solutions that favour the natural features and function of river catchments and coastal floodplains.
- Take a long-term view on floodplain management, with emphasis on the prevention of flooding problems, rather than cure.
- Seeking solutions that provide lasting benefit through a whole life approach to the provision of flood defence.
- Promote works that benefit flood alleviation and wildlife habitats.
- Provide both flood alleviation and conservation benefits through management of water levels and natural processes.
- Take an integrated approach to management of the environment through working with others.
- Have regard to the economic and social well-being of local communities in rural areas.

In September 1998, the Environment Agency published its response to the government's consultation paper *Opportunities for change: Consultation paper on a UK strategy for sustainable construction*. This document, entitled *Opportunities for change: The Environment Agency's response to the Government Consultation Paper on a UK strategy for sustainable construction* (Environment Agency, 1998) outlined the position of the Environment Agency on many key issues associated with sustainable construction.

In addition to the above, the Environment Agency has recently produced a policy document for the evaluation of tenders using a quality price model. A weighting of 10% has been given to environmental considerations and it is hoped that this will encourage contractors and consultants to think through environmental and sustainability issues as part of the tender process (see Chapter 4).

2.5. INTERNATIONAL STANDARDS AND ECO-AUDITING SCHEMES

There are several international standards and initiatives designed at improving environmental performance and sustainability. These include:

- ISO 14000 series of Environmental Standards
- Eco-management and audit schemes (EMAS).

These are discussed in Appendix 2.

Methods for assessing life-cycle impacts

3

3. *Methods for assessing life-cycle impacts*

Chapter 2 has introduced and outlined sustainable development and its role within current European and UK governmental policies. The following chapter introduces some of the general methodologies and concepts used to assess and minimise the environmental burdens associated with the life cycle of a particular product, material, structure or service.

The main aim of this chapter is to provide a very general introduction to the subject, focussing on the concepts, tools and policies that are most relevant to the construction industry. Much of the chapter is devoted to Life Cycle Assessment and Embodied Energy Analysis. How they relate to other concepts, such as Design for the Environment, and policy measures, is outlined later in the chapter. Life Cycle Assessment does not include technical, social or economic considerations.

3.1. SUSTAINABLE DEVELOPMENT AND LIFE-CYCLE IMPACTS

Sustainable development includes a wide range of topics covering social, economic and environmental issues. From an environmental perspective, it is concerned with improving the efficiency with which energy is used, materials are extracted from nature and waste is minimised. To apply the principles of sustainable development requires improvements in eco-efficiency throughout the life cycle of a particular product, structure or service.

The life cycle of a product embraces all activities that go into sourcing, using and disposing of that product. Within construction, the typical life cycle consists of a series of stages from extraction of raw materials, design, processing or manufacturing, distribution, construction, use, reuse, recycling and ultimately waste disposal. The relationship between sustainable development and the different concepts, analytical tools and policy instruments associated with the assessment of life-cycle impacts is shown in Figure 3.1

In the design of any product, system or service, life-cycle consideration (or life-cycle engineering) is aimed at supporting better and more informed decisions.

3.2. LIFE CYCLE ASSESSMENT

Life Cycle Assessment (LCA) is concerned with minimising environmental burdens and impacts throughout the entire life cycle of a particular product,

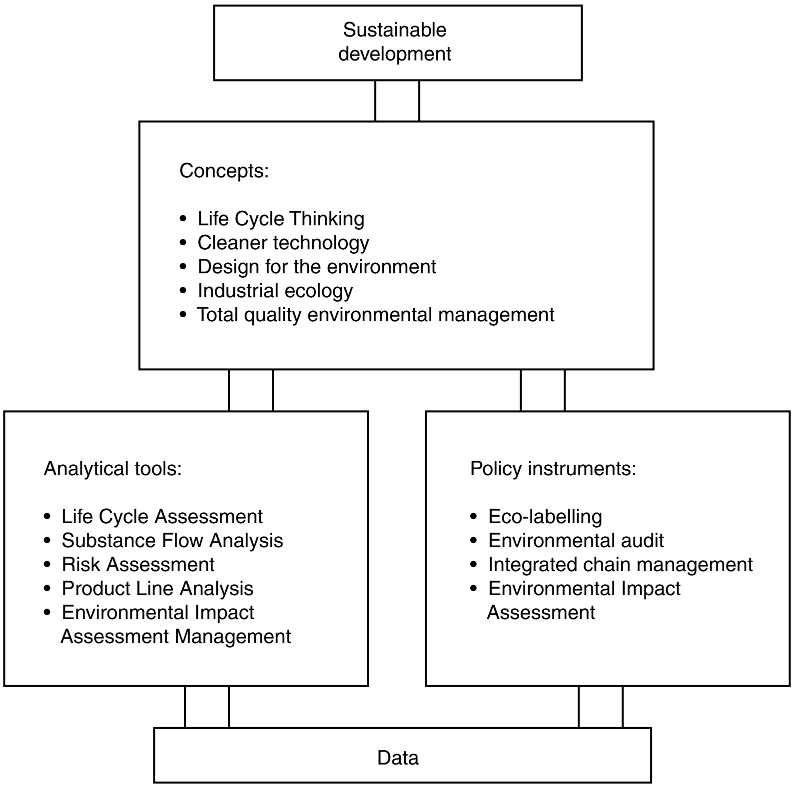


Figure 3.1. The relationship between sustainability, different concepts, analytical tools and policy instruments (Udo de Haes et al.*, 1996)*

material, structure or service. All products have some impact on the environment, the aim is to assess which products use more natural resources, result in more pollution or generate more waste than others.

The two main accepted definitions of LCA are provided by the Society of Environmental Toxicology and Chemistry (SETAC) and by ISO Standard 14040 (see Appendix 2).

SETAC (1991) defines LCA as:

> An objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials used and released to the environment; to identify and evaluate opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal.

ISO 14040 (1997) defines LCA as follows.

> LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by:

- Compiling an inventory of relevant inputs and outputs of a system.
- Evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory and impact phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle to grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences.

The life cycle of a particular product, material, structure or service consists of a range of activities normally shown as a series of stages from raw material extraction and harvesting (the 'cradle'), through processing, fabrication, packaging, distribution, use, possibly reuse or recycling, through to its eventual disposal (the 'grave'). Very few organisations, if any, will be involved in the entire life cycle of a particular product. Life-cycle stages that the product or materials go through before a particular organisation's involvement are referred to as 'upstream' stages, with the stages that follow beyond this organisation's involvement are known as 'downstream'.

All effects that cause environmental problems can be traced back to the particular inputs at each stage of the life cycle of a product (such as water, materials, land and energy) and the resulting outputs generated (air emissions, solid wastes and liquid effluents). The methodology aims to quantify how much energy and raw materials are used up, and how much waste (solid, gaseous, and liquid) is generated at each stage of the product's life. Such a study would normally ignore second generation concerns, such as the materials and energy used to build the manufacturing equipment used to process the raw material.

When conducting an LCA, the basic performance measurement used to normalise the input and output data and compare products, systems or materials is known as the functional unit. The result of an LCA study will define the environmental burdens associated with the functional unit. There are numerous ways of defining a functional unit depending on the goal and scope of the LCA study. It could be defined per unit length of structure, per component type or per unit surface area covered for a specified period.

There are a number of other phrases used to describe either the LCA process or the tools used to assess the process. These include:

- Life Cycle Analysis
- Life Cycle Management (LCM)
- Life Cycle Thinking
- Life Cycle Inventory (LCI)
- Life Cycle Impact Analysis
- Life Cycle Improvement Analysis
- Cradle to Grave Analysis
- Eco-balancing
- Material Flow Analysis.

All describe very similar types of methodologies for assessing environmental impacts.

There is a wealth of information available on LCA techniques, much of it accessible via the Internet. More detailed information on the methodological framework of LCA and different approaches for conducting LCA can be found in Appendix 3.

3.3. EMBODIED ENERGY ANALYSIS

The object of Embodied Energy Analysis is to quantify the energy that is required directly by the process (direct energy) and the energy required to manufacture the inputs of goods and services, particularly those associated with the stages upstream (indirect energy). In the case of construction, direct energy is basically the energy used on site for the assembly (of say a building) and other direct energy used by the construction firm. Indirect energy consists of the energy tied up in the inputs to the construction process (for example the summation of the energy consumed at each stage of a particular materials production).

Much of the research into embodied energy within the construction industry has been targeted at assessing embodied energy in buildings and establishing whether reduced embodied energy at the construction stage is counter-productive leading to higher direct or indirect energy requirements during the buildings design life. Studies in Australia (Tucker *et al*., 1993) have indicated that the embodied energy of the construction industry can be up to a fifth of the national energy consumption in Australia. In the UK, research into the embodied energy in buildings has been conducted by the BRE.

Embodied Energy Analysis can be used as an integral part of a full Life Cycle Assessment or it can be used in isolation depending on the particular requirements of the analysis. When used in isolation it has the disadvantage that it does not consider directly the particular natural resources used, nor the wastes produced at each stage of a particular material or product’s life cycle. Some materials may not have high embodied energy, but may be offensive nevertheless owing to the environmental stress their extraction, production, use or disposal can cause.

In construction, the materials are normally heavy and transportation can be energy intensive. The contribution of transport to the overall environmental impacts of construction materials is discussed in more detail in Section 5.1. Table 3.1 shows a qualitative comparison among different construction materials.

It should be noted that quoted values of embodied energy for different construction materials, usually in GJ/t, should not be compared directly in order to choose one material over another. It is often the case that smaller quantities of materials with a higher embodied energy are required to perform the same function as larger quantities of materials with a lower embodied energy. For this reason, it is preferable to compare the total embodied energy of different structural options rather than the individual materials. Further information is provided in Chapter 4.

Table 3.1. Qualitative comparison of the embodied energy of construction materials

Material	Embodied energy in resourcing, processing and manufacture per tonne of material	Embodied energy in transportation
Concrete	Moderate	Transport distances normally short, limiting energy requirements
Rock and aggregate	Low	Increases rapidly with distance transported
Timber	Low/moderate	Increases rapidly with distance transported
Steel	High	High owing to large distances for transporting raw materials

Note: The numbers on which the assessments are based can be found in Chapter 5.

In the example of a building, an Embodied Energy Analysis requires the quantification of the building materials used (often at a more detailed level than a bill of quantities) and the determination of the energy at all stages for each of these materials. The embodied energy is simply the unit energy intensity of the particular material multiplied by the quantities determined. However, the unit energy intensity should be calculated based on the actual material elements for the particular structure rather than a standard measure (e.g. per tonne of material).

An embodied energy analysis of a process can be considered to have four levels. These are shown in Figure 3.2.

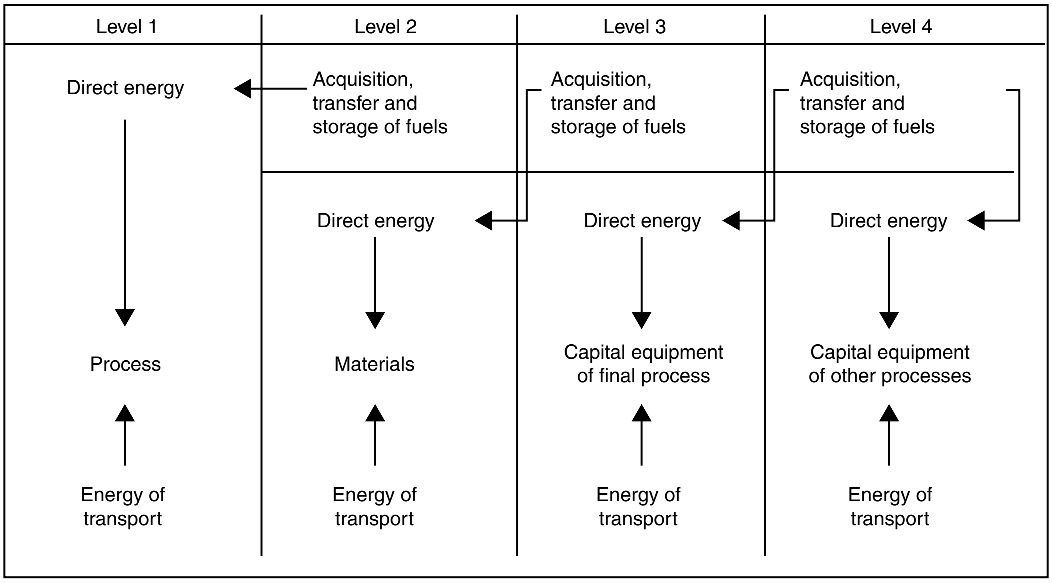


Figure 3.2. Energy analysis vertical levels of completeness (Baird & Chan, 1983)

Table 3.2. Emission factors for converting energy use into CO_2 (NETCEN, 1999)

Energy source	Total upstream and combustion emissions factors: kg CO_2/GJ
Coal	85·2
Natural gas	53·9
Fuel oil	81·0
Burning oil	75·8
Gas oil	76·7
Electricity	150·4

In the embodied energy of construction materials, levels 3 and 4 are of relatively little significance. Such an analysis can be said to be horizontally and/or vertically complete. If all of the direct energy in all of the levels is considered, the analysis can be considered horizontally complete. If all of the indirect energy is assessed, (in a particular level) the analysis for that level can also be considered to be vertically complete.

- Level 1 — The energy consumed directly by the process under consideration.
- Level 2 — The energy required to provide the direct energy sources (i.e. fuels) consumed at the first level and the energy required to provide the materials for the process at level 1.
- Level 3 — The energy required to provide the equipment for the process in level 1.
- Level 4 — The energy required to provide equipment for other processes.

More detailed information on the use and methodological framework of Embodied Energy Analysis can be found in Appendix 4. There is also a wealth of information available over the internet.

Embodied energy values are normally quoted in units of GJ/t. If detailed information on the energy sources is available, these can be converted into a carbon dioxide equivalent using the factors provided in Table 3.2. Carbon dioxide emissions are an important measure of environmental impact owing to concerns over global warming and the fact that governments from developed countries around the world have agreed to reduce greenhouse gas emissions over the coming years.

3.4. DESIGN FOR THE ENVIRONMENT

Design for the Environment (DfE) is about 'integrating environmental considerations systematically into the design of products, processes and services' (Environmental Council, 1997). DfE is a general term covering a number of methodologies but the approaches are very similar to the underlying philosophy of Life Cycle Assessment, considering the entire product (service, material, etc.) cycle, both upstream and downstream.

DfE involves applying Life Cycle Thinking to the key stages of a products life cycle (at the most basic level, as those shown in Figure A3.3) to identify the impacts of that product. DfE methodology was aimed at assisting new product development, particularly at an early stage in the product design. It considers not only the raw materials and energy used, and the wastes released back into the environment but also considers more qualitative aspects. Areas such as the customer's value of the product, the service and needs the product meets and whether these aspects can be provided in a way that has less impact on the environment are also considered.

In the DfE process there are a number of common themes within the design process although the specific principles will differ from one product to another. Box 3.1 gives the common themes that have been summarised by the World Industry Council for the Environment (1994).

The four main types of simplified tools used within DfE are outlined below (The Environment Council, 1997):

- negative checklists
- matrices
- indicators
- pre-defined weighting indices.

A more detailed explanation of each of these tools can be found in Appendix 5.

A comprehensive review of the methodologies used within DfE has been conducted by the Design for the Environment Research Group at Manchester Metropolitan University (de Caluwe, 1997).

3.5. OTHER CONCEPTS AND TOOLS

A wide range of concepts and analytical tools have been developed to assist decision making in environmental management. Many of these tools have been developed for a particular purpose and borrow or combine ideas and methodologies from other similar applications. For this reason, many are not described well and they can be difficult to distinguish from one another. Others, such as Environmental Impact Assessments (EIA) and risk assessment are well established in a wide range of fields. A list and brief description of some of these methodologies is provided by Jensen *et al*. (1997) and includes:

- Life Cycle Management
- Product Stewardship
- Cleaner Production
- Industrial Ecology
- Evaluation of Environmental Performance
- Technology Assessment
- Overall Business Impact Assessment
- Environmental Impact Assessment (EIA)

Box 3.1. Important issues in Design for the Environment (information supplied by the World Industry Council for the Environment from 1994)

Materials selection:

- minimise toxic chemical content
- incorporate recycled and recyclable materials
- use more durable materials
- reduce material usage.

Production impacts:

- reduce process waste
- reduce energy consumption
- reduce the use of toxic chemicals.

Product use:

- energy efficiency
- reduce product emission and waste
- minimise packaging.

Design for recycling and reuse:

- incorporate recyclable materials
- ensure easy disassembly
- reduce materials diversity
- label parts
- simplify products (e.g. number of parts)
- standardise material types.

Extending the useful life of products and components:

- design for remanufacture
- design for upgrades
- make parts accessible to facilitate maintenance and repairs
- incorporate reconditioned parts or subassemblies.

Design for the end of life:

- safe disposal.

- Risk Assessment (RA)
- Substance Flow Analysis (SFA)
- Energy and Material Analysis (EMA)
- Integrated Substance Chain Management (ISCM).

Many of these methodologies have been developed for manufacturing and few (apart from Environmental Impact Assessment and Risk Assessments) are currently used in construction.

3.6. SUMMARY OF THE LINKS BETWEEN LIFE CYCLE ASSESSMENT AND OTHER CONCEPTS AND TOOLS

This chapter has indicated that there are a wide range of both theoretical and practical tools that have been developed to attempt to assess environmental impacts of products, materials or services. Table 3.3 summarises some of the applications and how they relate to Life Cycle Assessment techniques. Information on the different levels of detail in LCAs can be found in Appendix 3.

Table 3.3. Level of detail in some applications of LCA (Jensen et al.*, 1997)*

Application	Level of detail in LCA			Comments
	Conceptual	Simplified	Detailed	
Design for Environment	●	❍		No formal links to LCA
Product development	❍	●		Large variation in sophistication
Product improvement		●		Often based on already existing products
Environmental claims (ISO type II-labelling)	●			Seldom based on LCA
Eco-labelling (ISO type I-labelling)		●		Only criteria development requires an LCA
Environmental declaration (ISO type III labelling)			●	Inventory and/or impact assessment
Organisational marketing		●	❍	Inclusion of LCA in environmental reporting
Strategic planning	●	●		Gradual development of LCA knowledge
Green procurement	❍	●		LCA not as detailed as in Eco-labelling
Deposit/refund schemes		●		Reduced number of parameters in the LCA is often sufficient
Environmental ('Green') taxes		●		Reduced number of parameters in the LCA is often sufficient
Choice between packaging systems	❍		●	Detailed inventory, scope disputed. LCA results not the only information.

Note: ● indicates the most frequently used level.

Part B

Sustainable use of new and recycled materials as part of the design process

Sustainable use of new and recycled materials as part of the design process

4

4. *Sustainable use of new and recycled materials as part of the design process*

4.1. INTEGRATION OF ENVIRONMENTAL SUSTAINABILITY ISSUES INTO THE DESIGN PROCESS

The design process, as shown in Figure 4.1, is a complex and iterative process. The principal stages are described in more detail in Box 4.1.

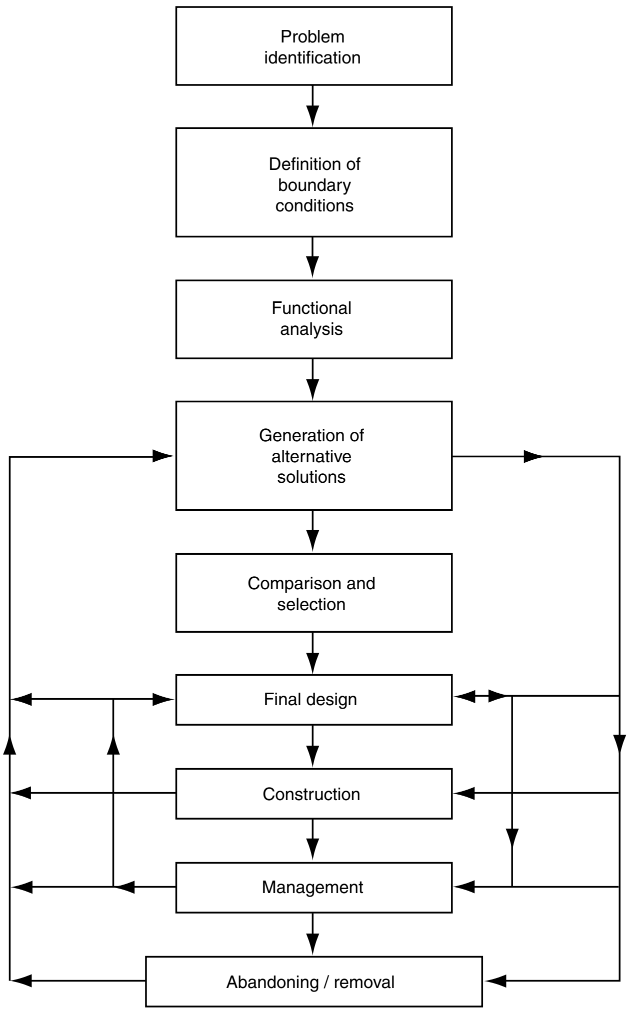


Figure 4.1. The design process (CIRIA, 1991)

Box 4.1. A summary of the principal stages in the design process (CIRIA, 1991)

Problem identification:

- the presence of an existing or future problem is acknowledged and defined
- the decision to find an appropriate solution is made
- boundary conditions that influence the problem and its potential solution are identified.

Functional analysis:

- the functions that the structure has to fulfil in order to remove the stated problem are analysed.

Generation of alternative solutions:

- generation of alternative design concepts to meet the boundary conditions and functional requirements
- the following principal areas are covered:
  - environmental considerations
  - determination of material sources and properties
  - understanding relevant hydraulic and geotechnical processes
  - structure specific design methods
  - construction considerations
  - maintenance considerations.

Comparison and selection:

- comparison of alternatives and selecting preferred options using techniques such as multi-criteria analysis (MCA) or benefit-cost analysis (BCA)
- selection process can include the following:
  - risk assessment during construction and operation
  - comparison with political, social and legislative conditions
  - environmental impact assessment
  - complexity of operation and maintenance relative to local technological experience and resources.

Final design and detailing:

- essentially consists of a series of calculationa and/or model tests to check and adjust as necessary all details of the structure to produce contract documents and a design report
- the design report will generally contain the following components:
  - description of selected structure and selected process
  - materials to be used, reasons for selection and anticipated method of production and transport to site
  - description of how the selected structure meets the functional criteria up to defined limit states
  - probabilities of failure in various hydraulic and geotechnic failure modes, ideally linked by a fault tree
  - construction methods and equipment envisaged
  - description of maintenance strategy agreed with future owner
  - environmental impact statement
  - cost estimates
  - economic benefit-cost justification.

Box 4.2. The three 'Es'

Engineering
The design must be sound technically, be fit for purpose and last for the required lifetime (allowing for any planned replacements).

Economics
The costs of the scheme, both capital and maintenance, must be evaluated over the entire projected life of the project (including maintenance renewals and disruption costs). These costs must be affordable and commensurate with the benefits they deliver, whether those benefits are economic (for nationally funded works) or financial (in terms of privately funded work).

Environment
Here it is commonly understood that the scheme must have an acceptable impact on the environment in which it is constructed. Ideally, the impact (as assessed under the requirements of the EU directives and national legislation) will be positive, e.g. aesthetically, socially and biologically. If negative impacts arise they must be more than balanced by positive impacts and mitigated or compensated for as far as is possible.

The design process involves a great deal of judgement on the part of the designer, as part of which he needs to be continually taking account of and balancing a range of issues. These issues have commonly been summarised as the three 'Es': Engineering, Economics and Environment. These are described further in Box 4.2.

Historically, the view of environmental issues in coastal and fluvial construction has excluded detailed consideration of the environmental sustainability of the materials themselves. This has been changing in recent years under the pressures of environmental lobbies. For example, proper justification has been required for the use of tropical hardwoods in coastal groynes (see Case example 5.1). This section of the manual will enable the engineer to consider the environmental sustainability of materials in a holistic way as part of the design process.

To provide an overview as to how this should be carried out, a flow diagram of the way in which environmental sustainability issues should be integrated within the design process is provided in Figure 4.2. The key issues identified in Figure 4.2 can also be viewed under the following principal headings, many of which need to be reconsidered at each stage of the design process.

4.1.1. *Identification of system 'design unit' and other options*

In order to effect a meaningful and accurate comparison of alternative project options it is essential to identify the functional unit or component of the design for which various material issues can be compared on a like-for-like basis. Examples of such units might comprise of an entire coastal groyne or of a 100 m length of fluvial bank protection or toe-boarding.

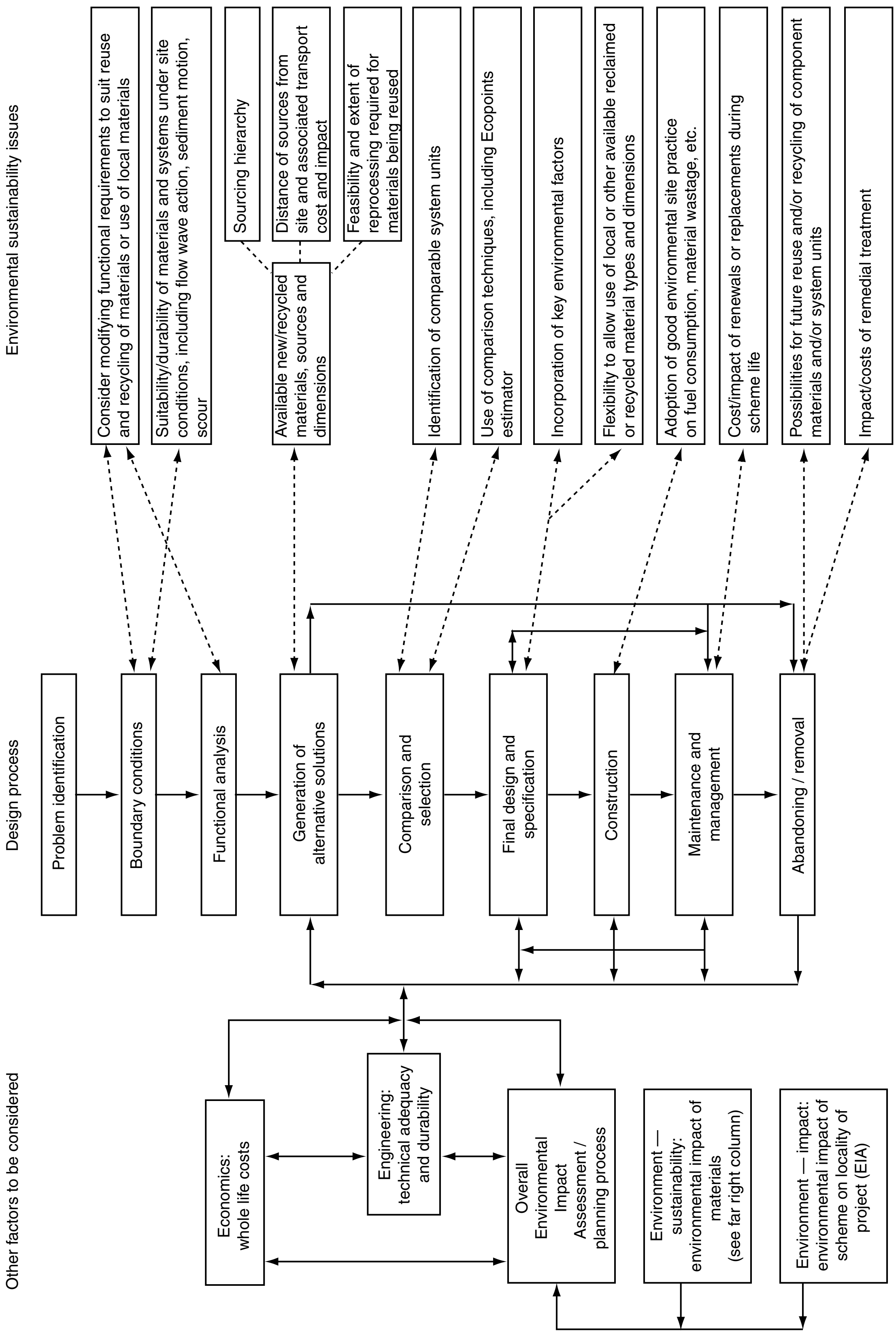


Figure 4.2. Integrating environmental sustainability issues into the design process

Box 4.3. Selecting design options (CIRIA, 1995e)

- Decide on the functional unit to be considered (e.g. the entire structure or a replacement component).
- Identify specific environmental criteria associated with the functional unit (see Chapter 5 and Section 4.5).
- Define the period over which environmental factors need to be considered.
- Consider the possibility of changes in the use of the structure.
- Consider alternative materials that could be used in the structure (see Table 4.1).
- Consider any variations in durability and maintenance arising from the use of these materials (see Chapter 5).
- Consider factors that will prolong the life of the material or structure including detailing, protection and access for maintenance.
- Consider the potential for reusing the materials or component parts of the structure (see Chapter 5).
- Avoid over-design, unless the need for flexibility of use is an overriding criterion.
- Seek specific environmental information on the options considered (see Chapter 5 and Section 4.5).

For each project option it is essential to estimate volumes or quantities of component materials for the identified functional units. While this is routinely carried out by engineers for costing purposes, the same information can also be used directly in environmental sustainability comparisons (e.g. as in the Ecopoints estimator spreadsheet described in Section 4.5).

The significance of volume can be seen by examining the different environmental impacts of the materials given in Part C. For example, the relatively high embodied energy per unit volume associated with steel (rather like its cost) has to be balanced in any assessment against the fact that the quantity of steel required in comparison with its alternatives is generally much smaller. Comparison of alternatives on the basis of quantified system units avoids distortions in the assessments.

Further considerations that should be taken into account in the selection of design options are given in Box 4.3.

4.1.2. Availability and sourcing of material types and dimensions

It is essential that proper consideration is given of the materials and dimensions available for the project, particularly where the reuse of existing materials is being considered. If this does not occur, assessments and comparisons of environmental impacts, like cost, may become distorted.

Initial design solutions should consider, as far as it is possible and practical, in order of preference, the material sourcing hierarchy shown in Box 4.4.

An overview of the range of alternative materials that can be used is given for typical coastal and fluvial structures in Table 4.1. The table is based on current uses of materials both in the UK and overseas.

Box 4.4. Hierarchy of material sourcing options

1. Suitable materials available on-site from a previous scheme or structure.
2. Locally-sourced reclaimed or recycled materials appropriate to fulfil the functions identified in the functional analysis.
3. Reclaimed or recycled materials from further afield that can be delivered to site predominantly by sea or rail or from locally-sourced primary materials.
4. Reclaimed or recycled materials transported from further afield by road or primary materials transported from further afield predominantly by sea or rail.
5. Primary materials transported from further afield by road.

4.1.3. The significance of transport

In the heavy civil engineering associated with coastal and fluvial construction, whatever measure of environmental impact is adopted (e.g. embodied energy, greenhouse gases as a carbon dioxide equivalent or some more complex combination of factors, such as is reflected in the Ecopoints system — see Section 4.5) the impacts of transporting the materials to site from their point of production can dominate the selection process. It is for this reason that the hierarchy of material sourcing options given in Box 4.3 prefers locally available sources to more distant ones.

Impacts at site owing to the incorporation of the materials in the works are relatively small in comparison to the effects from extraction, production and transport upstream. However, if there is significant on-site haulage (e.g. along a beach or fluvial embankment) this should be taken into account.

4.2. REUSE AND RECYCLING: MAKING THE MOST OF OPPORTUNITIES

4.2.1. Reasons for reducing, reusing and recycling waste

Minimising waste through design means avoiding over-specification of materials and services. A coordinated approach to design and construction within the supply chain will encourage designs that better meet client's requirements and that result in less waste. Every design does not have to be a prototype but adopting standardised solutions can help to reduce waste. For example, wastage of the timber formwork used in concrete construction could be reduced by adopting standardised sizes so that it could be reused more easily.

There are two fundamental reasons for reducing, reusing and recycling waste materials. These are as follows:

- the costs of waste disposal and raw material purchase are lowered
- the environmental impacts of the development that the waste comes from are lessened by conserving the raw materials and prolonging the inherent environmental value of the waste.

Table 4.1. Uses of new, reclaimed and recycled materials in coastal and fluvial structures

Structures	Materials																									
	Rock armour	Rip-rap	Rockfill	Tropical hardwood	Treated softwood	Concrete	Steel rebar	Steel piling	Galvanised steel mesh	Plastic mesh	Steel	Dredged aggregate	Quarried aggregate	Geotextile	Asphalt	Rubber	Recycled plastic	Recycled tyres	Reclaimed timber	Recycled aggregate	Reclaimed aggregate	Reclaimed rock	Pulverised fuel ash	ggbs	Willow	Vegetation
Bearing piles				✓		✓		✓									✓		✓							
King/Fender piles				✓	✓			✓									✓		✓							
Seawall*						✓	✓	✓				✓	✓							✓	✓		✓	✓		
Seawall†			✓	✓	✓	✓			✓	✓							✓		✓			✓				
Sheet piling				✓	✓						✓						✓		✓							
Groyne facing				✓	✓												✓		✓							
Breakwaters	✓		✓			✓	✓					✓	✓							✓	✓	✓	✓	✓		
Floating breakwaters†						✓											✓	✓								
Groynes*	✓		✓			✓						✓	✓	✓	✓					✓	✓	✓	✓	✓		
Groynes†			✓	✓	✓	✓			✓	✓				✓			✓		✓							
Wharves and quays						✓	✓	✓			✓	✓	✓		✓					✓	✓	✓	✓	✓		
Hand railings					✓						✓						✓		✓							
Decking					✓	✓											✓		✓							
Revetments*	✓	✓				✓					✓	✓	✓	✓	✓					✓	✓	✓	✓	✓		
Revetments†	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓		
Toe-boarding				✓	✓												✓		✓							
River bank protection*	✓	✓				✓		✓			✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓		
River bank protection†		✓	✓	✓	✓	✓			✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Concrete armour units						✓						✓	✓							✓	✓	✓	✓	✓		
Fenders/camels				✓	✓											✓	✓	✓	✓							
Pipe outfalls	✓		✓	✓		✓			✓	✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓		

* high energy conditions
† moderate energy conditions
Note: See relevant design manuals for guidance on high energy conditions and moderate energy conditions for each type of structure

Box 4.5. The waste hierarchy (adapted from DoE, 1995)

The waste hierarchy means that:

- the most effective environmental solution may often be to *reduce* the generation of waste
- where further reduction is not practicable, products and materials can sometimes be *reused*, either for the same or a different purpose
- failing that, value should be recovered from waste, through *recycling*, composting or energy recovery
- only if none of the above offer an appropriate solution should waste be *disposed* of.

A way with waste (DETR, 1999b) launched in May 1999, is the Government's draft waste strategy for England and Wales. It aims to encourage greater efficiency in resource use based on the principles of the waste hierarchy, as shown in Box 4.5.

Lean design and improved construction processes that enable more efficient material resource use, will help to deliver the strategy's objective. *A way with waste* also proposes the introduction of a programme to promote sustainable waste management and the markets for secondary materials, which could complement other existing best practice programmes. Guidance on greater use of construction and demolition waste and of secondary materials such as colliery spoil, china clay sand, industrial ashes and slag will be included in a revised Minerals Planning Guidance Note 6 (MPG6), which was due to be published by the Government during 2000.

4.2.2. Incorporating reuse and recycling into the design process

As already indicated in the material sourcing option hierarchy in Box 4.4, opportunities for reusing and recycling construction materials and using reclaimed and recycled construction materials should be considered throughout the design process as shown in Figure 4.2. Thus, they will be considered from the generation of alternative solutions through to dismantling and disposal. In this way, environmental impacts can be minimised and the sustainability of construction increased.

In addition to the points raised in the previous section, the following should also be considered. If the identified problem includes the obsolescence of an existing structure, there may be opportunities to reuse the materials from that structure (see Case example 4.1 and Case example 4.2) or incorporate it into the design solution (see Case example 4.3).

If opportunities to incorporate reuse and recycling do not exist or are limited within the context of the initial design solutions, could the functional requirements of the solution be modified in order to make this possible. For example, design life or acceptable scheme performance may be altered in order to incorporate secondary materials in the design.

Perhaps the best way of describing some possible ways in which reuse and recycling options can be incorporated into engineering activities is by example.

Case example 4.1. Attempts to incorporate recycling at every stage of the Whitton Road Autoweir demolition (information courtesy of the Environment Agency, 1999)

A derelict autoweir on the River Crane in Twickenham was to be removed as it no longer served any useful purpose. On removal, the bed was to be reinstated with rock and gravel to provide additional habitat. The derelict autowier and a maintenance footbridge can be seen in Figure 4.3.

For the demolition of the Whitton Road Autoweir, the recycling of materials and parts arising from the site and the use of recycled aggregates for the reinstatement of the site, if at all possible, was specified in the contract documents. Figure 4.4 shows the autowier on completion of the works after removal of the footbridge and reinstatement of the rock and gravel bed.

Around 17 tonnes of rubble was to be produced from the demolition of the control hut. Problems encountered during the works included:

- recycled material for the site reinstatement was not available from the suppliers specified within the contract documents
- some of the mechanical equipment was damaged during removal
- owing to the scale of the job, the quantities involved were small and therefore not practically reusable for other schemes
- some of the mechanical equipment removed was in a poor state of repair and was not suitable for use elsewhere
- insufficient areas were available in the Environment Agency storage yards to store the reclaimed materials until a use could be identified
- despite being advertised on the BRE Materials Information Exchange (see Chapter 7 for details) a use was not found for the reclaimed rubble.

Figure 4.3. Derelict Autoweir, Whitton Road, River Crane before demolition works (courtesy of the Environment Agency)

Figure 4.4. Derelict Autoweir, Whitton Road, River Crane after demolition works and reinstatement of the rock and gravel bed (courtesy of the Environment Agency)

Possible areas for improvement and action were identified as follows:

- better organisation for the storage of reclaimed materials (and mechanical equipment)
- better identification of uses for reclaimed materials (and mechanisms)
- increase the awareness of services such as the BRE Materials Information Exchange
- it may be better to involve local authority recycling schemes with smaller projects
- it may become easier to transport smaller quantities of material to a local recycling collection area as the numbers of recycling stations increases across the UK.

Case example 4.2. Using reclaimed timbers to enhance the walls along Deptford Creek (information courtesy of the Environment Agency, 1999)

A local authority initiative gained single regeneration budget (SRB) funding to enhance the walls along a part of Deptford Creek. The initial idea was to fix timber to existing steel piling and concrete walls in order provide habitats in the intertidal zone. It was felt that reclaimed timber, already weathered, would be ideal.

A wide variety of timbers were collected from old piers and wharves that were being dismantled on the tidal Thames. These were stored in a council yard with a frontage on Deptford Creek. While this work was proceeding, designers prepared cladding designs after consultation with environmentalists.

Tenders were called for and the tenderers were shown the stockpile of reclaimed timber. When the tenders were opened, none of the lowest three tenderers wished to use the available reclaimed timber, and the two highest tenderers only showed minimal savings by using it.

Further discussion showed that, because of a tight timescale and the need to carry out the design before the timber had been identified, the designer had not utilised the available timber sizes in his design. To comply with the design the contractors would have had to reprocess the timber on site which may have proved difficult if the timber was contaminated with metal fixings, etc.

There is further money available in the SRB budget and further lengths of sterile walls to be improved along the creek. The lessons learnt from this project mean that future designs will be based on the timber now available rather than on idealised sizes. The main lesson learnt during this project was not to treat reclaimed timber as a raw material that can be cut and shaped as easily as could be done when specifying new timber.

Case example 4.3. Incorporating an old structure within a new development (information courtesy of Dean & Dyball)

An old dock basin in Southampton was assigned for leisure and residential use in the 1980s. The main steel sheetpiled and masonry walls were suitable for ongoing use after local repairs and no alteration to the plan shape of the basin was necessary. In one corner of the basin a substantial linkspan support structure was going to incur high demolition costs and produce large quantities of waste. After investigating the form and condition of this structure it was decided to incorporate the structure as a support for a building to house the Royal Southampton Yacht Club, and some residential units (see Figure 4.5). Incorporating the linkspan in the design of the building permitted alternative use of the waterfront land, provided an improved position for the building over part of the marina and saved impacts on the environment by avoiding demolition works.

Figure 4.5. Incorporating a harbour structure into an apartment complex

Some examples are provided in Case examples 4.1 – 4.3. It should be noted that reuse and recycling is not without difficulty as is highlighted in Case examples 4.1 and 4.2. These are included in order to present some of the pitfalls encountered in the past and to identify lessons for the future.

4.3. COMPARISON AND SELECTION OF PROJECT OPTIONS AND MATERIALS

A range of possible methods is available for comparing the sustainability and environmental impacts of various design options. Some of these are best used at particular points in the design process. The available tools are summarised here including the Ecopoints estimator spreadsheet developed for this manual. However, it should be appreciated that there are many different environmental impacts from all stages of the life cycle of a construction material. Details for particular materials are given in Chapter 5. It is very difficult to quantify and compare many of these impacts in order to ascertain the overall impact a structure has on the environment. Some impacts, such as the energy used during production and manufacture, are easily quantified but others, such as habitat disturbance and climate change, are more difficult. For example, how should the environmental impacts of two structures be compared when one is constructed from materials that have high impacts from processing and the other relies on materials with minimal processing but has substantial impacts on biodiversity and from transport.

Work is currently being conducted around the world to address this problem and to formulate methodologies for comparing different impacts on a 'level playing field'. Most of these methodologies use a system of weighting factors to convert each environmental impact into a common functional unit. As yet there is no universally accepted method of doing this.

Some of the approaches that have been or are now being adopted are given below. In implementing these methods it should always be borne in mind that designs that incorporate the largest proportion of locally-sourced reclaimed or recycled materials should minimise impacts on the environment.

4.3.1. *Multi-criteria analysis*

Environmental factors can be included in a multi-criteria analysis (MCA) of project options with appropriate weightings on the various scores depending on the perceived importance of the different environmental impacts. An example of the kind of approach that might be adopted is given in Box 4.6.

Care should be taken in the scoring and weighting of the various factors. Although these will be necessarily subjective, a greater degree of objectivity, or at least of public acceptance can be achieved by canvassing opinions as widely as possible.

4.3.2. *Benefit-cost analysis*

Environmental factors can be taken into account in benefit-cost analysis. Environmental scheme impacts or benefits are already considered in this way, often using the Contingent Valuation Method described in Penning-Rowsell *et al.* (1992). The Contingent Valuation Method (CVM) relies on a structured interviewing system to ascertain willingness to pay for a particular scheme or other item. For example, car parking charges at a beauty spot are often used as a measure.

In terms of the environmental impacts of construction materials, it would be necessary to identify an appropriate range of individuals, say professionals, politicians, local members of the public and environmental activists in order to carry out some kind of CVM. If a CVM was being carried out in any event for a project appraisal, an extension to these aspects could easily be considered.

Box 4.6. Multi-criteria analysis (adapted from CIRIA, 1991)

A matrix is constructed with alternative options listed horizontally and the selection criteria listed vertically. An appreciation of each alternative is made with respect to each criterion. The appreciations are expressed as a mark using a predefined scale (e.g. 0, 1, . . . , 10), as shown in the simplified example presented in Table 4.2.

The use of weighting factors improves the method and these should be developed and agreed to by the project management team. A more objective approach is to assign priority to one or all possible pairs of criteria as shown in Table 4.3. For example, by assigning 1 to each dominating criterion, thus leaving the other with 0, weighting factors can be found by adding all of the 1s for each criterion (using 2, 1 and 0 can help where criteria are equally important).

Table 4.2. Simplified example of multi-criteria analysis (weight factors are given in Table 4.3)

		Alternatives					
	Criteria	1	2	3	4	5	Weight
A	Rock volume	2	4	2	1	9	1
B	Environmental impact	6	8	5	3	1	4
C	Construction time	8	1	4	5	2	2
D	Maintenance	9	7	4	2	2	3
E	Risk level	7	2	9	5	5	3
F	Initial cost	7	6	1	5	6	3
	Appreciation	111	82	72	59	56	

Table 4.3. Weight factors for Table 4.2

		A	B	C	D	E	F	
	Criteria	Rock volume	Environmental impact	Construction time	Maintenance	Risk level	Initial cost	Weight
A	Rock volume	–	0	0	1	0	0	1
B	Environmental impact	1	–	1	1	0	1	4
C	Construction time	1	0	–	0	0	1	2
D	Maintenance	0	0	1	–	1	1	3
E	Risk level	1	1	1	0	–	0	3
F	Initial cost	1	0	1	0	1	–	3

4.3.3. *Ecopoints*

The calculation of Ecopoints is a method developed by the BRE to provide a good indication of the relative environmental impacts of different structural options over a range of impact categories. Ecopoints are calculated from the effects on the environment of the extraction, processing and transport components of the life cycle of each material up until the factory gate. The method employed for calculating Ecopoints is explained in further detail in Section 4.4. Ecopoints can be used by the coastal and fluvial engineer through tools such as the Ecopoints estimator spreadsheet, as developed by HR Wallingford and the BRE.

4.3.4. *Specification*

Once the project moves to the stage of detailed specification, it is important to take account of more specific information that may be available. This includes the issues set out in Box 4.7. In all cases, the specification should reflect the material types and dimensions actually available, especially where it is desired to make use of reclaimed materials.

Box 4.7. Selecting source options (CIRIA, 1995e)

Dealing with specific potential impacts:

- identify particular environmental impacts associated with the specific material (see Chapter 5)
- favour manufacturers who can demonstrate particular environmental safeguards concerning these impacts.

Labelling or certification schemes:

- does a labelling or certification scheme exist for the material? (See Section 5.3.1 and Appendix 2)
- what are the criteria for the scheme?
- are there any objections to these criteria within any particular sector of the industry? If so, what is the basis of these objections and do they influence your decision?
- if you are satisfied with the basis of the label or certification scheme, favour materials or products complying with such a label.

Cases where no specific impacts or criteria are identifiable:

- seek reassurances from suppliers that appropriate environmental safeguards are being taken
- enquire whether the company (see Appendix 2):
  - has an environmental policy and whether this is openly available
  - has taken steps to be aware of the potential environmental impacts associated with its production activities
  - is, through an environmental management or similar programme, systematically seeking to reduce these impacts
  - openly publishes information on emissions related to production and compliance with discharge licenses and other regulatory controls.

Further information and more detailed guidance for specifiers can be found in CIRIA (1995e).

4.4. CALCULATING UK ECOPOINTS: METHODOLOGY AND ASSUMPTIONS

This section summarises the development of UK Ecopoints by the BRE. A brief description of the methodology for the Life Cycle Assessment of building materials and the formulation of Environmental Profiles is provided in Section 4.4.1. The full Life Cycle Assessment methodology as developed by the BRE is described in detail by Howard *et al.* (1999). From the work on Environmental Profiles, a weighting system was developed and this enabled the creation of Ecopoints. The weighting system and subsequent derivation of Ecopoints is outlined in Section 4.4.2.

4.4.1. The BRE methodology for Environmental Profiles of construction materials, components and buildings

The Environmental Profiles methodology and database are the result of over 3 years' work in collaboration with representatives of the construction materials sector through a DETR Partners in Technology project. The following organisations participated in the steering group for the project:

- Aluminium Federation
- Brick Development Association
- British Cement Association
- British Lime Association
- British Plastics Federation
- British Non-ferrous Metals Federation
- British Precast Concrete Federation
- British Wood Preserving and Damp-proofing Association
- British Woodworking Federation
- Cementitious Slag Makers Association
- Celotex Ltd
- Clay Pipe Development Association
- Eurisol
- Forestry Commission
- Gypsum Products Development Association
- National Council of Building Materials Producers
- Nickel Development Institute
- Quarry Products Association
- Reinforced Concrete Council
- Steel Construction Institute
- Stone Federation of Great Britain
- Timber Trade Federation
- UK Forest Products Association
- Wood Panel Industries Federation

It was the view of the majority of the members of the steering group that the methodology is a practical, consistent and comprehensive method for the Life Cycle Assessment of all types of building materials and components. International experts in Life Cycle Assessment and building undertook a peer review of the methodology and confirmed that the choices used in the methodology conform with International Standard Organisation Guidelines ISO 14041.

The work has been conducted to enable engineers, architects, specifiers and clients to make informed decisions about construction materials and components, by developing a method for providing independent, 'level playing field' information about the relative environmental impacts of different design options. The BRE believe that the collaboration between UK materials industries and the BRE has resulted in a methodology that is unique and worldwide in its consistent application of the LCA approach.

The work has achieved two significant results:

- an LCA methodology
- a UK national database providing access to Environmental Profiles generated by the industry.

The development of this set of common rules and guidelines for applying LCA to UK construction products enables materials producers in the UK to produce LCA data in the form of Environmental Profiles. An example of the inventory profile format of an approved Environmental Profile is shown in Box 4.8. Environmental Profile conformity with this methodology means that materials users can have confidence in the 'level playing field' status of Environmental Profiles, for every material type.

The methodology, as presented by Howard *et al.* (1999), describes in detail the consistent approach to the identification and assessment of the impacts of all construction materials and components over their life cycle, including:

- standard goal and scope
- inventory data collection procedures
- preferred data sources
- consistent treatment of transport
- calculation of emissions from fuel use
- allocating impacts to products from multiple product lines
- adjusting Environmental Profiles for recycled content
- impact assessment procedures for classification, characterisation and normalisation
- formats for Environmental Profiles.

Environmental Profiles may be calculated for materials, components and building elements. The building elements profiles can be presented 'as built' or over a nominal life. Materials are presented as 'cradle to factory gate' profiles, on a per tonne basis.

Profiles that have been created over the life of the project are held in The UK Database of Environmental Profiles of Construction Materials and Components and are available via an Internet service provided by the BRE (www.bre.co.uk). Materials producers can add new Environmental Profiles for additional products at any time and the database will be regularly updated.

Box 4.8. Inventory profile format: approved Environmental Profile (Howard *et al.*, 1999)

A13 INVENTORY PROFILE FORMAT

APPROVED
ENVIRONMENTAL PROFILE

BRE

Environmental Profile of Inventory Data for:	Manufacture of 1 tonne/1 m^3 [product]

	Quality of data
Start Date	
End Date	
Source of data	e.g. aggregated responses of average data from 5 UK manufacturers
Geography	e.g. UK
Representativeness	e.g. Current practice in UK
LCA methodology	e.g. BRE
Allocation	e.g. 100% to Product
Date of Data entry	
Boundary	e.g. Extraction of Raw Material and production to Factory gate
Comments	

INVENTORY

Inputs		
Materials Input		tonnes
Water Use		m^3
	Water from Water Company	m^3
	Water from Surface Water	m^3
	Water from Ground Water	m^3
Energy Use	Primary Energy	MJ
Outputs		
Product		tonnes
Co-products, by-products, other output for recycling/reuse		tonnes
Emissions to Air		grams
Emissions to Surface Water		
	Water discharged to surface	m^3
	E.g. suspended solids	mg
Emissions to Sewer		
	Water discharged to sewer	mg
Emissions to Land		
	Emissions to landfill	kg
	Emissions to incinerator	kg

4.4.2. UK Ecopoints

Developing weightings of sustainability issues

The BRE has carried out detailed research on the relative weightings of sustainability issues arising from buildings and construction. This research has addressed the economic, environmental and social aspects of sustainability relevant to construction. An additional aim of the study was to establish the degree of consensus on sustainability that exists between different interest groups.

The study sought an analysis methodology that could account for all the disparate issues involved in sustainable development. For example, while investment in building stock can be given a current financial value, the resulting environmental impacts vary considerably in their severity, geography and timescale. The findings provide a sound basis for making the first UK eco-indicator analysis for construction but should be regarded as interim results in the development of our understanding of sustainable construction and in setting priorities for further action.

There are no ‘absolute’ definitions of sustainability or of sustainable construction. In order to establish the range of key issues for sustainable construction to be considered by the weighting exercise, Internet research was conducted using keywords — sustainable development, Agenda 21, UK, construction. Over 19 000 references were identified by the research and sorted by keyword priority order.

The references were used to establish an extensive range of issues. These were placed in three broad themes: economic, environmental and social. Each theme had two or three sub-themes.

The themes, sub-themes and issues shown in Table 4.4 were presented to expert panels for discussion and weighting. The study used panels of professionals from across the industry to assess the sustainability issues, following the lead of the Eco-indicator methods in other countries. The expert panels were constituted by inviting key people from each of the following selected stakeholders to participate:

Table 4.4. Sustainable construction themes, sub-themes and issues

Theme	1. Environmental	2. Economic	3. Social
Sub-theme	1.1 Global 1.2 Local and site 1.3 Internal	2.1 Construction 2.2 Materials 2.3 Infrastructure	3.1 Equity 3.2 Community
Under each sub-theme an extensive range of issues was identified, including:			
Issues	Climate change Resources Internal environment External environment Wildlife	Profitability Employment Productivity Transport and utilities Stock value	Poverty Minorities Inner cities Transport Communications

- government policy makers and researchers
- construction professionals
- construction materials producers and manufacturers
- property and institutional investors
- environmental activists and lobbyists
- local authority policy makers and planners
- academics and researchers.

In all, some 60 participants discussed the issues of sustainable construction, based on a questionnaire presented by the BRE. The participants were then asked to 'spend' 20 points between all the issues. There were more issues than points to force some prioritisation. In a second exercise, participants were asked to score the relative importance of the themes and sub-themes, thus ensuring a test of consistency. A high degree of consistency between responses was apparent when comparing the summary results with the detailed results.

The aggregated results of the panel consultations are shown in Fig 4.6. Each of the expert groups participating is represented by a bar on the graph's x-axis. The final bar shows the average response from all participants. The results are shown as a percentage of the total response from each group; comparing the relative height of segments shows the degree of consensus over the importance of each theme. Analyses of allocation to individual sub-themes and issues are shown in Table 4.5.

There is a consensus between the majority of groups about the overall significance of the main sustainability themes. The aggregate weighting for environmental issues is 40%, for economic issues it is just over 30% and for social issues it is just over 20%. The few results which depart from this average reflect the interests of the groups fairly predictably.

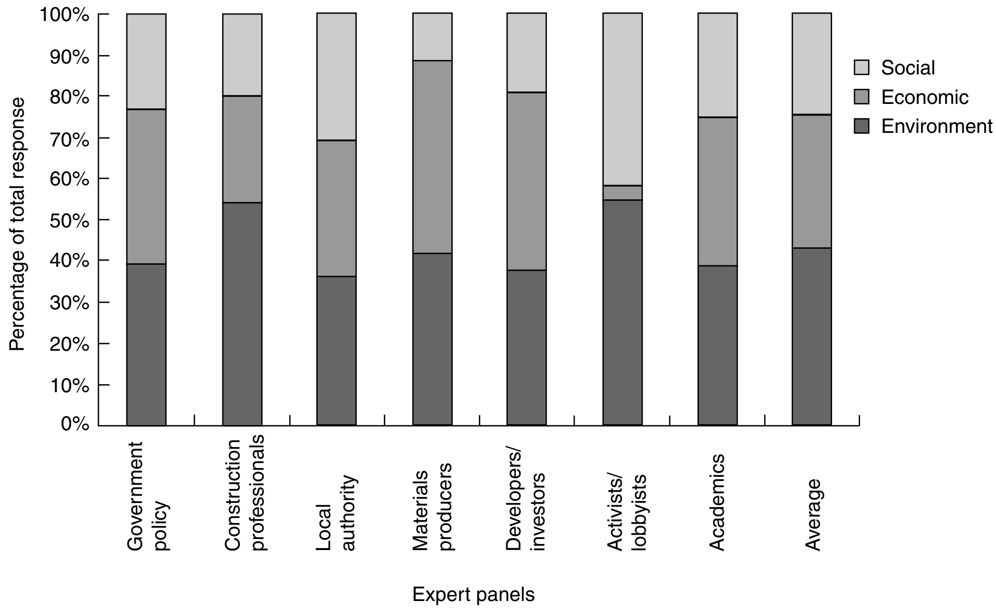


Figure 4.6. Overall weightings from expert panels

Table 4.5. Weightings of sustainability issues

Theme	Sub-theme	Sub-issue		Weighting
Environment: 43·5%	Global issues: 19·9%	Climate change		8·4%
		Acid deposition		1·1%
		Ozone depletion		1·8%
		Toxic air pollution		1·4%
		Fossil fuel depletion		2·0%
		Marine water pollution		1·2%
		Habitats and ecosystems		3·9%
	Local and site issues: 19·8%	Local air pollution		2·6%
		Water pollution		1·7%
		Contaminated land		1·2%
		Noise pollution		1·2%
		Dust pollution		0·2%
		Minerals extraction		0·8%
		Fossil fuel extraction		0·7%
		Water extraction		1·2%
		Waste disposal		1·4%
		Waste recycling		1·8%
		Transport pollution and congestion		3·5%
		Habitats and ecosystems		2·7%
		Forestry		0·6%
		Farming		0·4%
	Internal environment: 3·8%	Health		2·6%
		Comfort		1·2%
Economy: 32·1%	Construction: 13·5%	Profitability		2·3%
		Employment		3·3%
		Productivity		1·4%
		New build		1·2%
		Refurbishment		2·5%
		Maintenance and repair		2·1%
		Overseas competitiveness		0·8%
	Construction materials: 9·4%	Profitability		2·2%
		Employment		2·6%
		Productivity		1·4%
		Product value		2·0%
		Overseas competitiveness		1·2%
	Infrastructure: 4·4%	Energy and water		2·7%
		Telecommunications		1·8%
	Building stock: 4·8%	Stock value	Housing	1·7%
			Industrial	1·4%
			Commercial	1·4%
			Other	0·3%

Table 4.5. continued

Social: 24·4%	Equity: 14·5%	Social exclusion	Affordable housing	1·6%
			Healthy housing	1·6%
			Employment	5·6%
			Security	2·4%
			Education	3·2%
			Worship	0·2%
			Transport	1·0%
	Community: 9·9%	Urban	Identity stewardship	2·6%
			Integration	1·4%
			Consultation	0·7%
		Transport	Cities	1·4%
		Town and rural communications		2·7%

The breakdown of weightings for the environmental issues showed a good level of consensus over the importance of local issues, but quite a large variation in the response on global issues. Local authorities in particular gave less points to the global issues. During discussion it emerged that the participants felt that global issues could only be addressed by local action and that this had influenced their responses.

Academics, government policymakers and developers and investors all gave higher weighting to the internal environmental impacts, probably reflecting their interest in productive, healthy and hence low risk buildings.

Overall, the results show a surprising degree of consensus about the relative importance of different sustainability issues across a broad range of interest groups. Significant departures from the consensus are readily explained by the discussions that took place during the research or by the perspectives of the different groups.

The method used has been successful in determining the consensus within and between groups. Accordingly, the average results are considered to be meaningful for comparisons of the environmental, social and economic themes of sustainability, and for evaluation of the issues within each of these themes. For example, the weightings of environmental issues are the basis for Ecopoints.

Calculating UK Ecopoints

A UK Ecopoint is a single score that measures total environmental impact. It is calculated relative to absolute data on the current state of the environment in the UK and therefore applies to UK activities only. UK Ecopoints are calculated from Life Cycle Assessment inventory data, through four distinct steps:

(*a*) Classification
(*b*) Characterisation
(*c*) Normalisation
(*d*) Weighting.

The BRE's Environmental Profiles LCA methodology produces an inventory of all the inputs and outputs — the environmental burdens — from the product system, according to agreed boundaries.

Classification assigns these burdens to the environmental impact categories where they cause an impact. For example, CO_2 is assigned to 'Global Warming' and SO_2 is assigned to both 'Acidification' and 'Toxicity'.

Characterisation aggregates the environmental impact of each environmental burden in each category. It is necessary to combine components contributing to each issue using a single measurement unit, taking account of their relative potencies. For example, the global warming implications of different gases are converted to kg of CO_2 per 100 yr equivalent (eq.), taking into account their global warming potential and the time they remain in the atmosphere. By being of the same unit, these burdens can then be summed to calculate the total impact in each category.

Units of impact are chosen as a way of measuring the effects of environmental issues on sustainability. For environmental impacts, there is good consensus on the units that are suitable. The units used are shown in Table 4.6.

A brief explanation of some of the units used in Table 4.6 is given below (taken from Howard *et al*., 1999).

- *t CO_2 eq. (100 yr):* the global warming potential (GWP) of greenhouse gases has been calculated by comparing their direct and indirect radiative forcing to the emission of the same mass of CO_2 after 100 years. A timescale is applied to the GWP figure because the GWP of different gases is related to the amount of time that they will spend in the atmosphere and the amount of radiative forcing that they will induce over that period.
- *kg SO_2 eq.:* gases are related to the acidification potential of 1 t of sulphur dioxide (SO_2). The equivalents are calculated by dividing the contribution of protons (H+) to the ecosystem from a compound with the contribution from SO_2.
- *kg CFC11 eq.:* gases are related to the ozone depletion potential of 1 kg of CFC-11.
- *kg.tox:* Heijungs *et al*. (1992) CML method of toxicological weighting factors is used to derive this unit. For human toxicity these are calculated as (human toxicological classification factor) × (kg body weight/kg substance). The factors are based on tolerable concentrations in air, air quality guidelines, tolerable daily intakes and acceptable daily intake.
- *Toe:* this unit reflects the total quantity of fossil fuel energy depleted by consumption. It is measured in tonnes of oil equivalents — (toes) which is a unit of energy.
- *kg PO_4:* phosphate is the unit against which a number of emissions to air and water are measured for their eutrophication or 'nutrification' potential, leading to a loss of biodiversity through over-enrichment of water supplies.
- *kg ethene eq.:* the ozone creation potential of volatile organic compounds are compared to that of ethene.

Table 4.6. Basic UK Ecopoint scores and units

Issues	UK impacts per person	Unit	Weight: %	Basic Ecopoint scores for 1 unit
Global issues				
Climate change	11·4	t CO_2 eq. (100 yr)	19%	1·69
Acid deposition	40·4	kg SO_2 eq.	3%	0·0647
Ozone depletion	30	g CFC11 eq.	4%	0·133
Toxic air pollution:				
human toxicity	117	kg.tox	2%	0·0140
ecotoxicity	1·84	kg.tox	2%	0·891
Fossil fuel depletion	3·35	Toe	5%	1·36
Marine water pollution:				
ecotoxicity	0·40	kg.tox	1%	2·22
eutrophication	4·36	kg PO_4 eq.	1%	0·204
Habitats and ecosystems:				
land	No data available	ha.species	5%	No data available
river		ha.species		
Local issues				
Air pollution:				
human toxicity	1·18	kg.tox	2%	0·475
ecotoxicity	0·03	kg.tox	2%	52·2
asthma	19·8	kg.ethene eq.	2%	0·0991
River water pollution:				
human toxicity	0·03	kg.tox	1%	49·8
ecotoxicity	0·34	kg.tox	1%	3·87
eutrophication	2·40	kg.tox	1%	0·549
Contaminated land	1·62	ha	3%	1·66
Noise pollution	204	person.days > 55 dBaeq (24 h)	3%	5·01
Dust pollution:				
black smoke	23·1	kg.tox	1%	0·0226
Minerals extraction	5·74	t	2%	0·309
Fossil fuel depletion	3·35	Toe	2%	0·469
Water extraction	349	Litre	3%	7·95
Waste disposal	7·06	t	3%	0·446
Waste recycling	7·06	Mt	4%	0·573
Transport pollution and congestion:				
people	12·0	000s person.km	4%	1·03
freight	3·89	000s t.km	4%	0·335
Habitats and ecosystems	5·06	ha.species	8%	1·65
Forestry	Included in above	ha.species	1%	N/A
Farming			1%	N/A
Internal				
Comfort	No data available	N/A	6%	N/A
Health		N/A	3%	N/A

Table 4.6 shows the UK impacts per person (the basis for normalisation) and the dimensionless weightings for the environmental issues (which sum to 100). The Ecopoint scores for 1 unit are calculated by dividing the weight by the UK per person impact, e.g. the 11.4 t of t CO_2 eq. (100 yr) emitted per UK citizen are given a weighting of 19%, so 1 t CO_2 eq. (100 yr) gets 1·69 Ecopoints (19/11·4 = 1·69).

Normalisation compares characterised impacts to a defined norm, for example, the UK Ecopoints compare to the impacts of one UK citizen — hence the relation to the UK. National statistics have been used to derive the data needed as a basis for normalisation. These figures are updated as further statistics become available. The weightings will also be updated by ongoing research.

The Environmental Profile project (described in Section 4.4.1) stopped before this point but subsequently *weighting* has been added in order to achieve Ecopoints. The weighting step multiplies the normalised score in each environmental impact category by the weighting assigned to that category as follows:

$$\text{Ecopoint} = \frac{\text{Impact in appropriate units}}{\text{1 UK citizen's impact in the same units}} \times \text{weight (\%)}$$

The weight is the product of the BREs sustainability weighting research. The UK Ecopoints are derived by adding together the points calculated for each environmental issue. The normalisation process is aligned so that *the total number of Ecopoints for all the impacts arising from a UK citizen in a year amounts to 100* (in the same way that the Celsius scale is aligned with 100 degrees as the boiling point of water). *Higher Ecopoints represent greater environmental impact.* A simplified example of an Ecopoint calculation is given in Box 4.9.

4.5. COMPARING PROJECT OPTIONS USING THE ECOPOINTS ESTIMATOR SPREADSHEET

In order to illustrate the use of the Ecopoints estimator the following hypothetical example based upon real solutions, has been prepared:

Box 4.9. An example of an Ecopoint calculation

Calculating Ecopoints for 10 t km/s of HGV transport

To calculate the Ecopoint score for 10 t km/s of HGV transport we must first determine the inventory of resource consumption and emissions that it produces. The inventory records quantities in the units shown in Table 4.6. For example, 10 t km/s of HGV transport result in 0·76 kg of CO_2 eq., 0·0074 kg of SO_2 eq. and so on. We can then multiply each quantity by the corresponding weight and sum the results to show the Ecopoints score for the 10 t km/s of HGV transport.

4.5.1. Fluvial example

A 100 m length of bank on the outside bend of a river in Staines is eroding rapidly, and if nothing is done a road and buildings will be in danger of collapsing into the river. The local authority, as the riparian owner, therefore wishes to consider options for bank protection. Unfortunately, budget cuts have meant that it is now too late to consider a protected sloping bank, as there is insufficient space left for this option. A vertical or near-vertical 2 m high retaining wall is therefore required. This will have to be constructed around the bend, conforming to the existing bankline, which is not on a constant radius, and must allow for future bed scour.

The local authority wishes to consider the environmental impact of each scheme, as well as the costs, aesthetics, buildability, and construction impacts. Six options were considered, and scored using the Ecopoints estimator spreadsheet. The quantities of materials required for each scheme are shown in Table 4.7. Table 4.8 shows the resulting Ecopoints scores from inputting the estimated quantities, transport distances and methods into the spreadsheet.

A brief description of each scheme is provided below but it should be stressed that dimensions have not been derived from detailed designs and thus comparisons are indicative only.

Each option provides the same level of functionality and it is assumed that no component of each option requires replacing during the design life of the scheme.

Option 1 — steel piling with a capping beam

Cantilevered piling, using 7 m lengths of LX12 section piles at 63·9 kg/m, of nominal width 600 m. Total weight 74·7 t, transported by road a distance of 325 km.

Capping beam of reinforced concrete, 400 mm × 400 mm, total volume of concrete 16 m^3, delivered from a ready-mix plant sited 15 km from the site.

Reinforcing steel for the capping beam, say 0·5% of concrete cross-sectional area, i.e. 800 mm^2 (includes transverse links) also transported by road a distance of 325 km.

A quantity of timber, say 2 m^3 in total, will be used for strutting and strengthening the shuttering. Option 1 is shown diagrammatically in Figure 4.7.

Option 2 — precast concrete retaining wall

Precast concrete inverted Tee section wall units, with top of the toes set 0·5 m below bed level and made with high-precision reusable moulds, and high strength concrete. Sections come in 1 m lengths and weigh 2·8 t each. They are delivered by road a distance of 295 km.

This wall will be laid on a base of blinding concrete, total volume 25 m^3, obtained from the ready-mix plant 15 km from the site. Option 2 is shown diagrammatically in Figure 4.8.

Option 3 — in-situ concrete retaining wall

A similar option to option 2, but using in-situ methods. The wall has a larger sectional area, as the quality control of in-situ concrete is not as good as in a factory. The in-situ wall therefore has a weight of 4·7 t per m length and the concrete is supplied from the plant 15 km from the site.

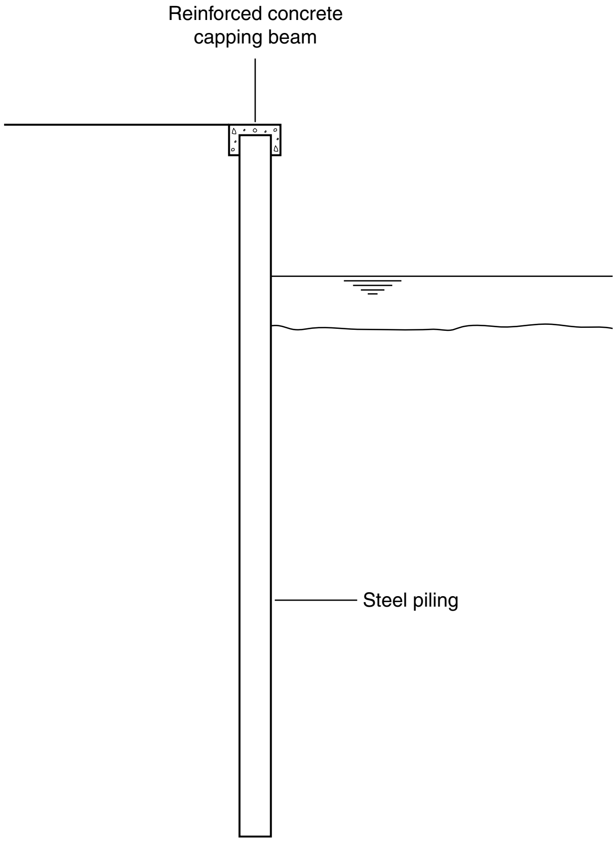


Figure 4.7. Steel piling with a capping beam

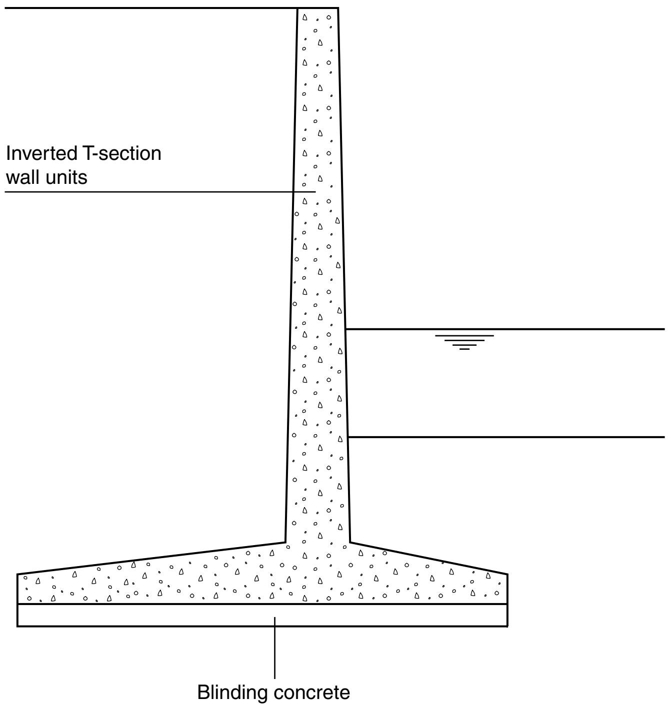


Figure 4.8. Precast concrete retaining wall

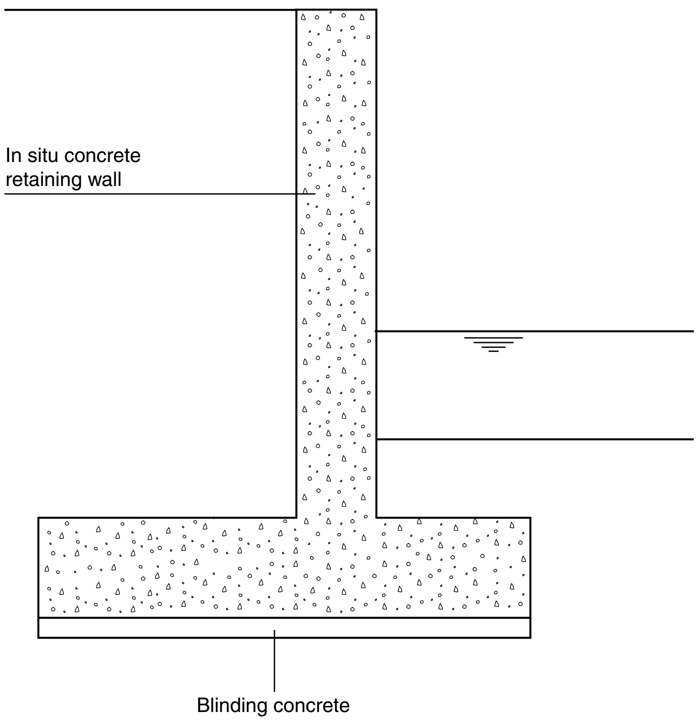


Figure 4.9. In-situ concrete retaining wall

8 m^3 of timber will be required for bracing, strutting and strengthening the formwork.

This wall will be laid on a base of blinding concrete, total volume 25 m^3, obtained from the ready-mix plant 15 km from the site. Option 3 is shown diagrammatically in Figure 4.9.

Option 4 — box gabion wall

The wall is laid on a 3 m wide Reno mattress, 300 mm thick, that is placed 0·5 m below bed level, and extends in front of the box gabion wall to provide erosion protection. The wall comprises one row of two 1 m × 1 m box gabions set on the Reno mattress, with one row of single 1 m × 1 m box gabions and one row of 1 m × 0·5 m above that.

The total volume of stone required is 100 m × 4·5 m^2, i.e. 450 m^3. This will be transported by rail from a quarry a distance of 425 km to a railhead 20 km from the site, from where it will be brought to the site by road.

The gabion baskets, weighing 6 t in total, will come by road a distance of 210 km, having being imported by sea a distance of 4800 km. Option 4 is shown diagrammatically in Figure 4.10.

Option 5 — blockstone wall

These are limestone blocks nominally 600 mm × 600 mm section, stacked to form a slightly sloping wall. Four rows were used, the lowest being set at 400 mm below bed level on a layer of blinding concrete.

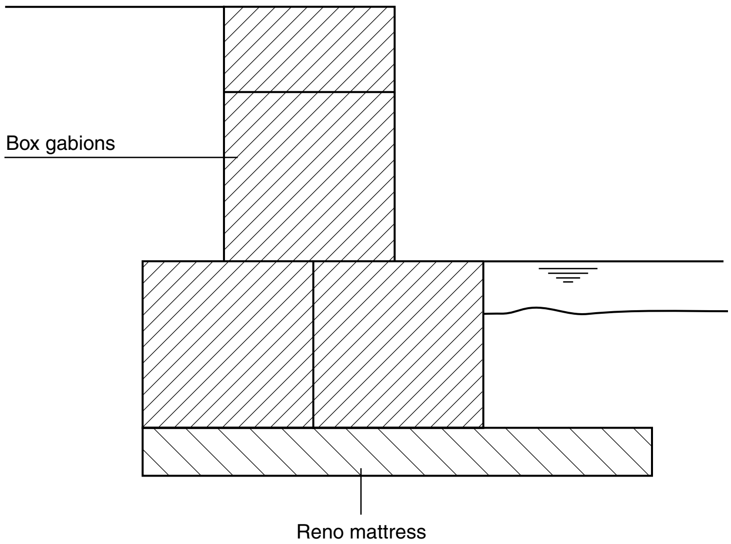


Figure 4.10. Box gabion wall

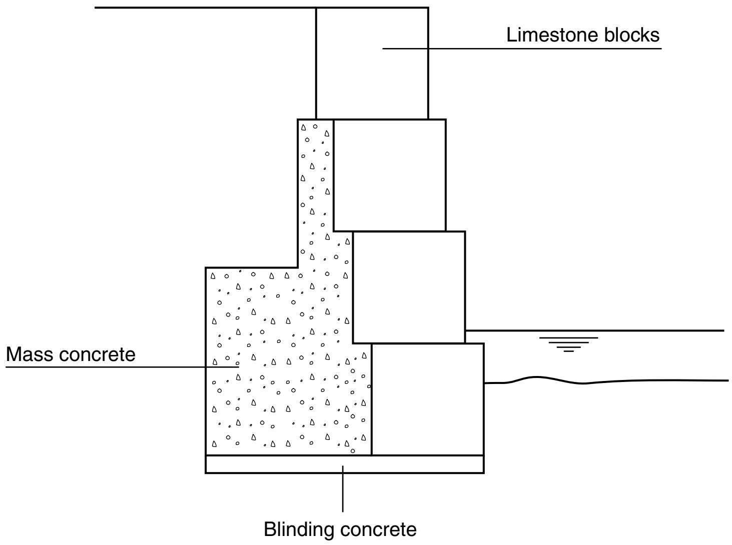


Figure 4.11. Blockstone wall

These blocks are too small to act as retaining walls by themselves, and need additional mass concrete behind them at the lower three levels.

The total weight of blockstone in the wall will be 300 t, transported by road a distance of 175 km. There will also be 100 m^3 of concrete used in this wall, delivered from the ready-mix plant 15 km from the site. Option 5 is shown diagrammatically in Figure 4.11.

Option 6 — H-pile and timber wall

This option comprises steel H-piles, typically 6 m long, and of size 200 mm × 200 mm × 30 kg/m, driven at 2 m centres. Each H-pile is anchored by a ground anchor near its top. Horizontal hardwood timbers, 200 mm nominal thickness, are then slotted between pairs of piles to form a retaining wall. The timbers will extend to 500 mm below existing bed level.

This option would require 9·2 t of steel, brought by road 325 km.

It would also require 50 m^3 of hardwood, imported 6660 km by sea and 70 km by road.

The ground anchors contain little material, but would require specialist plant working on the site to install the anchors. Option 6 is shown diagrammatically in Figure 4.12.

Table 4.7 summarises the material quantities entered into the spreadsheet for each project option.

An example of the input screen of the spreadsheet, showing the values for option 4 (box gabion wall), can be seen in Figure 4.13.

The resulting Ecopoints scores for each option can be seen in Table 4.8.

For the purpose of this example, the following assumptions were made:

- a rigid lorry, of an appropriate size, transported smaller quantities of materials by road
- an articulated lorry of an appropriate size transported larger quantities of materials by road

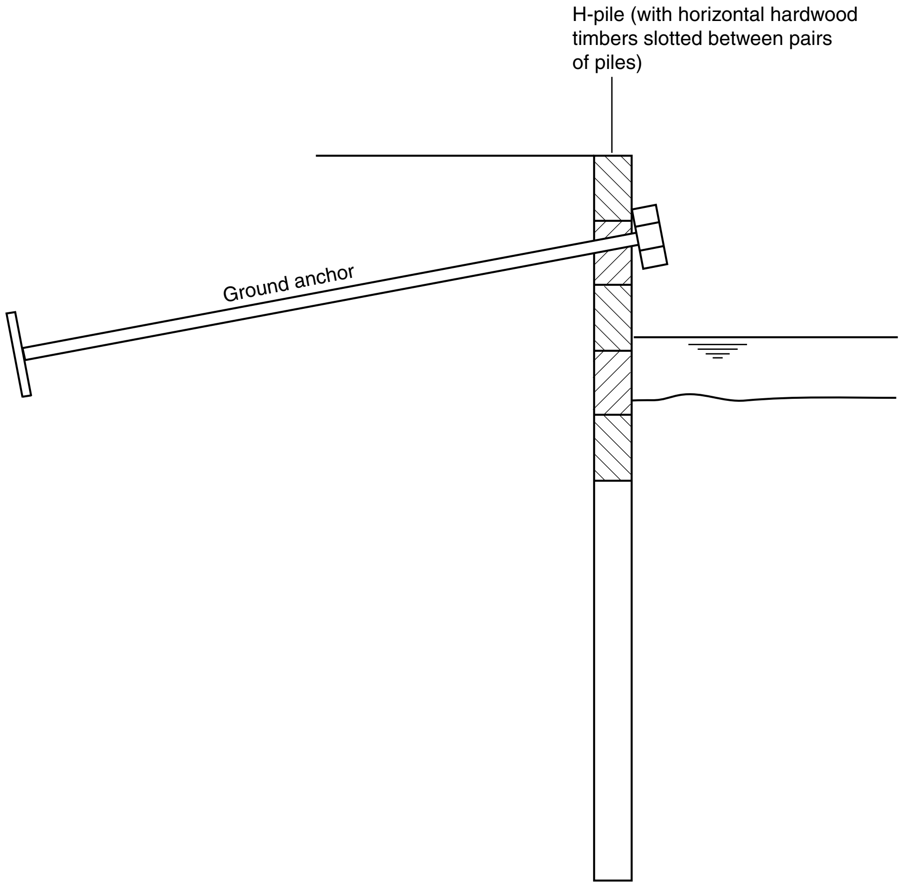
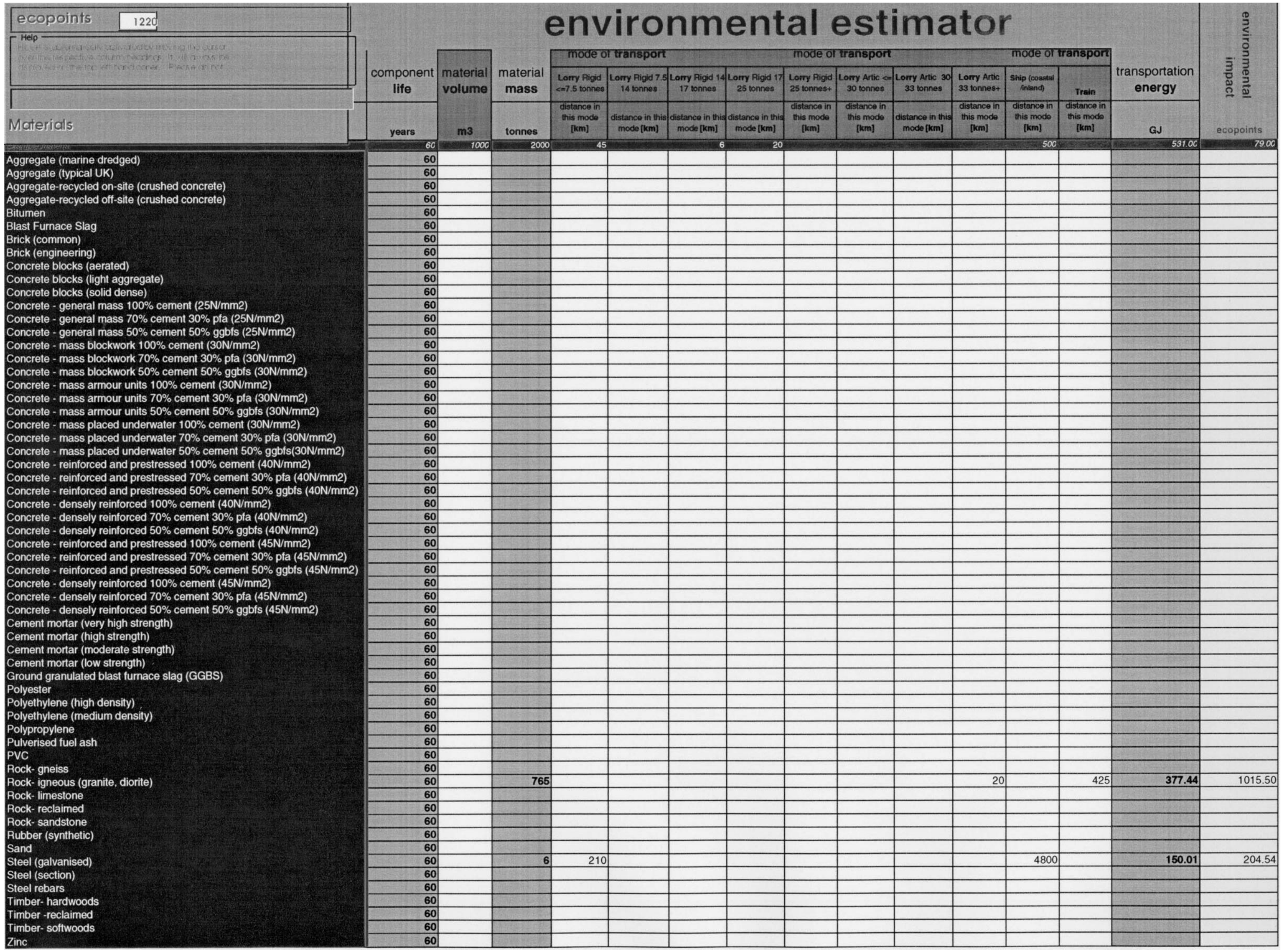


Figure 4.12. H-pile and timber wall



ecopoints 1220

Help

environmental estimator

Materials	component life	material volume	material mass	mode of transport: Lorry Rigid <=7.5 tonnes	Lorry Rigid 7.5 14 tonnes	Lorry Rigid 14 17 tonnes	Lorry Rigid 17 25 tonnes	Lorry Rigid 25 tonnes+	Lorry Artic <= 30 tonnes	Lorry Artic 30 33 tonnes	Lorry Artic 33 tonnes+	Ship (coastal /inland)	Train	transportation energy	environmental impact
	years	m3	tonnes	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	GJ	ecopoints
	60	1000	2000	45		6	20					500		531.00	79.00
Aggregate (marine dredged)	60														
Aggregate (typical UK)	60														
Aggregate-recycled on-site (crushed concrete)	60														
Aggregate-recycled off-site (crushed concrete)	60														
Bitumen	60														
Blast Furnace Slag	60														
Brick (common)	60														
Brick (engineering)	60														
Concrete blocks (aerated)	60														
Concrete blocks (light aggregate)	60														
Concrete blocks (solid dense)	60														
Concrete - general mass 100% cement (25N/mm2)	60														
Concrete - general mass 70% cement 30% pfa (25N/mm2)	60														
Concrete - general mass 50% cement 50% ggbfs (25N/mm2)	60														
Concrete - mass blockwork 100% cement (30N/mm2)	60														
Concrete - mass blockwork 70% cement 30% pfa (30N/mm2)	60														
Concrete - mass blockwork 50% cement 50% ggbfs (30N/mm2)	60														
Concrete - mass armour units 100% cement (30N/mm2)	60														
Concrete - mass armour units 70% cement 30% pfa (30N/mm2)	60														
Concrete - mass armour units 50% cement 50% ggbfs (30N/mm2)	60														
Concrete - mass placed underwater 100% cement (30N/mm2)	60														
Concrete - mass placed underwater 70% cement 30% pfa (30N/mm2)	60														
Concrete - mass placed underwater 50% cement 50% ggbfs(30N/mm2)	60														
Concrete - reinforced and prestressed 100% cement (40N/mm2)	60														
Concrete - reinforced and prestressed 70% cement 30% pfa (40N/mm2)	60														
Concrete - reinforced and prestressed 50% cement 50% ggbfs (40N/mm2)	60														
Concrete - densely reinforced 100% cement (40N/mm2)	60														
Concrete - densely reinforced 70% cement 30% pfa (40N/mm2)	60														
Concrete - densely reinforced 50% cement 50% ggbfs (40N/mm2)	60														
Concrete - reinforced and prestressed 100% cement (45N/mm2)	60														
Concrete - reinforced and prestressed 70% cement 30% pfa (45N/mm2)	60														
Concrete - reinforced and prestressed 50% cement 50% ggbfs (45N/mm2)	60														
Concrete - densely reinforced 100% cement (45N/mm2)	60														
Concrete - densely reinforced 70% cement 30% pfa (45N/mm2)	60														
Concrete - densely reinforced 50% cement 50% ggbfs (45N/mm2)	60														
Cement mortar (very high strength)	60														
Cement mortar (high strength)	60														
Cement mortar (moderate strength)	60														
Cement mortar (low strength)	60														
Ground granulated blast furnace slag (GGBS)	60														
Polyester	60														
Polyethylene (high density)	60														
Polyethylene (medium density)	60														
Polypropylene	60														
Pulverised fuel ash	60														
PVC	60														
Rock- gneiss	60														
Rock- igneous (granite, diorite)	60		765								20		425	377.44	1015.50
Rock- limestone	60														
Rock- reclaimed	60														
Rock- sandstone	60														
Rubber (synthetic)	60														
Sand	60														
Steel (galvanised)	60		6	210								4800		150.01	204.54
Steel (section)	60														
Steel rebars	60														
Timber- hardwoods	60														
Timber -reclaimed	60														
Timber- softwoods	60														
Zinc	60														

Figure 4.13. Example of spreadsheet containing data for option 4 (box gabion wall)

Table 4.7. Quantities of materials for each form of bank protection

		Material									
Scheme option	Retaining wall type	Reinforced concrete: m^3	Softwood timber: m^3	Mass concrete: m^3	Reinforcing steel: t	Structural steel: t	Hardwood timber: m^3	High strength concrete: t	Steel wire: t	Rockfill: t	Limestone blocks: t
1	Steel piling with a capping beam	16	2		0.6	74.7					
2	Precast concrete retaining wall			25				280			
3	In-situ concrete retaining wall		8	25				470			
4	Box gabion wall								6	765	
5	Blockstone wall			100							300
6	H-pile and timber wall					9.2	50				

Table 4.8. Ecopoints scores for alternative project options

Scheme option	Retaining wall type	Ecopoints score
1	Steel piling with a capping beam	1847
2	Precast concrete retaining wall	927
3	In-situ concrete retaining wall	912
4	Box gabion wall	1220
5	Blockstone wall	767
6	H-pile and timber wall	502

66no components would be replaced during the life of the retaining wall (i.e. all options were assumed to satisfy the design life criteria without the need for replacement of component parts)

- timber formwork used during construction was not considered
- in option 4 it was assumed that 1·7 t of rockfill was required per cubic metre of gabion basket volume
- concrete of an appropriate strength was selected for options 1, 2, 3 and 5.

It can be seen from Table 4.8 that the Ecopoints estimator spreadsheet gave the lowest score and thus the least environmental impact for the materials and transport of option 6 and gave the highest score and the greatest environmental impact for the materials and transport of option 1.

The main points of interest arising from this example are summarised below.

- Project options requiring large quantities of bulky materials such as rock have higher Ecopoints scores than project options requiring significantly smaller quantities of less bulky materials such as timber.
- Ecopoints attributable to transport by sea and rail are significantly less than those attributable to transport by road over similar distances.
- Ecopoints attributable to road transport are dependent on the size of lorry used.
- Ecopoints attributable to transport when moving small quantities of materials a long distance by road can form a significant percentage of the overall Ecopoints attributable to that material.

The Ecopoints estimator spreadsheet is a tool that can be used to complement other methods and processes, such as Environmental Impact Assessment, for evaluating the environmental impacts of different project options. It can help to identify specific areas of different project options that can be targeted and modified in order to decrease their impact on the environment. It should be noted that the spreadsheet does not currently take account of all of the possible environmental impacts discussed in Chapter 5. Those not included, as shown by the entries not in italic in Checklists 5.1 – 5.5, should also be considered at the project appraisal stage and efforts to minimise them should be investigated. The spreadsheet is not currently suitable for use in every situation as it does not contain an exhaustive list of material options. It should be regarded as an interim tool to assist in the development of our understanding of sustainable construction.

In project appraisal and tender assessment, authorities may want to include the use of the Ecopoints system in the evaluation process, where applicable, with an appropriate weighting. It may be appropriate for tenderers to use the Ecopoints spreadsheet to assess the environmental impacts of using alternative sources of materials.

This section has described the use of the Ecopoints estimator spreadsheet which can assist the coastal and fluvial engineer in identifying scheme options that have less impact on the environment and are more sustainable. There are additional considerations that should be made for ensuring that the engineering solution adopted has a minimal impact on the environment and is the most sustainable option. Some of these are identified throughout Chapter 4 but a thorough Environmental Impact Assessement should provide the framework for comprehensive consideration of all impacts.

The life cycle of construction materials

5. *The life cycle of construction materials*

Understanding the life cycle of construction materials is an essential part of assessing their total environmental impact. The life cycle of a construction material can be broken down into the following stages:

- raw materials and extraction
- production and processing
- construction, use and maintenance
- reuse and recycling
- disposal.

There is also a transport phase between most of these stages.

The environmental effects from transporting construction materials often comprises a significant proportion of the total impact of those materials on the environment. For this reason, issues relating to transport are discussed at the beginning of this chapter in Section 5.1.

In Sections 5.3 to 5.7, the life cycles of the five primary materials used in coastal and fluvial construction — rock, timber, aggregate, concrete and steel — are reviewed and the associated impacts discussed. Wherever possible, quantitative information has been included in order to provide insight into specific environmental impact areas. In Sections 5.8 and 5.9, the lifecycles of recycled plastic and recycled rubber are discussed from the time that they become waste materials. Section 5.11 summarises the information contained in Sections 5.3 to 5.9 in a series of checklists.

When comparing materials on the basis of their environmental impacts, it is important to understand that the durability of each material over the lifetime of a structure can influence greatly the net impact of that material on the environment.

It is not the aim of this manual to provide full Life Cycle Assessment data for each of the construction materials. It is, however, hoped that the information contained herein will contribute to a more informed decision with respect to material selection in coastal and fluvial engineering projects.

5.1. THE IMPORTANCE OF TRANSPORT

In coastal and fluvial construction, energy use during the working life of a structure is negligible. This means that the energy used during the transport of materials is important as an area to target for reducing environmental impacts.

Transport distances and the mode of transport employed in moving construction materials at each life cycle stage can contribute significantly to the overall impact that materials have on the environment.

The principal environmental impacts from the combustion of fossil fuel during transport include:

- energy use
- carbon dioxide production
- depletion of fossil fuel reserves.

Environmental impacts from transport will be minimised when:

- materials are sourced locally and transport distances are minimised
- transport is by rail or sea rather than road.

Minimising the impacts from transport is important when considering the use of reclaimed or recycled materials as the environmental benefits of using these materials can be compromised if they need to be transported long distances, especially if this is by road.

Estimated levels of energy use for different modes of transport are shown in Table 5.1.

It can be seen from Table 5.1 that there is a significant difference in the energy used by different modes of transport. Transport by road uses around 18 times more energy per t.km than transport by sea.

5.2. ASPHALT

The principal components of asphalt are bitumen and aggregate. The life cycles of bitumen and asphalt are discussed in the following sections. The environmental impacts associated with the life cycle of aggregates will be discussed in Section 5.5.

5.2.1. Raw materials and extraction

Bitumen was originally derived from naturally occurring seepages, notably in Trinidad, but today's bitumen is manufactured from a residue of the distillation process that is part of the modern oil industry.

Table 5.1. Estimated energy use for different modes of transport (West et al.*, 1994)*

Mode of transport	Energy intensity: GJ/t.km
Bulk sea vessel	0·25
Rail	0·60
Road — heavy goods vehicle	4·50

Crude oil is the principal raw material used in the production of bitumen. It is extracted from underground reservoirs situated around the globe, either beneath the land or the sea. To extract the oil, holes are drilled through the surface layers of rock and pipes transport the oil directly to a refinery or storage facility for further transportation.

The principal environmental impacts from the extraction of the raw materials used in bitumen production include:

- nuisance effects from noise and plant at well installations and offshore platforms
- habitat disturbance and removal
- disturbance of ground or seabed
- carbon dioxide emissions from flame stacks and general operating plant
- energy consumption installing and operating wells
- visual impacts
- production of solid waste as a result of drilling operations
- depletion of raw material reserves
- possible uncontrolled flows of oil from wells
- risks from accidental spills.

It should be noted that in the western world, oil companies are required to assess the environmental impacts and licences to extract oil are issued under strict environmental guidelines.

The principal forms of aggregate extraction for use in asphalt include surface extraction for crushed rock and marine dredging for sand. The environmental impacts associated with aggregate extraction are discussed in Section 5.5.1. Aggregate, for use in some asphalts can also be obtained by recycling demolition materials and reusing the waste products of other industries.

5.2.2. *Transport to the processing facility*

Oil refineries are very often located at ports. The crude oil is transported to the refineries either by pipeline or by ship.

5.2.3. *Production and processing*

Bitumen

The first process in the refining of crude oil is fractional distillation. This is carried out in tall steel towers. The lighter fractions of the crude are drawn from the tower at different levels (temperatures) leaving a residue at the bottom that is a complex mixture of high molecular weight hydrocarbons. This residue is further distilled at low pressure to produce the bitumen feedstock.

The principal environmental impacts from the manufacture of bitumen include:

- energy consumption (heating process)
- particulate emissions to air

- small amounts of pollutants such as sulphur and H_2S may escape
- visual impact of large refineries.

Asphalt
Asphalt can be manufactured and placed on site or manufactured off-site and delivered hot. Three distinct types of hydraulic asphalt are produced, depending on the 'degree of filling' of the mix.

(*a*) 'Overfilled' mixes, e.g. Asphaltic mastic, used to strengthen rip-rap and also to fill joints between concrete blocks and stone pitching.
In an overfilled mixture the volume of bitumen is greater than that of the voids in the mineral aggregate. In such a mix the properties of the bitumen predominate, the mineral providing only a certain amount of stiffening. This type of mix is impermeable and requires no compaction.

(*b*) 'Filled' mixes, e.g. Asphaltic concrete, used as impermeable revetment or promenade for coastal defences.
In a filled mixture the voids in the aggregate are almost completely filled with bitumen, and this type of mix is impermeable and must be compacted when placed. Both the stone skeleton and the bitumen contribute to the mix properties.

(*c*) 'Underfilled' mixes, e.g. Open Stone Asphalt, used in layers (100–500 mm thick) for erosion protection armour layers on coastlines, placed above or below water.
In an underfilled mixture the bitumen only serves as a binder, to hold the aggregate together. The properties of such a mix are directly related to the properties of the stone skeleton. The mix is permeable and requires no compaction when placed.

Asphalt is manufactured by mixing dried and heated aggregate with hot bitumen in specific quantities. The mix proportions vary widely depending upon the mix properties required. The most common mixtures are identified in Table 5.2 below.

The principal environmental impacts from the manufacture of asphalt include:

- energy consumption (heating aggregates)
- particulate emissions to air
- noise, dust and fumes owing to plant and aggregate handling.

Table 5.2. Common asphalt mixtures

	Asphaltic Mastic Grout	Asphaltic Concrete	Open Stone Asphalt
Bitumen	15%	7%	4%
Limestone filler (dust)	15%	10%	4%
Sand	45%	12%	12%
Crushed stone	25%	71%	80%

5.2.4. Transport from the processing facility to the construction site

Asphalt or its components are generally transported to the construction site by road. It either arrives hot or it arrives as separate components and is mixed on site. Transport distances vary depending on the availability of the raw materials. Typical energy usage values for each mode of transport are given in Table 5.1.

5.2.5. Construction, use and maintenance

Asphalt has many applications in coastal and fluvial construction. It can be used for underwater scour protection, revetment construction and promenades. Examples of different coastal and fluvial structures containing asphalt are shown in Figures 5.1 – 5.5.

Coastal and fluvial construction involving asphalt has a number of environmental impacts that include the following:

- nuisance effects from noise from mixing, transporting and placing plant
- disruption to the local community from delivery traffic
- carbon dioxide emissions from plant
- energy consumption from plant
- visual impacts both during and after construction
- low amount of excavation spoil due to thinner constructions than for rock or concrete

Figure 5.1. Grouted rock breakwater, New Brighton, The Wirral (courtesy of Hesselberg Hydro 1991 Ltd)

Figure 5.2. Pattern grouted revetment, Megget reservoir, Scotland (courtesy of Hesselberg Hydro 1991 Ltd)

Figure 5.3. Open Stone Asphalt Revetment, Arlington reservoir, Sussex (courtesy of Hesselberg Hydro 1991 Ltd)

- waste material can be minimised as asphalt can be placed to follow contours, on slopes up to 1 in 1·5 and around structures without the need for formwork or cutting of concrete blocks.

Asphaltic structures with an open textured surface can provide areas for the anchorage of algae and crustaceans. They can also provide recreational value for walking and fishing.

Figure 5.4. Floodgrouted revetment, River Thames, Coryton, Essex (courtesy of Hesselberg Hydro 1991 Ltd)

Figure 5.5. Grout around rock to retain natural appearance, Waterloo Lake, Leeds (courtesy of Hesselberg Hydro 1991 Ltd)

When first placed, the black appearance of asphalt is less aesthetically pleasing than natural materials such as rock and timber. However, the surface bitumen is soon abraded to leave the aggregate showing through (see Figure 5.3) and the open texture of Open Stone Asphalt allows vegetation to establish itself over the surface. Grout can be placed around the rock so as to retain the natural appearance of the rock (see Figure 5.5).

Hydraulic asphalt structures are generally perceived as being low maintenance. If the formation on which the asphalt is placed is stable, and the mix is placed at the correct temperature, the main problem a revetment may face is abrasion from gravel on the foreshore. In such areas a harder aggregate can be selected to mitigate this abrasion.

Being a bound, flexible material, asphalt will follow considerable settlements and if the surface is damaged, failure will not be rapidly progressive, as with revetments consisting of individual, loose elements.

Failure of grouted stone can be repaired easily with the replacement of stone followed by more mastic grout. Open Stone Asphalt is more difficult to repair. Small areas can be patched with hot-poured mastic but for larger repair areas the revetment can be replaced or overlaid with a new layer. For the latter, the existing revetment must be cleaned and primed prior to overlaying.

5.2.6. Reuse, recycling and disposal

Much asphalt waste is produced from road replacement and resurfacing across the UK every year. These road plannings can be used as bulk fill or for temporary access roads. There are now increasing opportunities to recycle asphalt by mixing it in with fresh asphalt for roadbase asphalt, but not the wearing course. There have also been recycling trials in connection with revetments (see below).

Hydraulic asphalt can be reused or recycled depending on its classification.

Overfilled mixes, e.g. Asphaltic Mastic

Mastic is either supplied hot in boilers or as solid blocks which are re-heated on site. Any waste from site operations can be easily collected up and placed back in the boiler for reuse.

If a revetment must be replaced, the old mastic can be reused due to the following points.

- The dense nature of the material means it will not generally be contaminated.
- When cold the mastic can be separated from rock relatively easily.
- Air and ultraviolet light cannot penetrate the mix so, apart from on the surface of the mastic, the bitumen will be as fresh as when it was placed.
- The high bitumen content means that when heated the mix returns to a fluid state.

If a different quality mastic is required, additional bitumen or additional aggregate can be added to the recycled material when it is re-heated. A mastic boiler mixes while it heats so a homogenous material will be produced. The crushed stone component of mastic grout serves only to 'bulk-out' the material, reducing the amount of bitumen required, and up to about 30% the stone has very little effect on the mechanical properties of the mix. Therefore, a recycled material such as concrete could be used providing it was single-sized (i.e. no fines) 10 – 15 mm grading.

Filled mixes, e.g. Asphaltic Concrete

Asphaltic concrete is compacted to produce very dense layers (< 3% voids) and can be recycled as follows.

- The dense nature of the material means it will not generally be contaminated.
- It is removed using a standard planing machine or by powerful excavator.
- Before recycling, large lumps (> 20 mm) must be granulated.
- The new asphalt can be recycled in new asphalt in a standard asphalt recycling plant, as is common with road asphalts.
- To reduce fumes associated with re-heating in a drum mixer, the fumes can be burnt off in the burner flame, or alternative heating methods can be adopted (e.g. microwaving).
- Usually 20 – 30% recycled material is added to the fresh material in the production process.

If asphaltic concrete planings are not recycled in new asphalt they can be used for general construction fill or to make temporary access roads.

Underfilled mixes, e.g. Open Stone Asphalt

These materials are very open, porous layers of aggregate (typically 40 mm) coated with mastic to form a bound structure.

The oldest revetments are over 30 years old but still in service so the process of recycling the material is in its infancy. However, small scale trials have taken place and indicate the following.

- The material is placed in layers separated from the formation by a filter layer so it can be removed relatively easily.
- The open structure means that the material is likely to be contaminated throughout with soil, sand, vegetation, etc.
- When reclaimed, the material must first be washed and cleaned to leave just stone and mastic.
- The material must then be granulated to small units and up to clusters of only a few stones.
- This material may then be passed through a conventional recycling facility, or it may be upgraded by recoating it, together with a percentage of new aggregate, with fresh mastic.

5.3. ROCK

5.3.1. Raw materials and extraction

Rock is required for coastal and fluvial engineering in its raw state in varying dimensions. It is used as armour, underlayer and core materials in rubble mound construction. It is also utilised in its crushed state for aggregates in concrete and occasionally as a beach replenishment material or in fluvial bank protection.

Rock used in coastal and fluvial construction projects is quarried either by loosening stone with explosives or, as in dimension stone quarries, by diamond cutting and rotary percussive drilling. An ammonium nitrate/fuel oil mixture combined with high explosive is commonly used to reduce costs. Around a quarter of a kilogram of explosive is typically used for each tonne of rock for the explosive method. A quarry can either be established as a side hill or pit type operation. The sizes and proportions of the rock produced depend on the following factors (CIRIA, 1991):

- geological characteristics of the rock
- method of extraction
- properties and detonation methods of the explosives used
- blast design.

The desired rock material is selected using a number of different methods. These can include passing the blasted material through a series of grids and screens or comparing blasted rocks to example rocks of the desired size. The maximum size of rock and the gradation for larger sizes can vary enormously as a result of each blast but an indication of what may be possible in a quarry blast designed for retrieving larger armour from a competent rock source is given below (Abbott and Price, 1994):

- maximum size 15 t
- stone up to 200 kg — 50% of quarry product
- 200 kg to 1 t — 15% of quarry product
- greater than 5 t — 10% of quarry product.

These yields of large material would be unusual in a typical UK aggregate quarry, where the yield of armour rock greater than 1 t is generally only about 5% due to a combination of geology and blasting technique. However, in dimension stone quarries the very small amount of explosive blasting used ensures a higher yield of the larger rocks. It can be seen that significant quantities of potentially waste material will be generated to produce the required amount of larger rock sizes, unless, as is usually the case, the quarry is crushing the smaller rocks to produce aggregate or the smaller sized material is being used as fill.

In some cases, depending on the location of the works and the local geology, a dedicated new quarry may be opened for a specific scheme. Quantities of the various range of sizes available from such a quarry should be ascertained before the design of the works. This will ensure that where possible, designs are aimed at maximum use of the rock available and therefore minimum waste.

The blasted material is handled using a variety of equipment, including wheeled loaders, hydraulic excavators, grabs and cranes. A hydraulic excavator uses around 23 MJ/t of rock moved. The energy used by the heavy plant, together with that used in the primary blasting, accounts for the majority of energy consumption in the production of rock armour since there is little further processing. For aggregates, further processing is required (see Section 5.5.3).

The principal environmental impacts of quarrying include the following:

- nuisance effects from noise and vibration during blasting and crushing
- habitat disturbance and removal
- disturbance and removal of topsoil
- particulate emissions to air and water
- interruption of ground and surface water flows
- disruption of the local community from delivery traffic
- carbon dioxide emissions from the burning of fossil fuels during extraction
- energy consumption during screening, crushing and drilling
- energy consumption from transporting rock around the quarry
- production of solid waste
- visual impacts.

All quarries in the UK are required to prepare and submit environmental management plans to mitigate these effects as a condition of their planning approval. These plans generally include site rehabilitation on completion of quarrying.

5.3.2. *Transport to the processing facility*

The processing of rock often occurs within the quarry site. Transport to processing facilities outside of the quarry is rare. Rock can be transported around the quarry on trucks ranging in size from 20 to over 80 t. Smaller rocks may be transported on conveyor belts.

5.3.3. *Production and processing*

The processing of quarried rock can involve further splitting, sawing and grinding. The environmental impacts of this stage can include:

- nuisance effects from noise
- energy consumption during processing operations
- carbon dioxide emissions from the burning of fossil fuels during processing
- particulate emissions to air and water.

The overall energy required to win natural rock ranges from around 1·8 GJ/t to as much as 4 GJ/t (Ashby, 1992, CIRIA, 1995a). Higher values are mainly due to high wastage rates.

5.3.4. *Transport from the processing facility to the construction site*

Rock used for coastal defences may either be delivered to the beach by road or by barge, with subsequent unloading and transport to the point of construction by excavators and dumptrucks. As can be seen from the figures in Table 5.1, delivery by barge uses significantly less energy (and also has less CO_2 emissions) than delivery over land by truck.

The technology now exists for armourstone rock to be delivered to coastal sites and tipped almost directly onto the beach or in the location required. Ships designed specifically for the purpose have a small draft enabling access in shallow water. The armourstone is transported in compartments on the ship that can be tipped on arrival at their destination. In this way, excavators, dumptrucks and shovels are not required to unload the ship. As a result, less fossil fuels are burned, less energy is used and there are lower emissions of carbon dioxide. Nearly 40% of armourstone in the UK was delivered in this way in 1998 (Quarry Management, 1999).

Smaller rock, for use in bank protection, is usually delivered to the construction site by road.

5.3.5. *Construction, use and maintenance*

Rock can be used as armourstone in groynes and breakwaters, rip-rap in bank protection, fill in gabions or in the form of dressed blocks in sea-walls and river bank protection. Natural stone can be selected that is resistant to abrasion, chemically inert and free of microcracks. In 1998, the UK demand for armourstone in sea defence works was around 700 000 t (Mine and Quarry, 1999). Examples of different structures containing rock are shown in Figures 5.6 – 5.17.

In locations where rock is scarce or local rock is of relatively poor quality/grading, there is an alternative to importing rock from afar. By combining grout (bituminous or cementitious) with rock, a revetment can be constructed which can withstand waves of up to about 6 m. Generally, a grouted revetment will use approximately 20 – 30% less material (rock and mastic) than an ungrouted one. It should be noted that the grouted rock will still be porous but will result in increased wave run-up, so some additional works may be required at the crest.

During extreme wave attack, all rock revetments will suffer a degree of damage. For a pattern grouted revetment, stones may well be removed but with a very strong grid of grouted stone present, damage will be contained and so the security of a structure can be increased during severe attack.

Coastal and fluvial construction involving rock has a number of environmental impacts. These include the following:

Figure 5.6. Gabion revetment, Brancaster, Norfolk (courtesy of HR Wallingford)

Figure 5.7. Rock armourstone revetment, Arklow, County Wicklow, Ireland (courtesy of HR Wallingford)

Figure 5.8. Gabion groyne and seawall, Hunstanton, North Norfolk (courtesy of HR Wallingford)

Figure 5.9. Gabion river bank protection, Chesil Beach, Portland Harbour (courtesy of HR Wallingford)

Figure 5.10. Placing armourstone in Felpham sea defences (courtesy of Arun District Council)

Figure 5.11. Rock groyne, Pagham Harbour, West Sussex (courtesy of HR Wallingford)

Figure 5.12. Barge delivering armourstone for use in offshore breakwaters, Elmer, West Sussex (courtesy of Arun District Council)

Figure 5.13. Box gabion wall below reno mattress slope protection adjacent to brick clad steel pile weir, Fray's River, Uxbridge (courtesy of the Environment Agency — Thames Region)

Figure 5.14. Coir rolls on stone bank toes, Colne Brook, Uxbridge (courtesy of the Environment Agency — Thames Region)

Figure 5.15. Coir rolls on stone bank toes, Colne Brook, Uxbridge, 12 months later than Figure 5.14 (courtesy of the Environment Agency — Thames Region)

Figure 5.16. Blockstone as a retaining wall and internal groynes to define a low flow channel, Wraysbury River, Poyle (courtesy of the Environment Agency — Thames Region)

Figure 5.17. Blockstone as a retaining wall and internal groynes to define a low flow channel, Wraysbury River, Poyle, 12 months later than Figure 5.16 (courtesy of the Environment Agency — Thames Region)

- nuisance effects from noise during the movement of armourstone by heavy plant (night-time disturbance during barge discharge and material collection is also possible when there is sea-borne delivery as this is dependent on the tides)
- effects on sediment balance and habitat owing to excavation (this is generally less than for concrete structures as rock structures are not as dependent on high capacity foundations for their integrity)
- visual impacts and habitat disturbance from material stockpiles (these are generally located much closer to the actual construction than for other materials)
- low risk of wind-borne pollution (unless stockpiles of dry sand are also required)
- disruption to the local community from delivery traffic
- low risk of the spillage of fuel
- visual impacts both during and after construction
- energy consumption during the movement and placing of rock
- carbon dioxide emissions from the burning of fossil fuels during the movement and placing of rock.

Rock structures can provide additional habitats and niche environments attracting crustaceans, molluscs, algae and birds when used within the lower part of the tidal range on the coast. When used in riverbank protection they allow the growth of terrestrial plant species and provide a more natural alternative to other materials. Rock structures can also have a recreational value providing areas for fishing and walking.

There is generally very little wastage associated with the construction of rock structures due to the stringent specification of the rock sizes required. Surplus rock is either added to the structure or stockpiled to provide a supply of material for future maintenance operations.

Rock structures will generally require some maintenance owing to their flexible nature and for this reason designs should include a provision for heavy plant access. Rock can be displaced, abraded, fractured or, rarely, dissolved. Maintenance usually includes repositioning rocks that have moved or replacing rocks that have split. Environmental impacts during maintenance operations are generally minimal, consisting of small local disturbances and emissions of carbon dioxide and energy consumption from the burning of fossil fuels. The plant commonly used for repair of rock structures includes hydraulic excavators and cranes. Major reconstruction can be achieved relatively easily by overlaying an old structure with new armour.

5.3.6. Reuse, recycling and disposal

It is believed that natural stone forms only a small fraction of the 25 million tonnes of demolition and construction waste generated in Britain each year. An even smaller portion of this arises from coastal and fluvial construction. For this reason, there are few opportunities for reusing or recycling primary rock that would otherwise end up in landfill. However, within the context of scheme development, rock recovered from previous schemes at a particular site can be directly reused in new schemes. In this respect it is an ideal reusable material.

When a rock revetment is no longer sufficient in terms of the grading owing to degradation of the rock or because of increased wave attack owing to lowering of the foreshore, etc., it could be upgraded with grout rather than being replaced or overlaid with larger rock. Either bituminous or cementitious rock can be used. The amount of grout required (250 – 500 kg/m^2) to upgrade a typical revetment will be significantly less than the amount of new rock required. It should be noted that the grouted rock will still be porous but will result in increased wave run-up, so some additional works may be required at the crest.

Rock waste and rip-rap can also be crushed and recycled into aggregate for concrete. Environmental impacts from recycling rock waste include the consumption of energy and the production of carbon dioxide from the consumption of fossil fuel during crushing operations.

The rock used in coastal and fluvial construction projects is sometimes a by-product of other quarrying activities. Quarries often produce large quantities of reject material owing to the stringent requirements associated with supplying rock of a specific dimension and quality. An example of this is shown in Figure 5.18. This material is often sold as a primary product and for this reason it is debatable whether it can be considered as a waste.

Owing to its inert nature and durability there are few environmental threats from disposing of waste rock in landfill sites apart from filling valuable land space.

Figure 5.18. ‘Waste’ rock transported from Norwegian quarries by barge for use in sea defences at Felpham, West Sussex (courtesy of Arun District Council)

5.4. TIMBER

5.4.1. Raw materials and extraction

Timber is derived from a renewable resource and in theory this sets it apart from many construction materials. However, the resource is only renewable within a sustainable timescale if its extraction is managed properly. Timber has the potential to become an environmentally responsible material option.

Approximately 90% of the forest products consumed in Britain each year are imported. Around 88% of these come from coniferous forests in Scandinavia, Canada and Russia, about 3% come from deciduous forests in Europe and North America and approximately 9% are imported from the tropics (Forests Forever, 1998).

Tropical hardwoods are the principal timbers used in coastal and fluvial construction projects owing to their durability in marine conditions and their natural resistance to marine borers. Some examples of the tropical timbers historically used include Greenheart, Ekki, Opepe and Basralcous. These originate in Guyana, throughout West Africa, Nigeria and Surinam respectively. Other hardwoods sometimes used include European Oak. Softwoods such as Douglas Fir are also used in coastal and fluvial engineering projects, particularly in riverbank protection. There are significant environmental impacts associated with the harvesting of timber, especially tropical hardwoods, and these are discussed in the following sections.

Tropical hardwood

Tropical countries are being deforested at an alarming rate and this has a serious impact on species' biodiversity. Tropical forests cover only 7% of the earth's surface yet contain over half of the world's plant and animal species (CIRIA, 1995b). There is currently around 1·7 billion ha of tropical forest left in the world but it is disappearing at a rate of around 17 million ha annually (CIRIA, 1995b). Over half of the world's tropical forests have been destroyed in the last 100 years (WWF, 1998).

The underlying causes of rainforest destruction are many and varied but there is no doubt that commercial logging is an important contributing factor. The UN Food and Agriculture Organisation estimates that around 95% of deforestation is caused by the clearing of land for farms and towns. Around half of the felled timber is burnt as fuel and roughly a third goes into sawn timber for construction (TTF, 1998).

Commercial logging practices vary enormously and at their worst can be very destructive. Often, only a few high-value specimens are taken from an area and little regard is paid to the rest. Repeated surveys in South-east Asia have shown that on average between one-third and two-thirds of residual trees can be damaged beyond recovery (Myers, 1980).

Logging roads, which can reach lengths of over 10 km for every square kilometre of forest exploited, provide access into the forest enabling further destruction. Within a short time, the forest on either side of a logging road can be cleared and replaced by farmland and settlements (WWF, 1998a). When the land area taken up by logging tracks is added to the land taken up by dumping zones and lands for logs, it can account for as much as 10–30% of the forest area (Myers, 1980).

Research for the International Tropical Timber Organisation (ITTO) has shown that the volume of tropical hardwood exported represents around 6% of removals of trees from the forest (CIRIA, 1995b).

In addition to the loss of forest cover and the effects on biodiversity, there are numerous other environmental impacts from commercial logging. These include:

- carbon dioxide emissions from the burning of fossil fuels during extraction
- energy consumption during felling and abstraction
- loss and compaction of topsoil (the removal of vegetation for roads exposes soil to increased erosion and this can be a major source of sediment into waterways of small catchments adversely affecting water quality)
- an estimated 10–30% contribution to annual atmospheric carbon dioxide emissions (CIRIA, 1995b)
- impacts on local and global climate
- changes in water tables (this can lead to salinity problems)
- long timescales for forest regeneration (in tropical forests, regeneration may be relatively swift but the species mix can be altered)
- loss of future resources, particularly medicines
- severe disruption to the lives of native people
- depletion of timber reserves.

Despite the negative impacts on the environment from bad commercial logging practices, the use of timber from sustainably managed forests should be encouraged. This will enable developing countries to value their forests as a resource and provide them with an economic incentive to manage them in a sustainable and environmentally acceptable way. Independent timber certification schemes, such as those discussed later in this section, are one way of ensuring that forest products have been harvested in an environmentally sensitive and sustainable manner.

Softwood

The majority of softwood timber imported into the UK comes from Sweden, Canada, the former Soviet Union and Finland. In many European countries, old growth forests were cleared many years ago and less than 5% of the original forest cover remains. In Western Europe, the situation is worse with only about 1% of the original forest cover remaining (CIRIA, 1995b).

Around the world much of the original temperate forest has been felled. Large areas are currently being replaced with predominantly monoculture plantations. In Europe, the amount of forest cover is increasing every year due to the establishment of plantations. The environmental impacts associated with timber plantations are discussed in the following section.

The major environmental impacts from the harvesting of softwood timber are similar to those of harvesting hardwood timber as discussed in the previous section. They include the following:

- loss of biodiversity
- loss and compaction of topsoil
- carbon dioxide emissions from the burning of fossil fuels during extraction
- energy consumption during felling and abstraction
- changes in water tables (this can lead to salinity problems)
- long timescales for forest regeneration
- depletion of timber reserves.

Timber plantations

Timber plantations could prove to be a useful means of easing the burden on old growth forests around the world if they are established and managed in an environmentally sensitive way. The vast majority of plantations are for softwood species.

Timber species such as *Vitex cofassus* are currently being cultivated in tropical hardwood plantations in Papua New Guinea and the Solomon Islands. These plantations have Forest Stewardship Council certification (see section on timber certification schemes). Vitex is not currently calibrated by the Timber Research and Development Association (TRADA) and is therefore not perceived as being an acceptable option by most engineers.

Timber plantations can have a positive effect on soil conservation and can contribute to the health of watercourses through reduced soil erosion. However, there are also a number of environmental concerns associated with their establishment. Some of these include the following:

- clearing of old growth forests or other important habitats to establish plantations
- the plantations are generally monocultures and provide limited habitats for native flora and fauna
- visual impacts from planting in inappropriate locations
- they can attract diseases and pests (like other monoculture crops)
- fertilisers, weedicides and pesticides are commonly used (these can leach into waterways adversely affecting water quality)
- large amounts of water are sometimes necessary to achieve the rapid growth rates desired.

Carbon sequestration

Global warming is recognised as an important environmental issue. It is caused by the build-up of ‘greenhouse gases’ such as carbon dioxide in the earth’s atmosphere. Trees absorb carbon dioxide from the air and fix it in woody tissue as part of photosynthesis. In one year, an average tree absorbs 9·1 kg of carbon dioxide and emits enough oxygen to sustain a family of four for twelve months (TTF, 1998). The primary benefit of carbon sequestration comes from young fast growing trees. At the time when trees are harvested, their capacity to absorb carbon dioxide has diminished. The harvesting of older trees and the replacement with younger ones can assist in lowering atmospheric carbon dioxide levels.

Sustainable forestry and timber certification schemes

Efforts are currently being made around the world to introduce sustainable forest management practices. Sustainable forestry balances economic and ecological needs and aims to provide a continuous yield of forestry products without compromising the health and biodiversity of the forest. It is proving difficult to reach international consensus and to set in place specific criteria for sustainable forestry owing to the wide range of attitudes towards the role of forests and the varying ideas about sustainability. Despite these difficulties, progress is being made on a number of fronts.

The Forest Stewardship Council (FSC) is a non-governmental independent organisation set up in 1993 to support environmentally appropriate, socially-beneficial and economically-viable management of the world's forests. The FSC achieves its goals by accrediting independent certifiers, of which there are currently two in the UK (SGS Forestry and the Soil Association) and two in the USA, who in turn certify forest products (contact details can be found in Chapter 7). It has gained wide support throughout the environmental and social community, from the softwood timber industry, including the Forestry Commission and commercial forest managers as well as many of the major retail DIY chains. However, it has yet to enjoy the same level of support from some of the tropical hardwood suppliers.

There are now nearly 18 million ha of forests around the world that are independently certified under the auspices of the Forest Stewardship Council and a new target has been set for 2001 of at least 25 million ha of well managed forest (FSC, 1999).

All of the major tropical timber producing countries are members of the International Tropical Timber Organisation (ITTO). The ITTO was established in Yokohama, Japan in 1986 to promote forest management and conservation. The mission statement of the ITTO reads as follows (ITTO, 1999):

> The ITTO facilitates discussion, consultation and international cooperation on issues relating to the international trade and utilisation of tropical timber and the sustainable management of its resource base.

In 1991, the ITTO council committed itself to the sustainable management of natural tropical forests. A target date of the year 2000 was set for ensuring that all tropical timber products traded internationally by member states came from sustainably managed sources. The ITTO has since been criticised for not following through with this commitment and for refusing to promote product labelling (CIRIA, 1995b).

The Guyana Forestry Commission (GFC) currently operates a concession system aimed at increasing the sustainability of its forestry operations. Documentation certified by the GFC can be acquired for timber exported from Guyana's state forests — including Greenheart.

Other certification schemes are also under development by the following bodies.

- The African Timber Organisation, which comprises 13 of the major timber producing nations in Africa.
- The countries of the Amazon Cooperation Treaty, as of 1995.
- The ISO 14001 working group set up in 1996.

In 1998, a World Wide Fund for Nature (WWF) Cameroon commissioned study into the possibility of implementing a certification scheme for Ekki (azobé) concluded that (WWF, 1998b):

> ... short term certification of forests where azobé occurs does not seem to be possible in Cameroon and no signals were found that this might be feasible in any of the other countries of its growing range.

The process of developing a certification scheme for Ekki was deemed to be long term. FSC certified tropical hardwood alternatives to Ekki highlighted in the study included Vitex from Papua New Guinea and the Solomon Islands and Angelim vemelho and Massaranduba from Brazil.

There is currently no FSC certification for the two hardwood species predominantly used in coastal and fluvial engineering projects in the UK, Greenheart and Ekki. However, there are initiatives underway to increase the sustainability of forest management practices affecting these two species and to develop certification schemes. Case example 5.1 highlights some of the problems that currently exist when specifying hardwood timber sourced from sustainably managed forests.

Case example 5.1. Pressure to use FSC certified timber in the sea defences at Eastbourne (information provided by Eastbourne Borough Council)

Historically, the shingle beaches around Eastbourne provided protection from wave attack and flooding. Traditionally, timber groynes slowed the movement of shingle along the shore and ensured that the beaches were wide enough to provide an effective sea defence. In 1990, a study was conducted to recommend a long-term coast protection strategy as it was noted that the natural supply of shingle was diminishing and that there was not enough left to absorb the impact of storms. As a result of the shingle loss, the groynes were collapsing and the foundations of the seawall were exposed.

Many alternative options, such as constructing rock or concrete groynes or continual shingle recycling, were considered but it was decided that constructing large timber groynes, repairing the seawall and importing shingle was the best all round solution on engineering, environmental and economic grounds.

Tropical hardwoods were chosen as the preferred material from which to construct the groynes as they are hard, durable and are resistant to rot and abrasion as well as attack from marine borers. Greenheart from Guyana was chosen as the preferred timber.

Case example 5.1. continued

There was significant pressure on the council from environmental groups to specify that the timber to be used in the scheme was certified under the auspices of the FSC and that the timber was from sustainably managed sources. This was not possible as there were no FSC certified Greenheart forests and FSC certification did not exist for other species of timber suitable for the scheme.

The council investigated the options and in 1995 pledged that:

- the timber would be procured from a 'well managed' source (where logging and other forestry operations are controlled properly)
- the timber extraction operations would be carried out by a company certified in accordance with the FSC principles and criteria.

After much investigation, the council came to the conclusion that using tropical timbers was important for the conservation of tropical forests as it gave the forests an economic value and lessened the likelihood that they would be destroyed by slashing.

The timber was extracted from Guyana by Demerara Timber Ltd which has its own Green Charter and the forest area was approved as being well managed by the World Wide Fund for Nature and independent forestry inspectors, SGS Forestry. Around 7000 t of timber was needed to repair the four miles of sea defences.

The council was congratulated by environmental groups for its efforts to procure the timber from well-managed sources and in a sustainable way.

It is currently at the discretion of the specifier and purchaser of timber products as to whether they ensure that the timber has been extracted from a sustainable or well-managed source. This should be encouraged and can be achieved by requiring that timber is certified, where possible, by an independent organisation such as the FSC or is regarded as being well managed by organisations such as the WWF.

5.4.2. Transport to the processing facility

Tropical hardwood saw-logs are imported over long distances in bulk sea carriers before reaching timber yards or manufacturing plants in the UK. This phase in the transport of timber products can contribute significantly to their embodied energy and carbon dioxide emissions.

Softwoods are imported from countries within Europe but also from as far away as Russia and North America. This makes it difficult to provide a general guide on the environmental impacts from transport as the distances involved are varied. It is generally true that softwood timber sourced locally (i.e. involving minimal road transport) will have the least environmental impacts from transport.

It is difficult to quantify the energy used and carbon dioxide emitted during this phase as they are both dependent on the distances travelled between the extraction site, the sawmill, the manufacturing plant and the timber yard. However, timber is usually transported to the sawmill on logging trucks and then either by truck or rail to bulk sea vessels ready for export. Timber harvested in Canada is generally floated down rivers to the sawmill. Typical energy usage values for each mode of transport are given in Table 5.1.

5.4.3. *Production and processing*

The processing of timber is comparatively simple. In general, the logs require drying either in the open air or in a kiln, sawing and further cutting and shaping.

Processes such as kilning can be highly energy-efficient as wood waste is often used as a fuel. Trials are also being conducted on kilns powered by solar energy. There are many opportunities to use the waste produced at the manufacturing stage. It can be reused as fuel or in wood products such as mulch, woodchips, particleboard and fibreboard.

Some of the environmental impacts of timber processing include:

- the creation of wood dust
- potential hazards from preservatives and other timber treatments (these are generally used in accordance with strict guidelines — Copper Chrome Arsenic can be used to slow the decay of softwood timber in marine applications and increase its resistance to attack from marine organisms such as Teredo and Limnoria)
- adverse effects on water quality (effluent from timber storage yards can leach into waterways)
- energy consumption during drying, cutting and sawing
- carbon dioxide emissions from the burning of fossil fuels during processing.

Around 30 kg/t of carbon dioxide is produced and around 1·5 GJ/t of energy is used in the manufacture of rough sawn timber (Ferguson *et al.*, 1996).

The embodied energies of imported sawn hardwood and imported sawn softwood are estimated by West *et al.* (1994) to be around 7 – 10 GJ/t and about 7 – 9 GJ/t, respectively. These values were very dependent on the transport distances involved.

5.4.4. *Transport from the processing facility to the construction site*

Timber is generally transported to the construction site from timber storage yards by road unless the location is near a rail line. In general, the distances travelled will be relatively short for softwood timber owing to the large number of timber yards located around the country. Fewer timber yards hold the species of hardwood timber used in coastal and fluvial construction or the larger sizes of softwood timber in stock. For this reason, transport distances and thus the impacts on the environment for hardwood timber and larger sizes of softwood timber may be greater during this stage. Typical energy usage values for each mode of transport are given in Table 5.1

5.4.5. Construction, use and maintenance

Timber has numerous applications in coastal and fluvial engineering. It is used in groynes, breastwork, piling, toe boarding, wavescreens, jetties and in mattresses or fascines. Examples of different coastal and fluvial structures containing timber are shown in Figures 5.19 – 5.24.

Coastal and fluvial construction involving timber has a number of environmental impacts. These include:

- nuisance effects from noise and vibrations if piling equipment is used
- disruption of the local community from delivery traffic
- carbon dioxide emissions from the combustion of fossil fuels during installation
- energy consumption by trucks and cranes that transport the timber around the site and into position
- a low risk from accidental spills of fuel.

There are potential hazards from splinters and dust if hardwood timbers, such as Greenheart, require cutting and shaping on site. However, timber is a favoured material if there is a requirement to minimise the environmental impacts during

Figure 5.19. Timber and rock revetment, West Wales (courtesy of HR Wallingford)

Figure 5.20. Timber jetty, Aberystwyth, West Wales (courtesy of HR Wallingford)

Figure 5.21. Timber seawall and groyne field, East Wittering, West Sussex (courtesy of HR Wallingford)

the construction phase. Timber structures generally require little or no excavation, the material can be easily stockpiled and stored and there is little wind-borne pollution apart from sawdust if the timber needs to be cut. The cutting and shaping of the timber is usually carried out using small machines or is even done by hand and the amount of energy consumed at this stage is unlikely to be significant. Timber structures provide some anchorage for molluscs and algae and can provide roosting sites for birds.

In service, timber generally requires more maintenance than rock or concrete and it can sometimes pose hazards to the public in the form of broken planks and abandoned piling. The durability of timber structures along the coast and inland waterways depends upon good design and choosing the correct species for the job. Timber can be susceptible to damage from abrasion and storms, especially where

Figure 5.22. Timber groyne field in estuary, Southwald (courtesy of Tom Stevenson)

Figure 5.23. Willow spiling used as a low retaining wall, Wraysbury River, Poyle (courtesy of the Environment Agency — Thames Region)

Figure 5.24. Willow spiling used as a low retaining wall, Wraysbury River, Poyle. View of spiling from opposite bank showing growth after 12 months (courtesy of the Environment Agency — Thames Region)

maintenance is lacking. Maintenance of timber structures usually involves replacing damaged elements of the structure, such as facing, boarding or sacrificial softwood rubbing strips. Routine maintenance activities do not generally cause significant impacts on the environment.

Wastage arising from the use of timber in construction has potentially the largest impact on the environment during this stage of the life cycle. Timber waste arises for a number of reasons, including over-specifying, poor or inappropriate design, damage during transport, packing and storage or waste from cutting and shaping.

5.4.6. Reuse, recycling and disposal

Around 2·5 million tonnes of timber waste is generated from demolition and construction activities in Britain each year (e.g. formwork from non-standard shapes of in-situ reinforced concrete). At present, very little of this is reused or recycled and the majority is disposed of in landfill (CIRIA, 1995b). It is estimated that approximately 1·2 million tonnes of the timber waste produced each year is reclaimable.

Timber components, such as piling and boarding, can be in good condition when they are extracted from coastal and fluvial structures and can often be reused in new construction projects with little or no reprocessing. If necessary, reprocessing activities may include cleaning, de-nailing and resizing. When reusing timber in this way it is important that the quality and suitability of the timber is thoroughly assessed. Reusing locally available timber that is deemed suitable for the purpose is the best option from an environmental perspective. Examples of this are described briefly in Case examples 5.2 and 5.3.

In addition to reusing timber available at the construction site, reclaimed and recycled timber can be purchased from timber yards around the country. It should be noted that using locally available reclaimed timber brings the largest benefit to

Case example 5.2. Using reclaimed timber in groynes at Felpham (information provided by Arun District Council)

The existing groynes at Felpham were constructed in the 1960s. Excessive wear had occurred to some of the components through continual shingle abrasion and it was considered necessary, as part of the major refurbishment of the defences along the frontage, to replace the landward sections of all of the groynes.

Timbers that had been buried almost permanently under the beach, and not therefore subject to shingle abrasion, were found to be in good condition and suitable for reuse.

Timber sheet piles fixed to a lower waling below the planking were remove in bays (see Figure 5.25) without undue difficulty.

They were then removed from the lower waling by cutting with a chainsaw just below the lower waling and stacked for reuse (see Figure 5.26).

These were redriven and refixed to a new lower waling as part of the new section of groyne (see Figures 5.27 and 5.28).

Similarly, main piles were extracted complete by excavating part of the length of the pile and then pulling. Some difficulty was experienced at times depending on the suction created by the sub-strata. Some of the shorter piles at the seaward end of the groyne had not been badly abraded and were reused in the new groynes and in other structures as main piles by redriving. Sections of the longer piles that had been predominantly below beach level throughout their life were also in good condition, these lengths were cut from the pile for reuse as pile extensions on original lengths of groyne that were being retained but reprofiled.

Figure 5.25. Reclaimed timber after removal (courtesy of Arun District Council)

Case example 5.2. continued

Figure 5.26. Reclaimed timber stacked ready for reuse (courtesy of Arun District Council)

Figure 5.27. Recycled timber sheet piling (courtesy of Arun District Council)

Case example 5.2. continued

Figure 5.28. New timber being installed above recycled timber sheet piling (courtesy of Arun District Council)

Approximately 30–40% of 'new' timber sheet piles were by use of recycled timber. Approximately 5% of 'new' main piles were recycled — recycling of main piles was limited by the general requirement for longer length piles. 100% of the extension piles comprised reclaimed timber.

Apart from the obvious environmental advantages of not using new timber, there was a saving in cost. The recycled timber was generally in the order of 50% of the cost of new timber, allowing for all additional costs incurred by careful removal, preparation for reuse and for non suitability for reuse of some of the timber. There was also a reduction in the volume of material sent to landfill.

There were few disadvantages from using recycled timber. Assessing the quantities suitable for reuse and recycling was difficult but this was overcome by underestimating. The cutting of the reclaimed timber also posed some problems but these were overcome at a small cost increase.

A large proportion of the timber that was not reused on site was sold to a recycling company. This included main piles and planking. The company was proposing to market the material to the landscape and 'feature' building industries. Some ad hoc recycling was also carried out in the local community. Following numerous requests, facilities were made available for local residents to collect reclaimed planking that was not considered suitable for reuse in the coast protection scheme or commercial recycling. This found its way into numerous gardens as lawn/footpath edging, garden retaining walls, etc. Some material was given to three local craftsmen who specialise in creating feature furniture from salvaged timbers.

Case example 5.3. Using reclaimed timber in the flood defences at the site of the Millennium Dome (information provided by the Environment Agency)

Timber over 130 years old was reclaimed from a jetty at the mouth of the Regents Canal Dock in London and used to face the steel sheet piling as part of the flood defences at the Millennium Dome site in Greenwich (see Figures 5.29 and 5.30). The timber was generally found to be in excellent condition. The reclaimed timber stacked ready for reuse can be seen in Figure 5.31.

Figure 5.29. Engineers inspecting the work done to put the 130 year old beams in place

Figure 5.30. Reclaimed timber facing in front of the Millennium Dome

Case example 5.3. continued

Figure 5.31. Reclaimed timber stacked ready for reuse

In all, 262 lengths of timber each 2·1 m long, and a further 121 m of varied lengths were reused in the project. There were no real difficulties encountered while extracting the timber. However, a number of lengths were deemed unsuitable for reuse as they were either defective, rotten, of insufficient size or were offcuts.

Once dismantled, the timber lengths were stored at the Thames Barrier depot and transported a short distance (2 – 3 km) to the Greenwich site by road.

The Environment Agency were able to save money by using reclaimed timbers and made extra savings by locating the source of the reclaimed material themselves. The cost of cladding with reused timber sourced by the contractor was over £100 per 2·1 m in length more than for timber provided by the client.

Some of the advantages and disadvantages from using reclaimed timber in this project are outlined below.

Advantages:

- provides an excellent habitat for wildlife
- provides a food source for flora and fauna
- saves landfill space
- preserves timber resources
- less impact from carbon dioxide emissions
- less impact from energy consumption
- cost savings.

Disadvantages:

- embedded ironwork
- non-standard sizes

Case example 5.3. continued

- storage requirements
- double/treble handling
- indeterminate strength
- require the design to account for available timber, hence the need for full inventory of timber.

The work conducted at the site of the Millennium Dome has increased the awareness of the benefits of reusing materials. The Environment Agency is promoting the use of reclaimed and recycled materials across the whole of the tidal Thames, not only in its own schemes but also on those promoted by private developers.

the environment. In this way, transport distances are reduced and resulting carbon dioxide emissions and energy consumption are less.

Timber deemed to be unsuitable for direct reuse in construction projects can be utilised in a variety of ways. Some of these are listed below:

- woodchip production
- soil conditioning and mulching
- landscape works
- recycled plastic lumber (containing wood fibres)
- manufacturing of chipboards or particleboards
- production of energy through controlled burning
- aggregate in the production of lightweight concrete.

One of the major problems associated with the use of reclaimed timber is the variety of contaminants that may be present. These can range from items such as nails, screws and bolts to treatments such as creosote, paints, preservatives and fungicides. The costs associated with extracting timber in a usable form may also be prohibitive.

The major environmental impacts from this stage of the life cycle of timber materials include the following:

- energy consumption during collection, transportation, handling and reprocessing
- carbon dioxide emissions from the burning of fossil fuels during processing
- methane emissions if left to decompose
- inherent energy wastage from uncontrolled burning
- increased chance of toxic emissions from uncontrolled burning
- release of contaminants from coatings and treatments.

In addition to the environmental benefits, reusing and recycling timber reduces disposal costs and can provide a cheaper alternative material option as it is around 60–90% of the cost of new timber (CIRIA, 1999). Recycled Greenheart Developments estimate that reclaimed Greenheart can be in the order of 40–90% of the cost of new timber. They advise that cost savings are dependent on the suitability of the timber for the purpose for which it is required and costs rise rapidly if reprocessing is required and the transport distances involved are large. If reclaimed timber requires substantial reprocessing it can prove to be more expensive than new timber so the design should take full account of the sizes of timber available.

5.5. AGGREGATE

5.5.1. Raw materials and extraction

The principal forms of winning primary aggregate are surface extraction and marine dredging.

In surface extraction, aggregates are produced either by blasting rock from a quarry face and crushing it to the desired grading or by the removal of granular deposits using draglines or excavators. The environmental impacts associated with surface mineral extractions have already been discussed in Section 5.3.1.

The Crown Estate is responsible for granting licences for marine aggregate extraction. Official Crown Estate figures show that 23 million tonnes of marine-dredged aggregate was extracted during 1998 (EMSAGG, 1999). Over 2 million tonnes were used in beach replenishment schemes. In 1998, marine-dredged sand and gravel made up about 17% of the total consumption of sand and gravel for construction purposes in England and Wales (Business Monitor, 1998).

Aggregate won from the marine environment can reduce the pressure for new land-based extraction sites and can often be landed at wharves close to the point of demand thus reducing environmental impacts from transport. There are, however, environmental impacts associated with this method of extraction and these can include:

- damage to benthic flora and fauna
- disturbance or resuspension of fine materials or contaminants
- damage to commercial fisheries
- damage to coastal defences by beach drawdown and changes in wave climates and currents
- interference with the supply of beach material to adjacent beaches
- possible impacts to historic sites
- energy consumption during dredging activities
- carbon dioxide emissions from the burning of fossil fuels during dredging activities
- depletion of raw material reserves.

It should be noted that in order to obtain a licence from the Crown Estate the views of MAFF and English Nature (or the Countryside Council for Wales) are sought in order to identify any environmental or fisheries' concerns. An environmental assessment may be required. Studies are also carried out to identify any possible impacts on coastal processes (CIRIA, 1996).

5.5.2. Transport to the processing facility

The processing of aggregate often occurs at, or very near to, the extraction site and so minimal transport distances are involved and impacts on the environment are negligible.

5.5.3. Production and processing

The processing of aggregate can involve crushing, screening, washing and drying. The major environmental impacts of this stage can include:

- particulate emissions to air and water (see Figures 5.33 and 5.34)
- nuisance effects from noise
- energy consumption during crushing, screening, washing and drying
- carbon dioxide production from the burning of fossil fuels during processing operations.

The embodied energy of natural aggregates ranges from about 0·03 GJ/t to around 0·12 GJ/t depending on the methods used (figures published by the BRE in 1994).

Figure 5.32. Spraying aggregate directly onto the foreshore for use in beach renourishment (courtesy of Arun District Council)

5.5.4. *Transport from the processing facility to the construction site*

Aggregate from land-based extraction is generally transported to the construction site by road. Marine-dredged aggregate for use in beach renourishment can be pumped ashore either through a pipeline or sprayed directly onto the beach. The spraying method is illustrated in Figure 5.32.

An example describing the environmental benefits of transporting aggregate by barge rather than by truck is discussed in Case example 5.4.

5.5.5. *Construction, use and maintenance*

Aggregate other than that used in concrete is predominantly used for the renourishment of beaches. Figures 5.33 and 5.34 illustrate the dredging process. Aggregate used in concrete structures can be seen in Figures 5.35 – 5.42.

Case example 5.4. A comparison of the environmental impacts of transporting aggregate by barge and truck (information provided by Mackley Construction)

During the feasibility phase of a large coast protection scheme it was required to recycle and transport approximately 150 000 m^3 of shingle. The shingle would be won from an area adjacent to the terminal groyne at the downdrift end of the site and transported and deposited along a 4 – 5 km frontage at the upstream end of the site approximately 9 km away.

This kind of shingle recycling is currently carried out by the Environment Agency using 10 – 16 t trucks at a rate of around 30 000 – 40 000 m^3 per year. The proposed recycling scheme required that the 150 000 m^3 be transported and placed within one year. This would increase traffic dramatically on a small single track road which is the only access available along the entire frontage behind the crest of the beach. It would also mean increased impacts on the environment through an increased use of fossil fuels resulting in more energy consumption and emissions of carbon dioxide.

In order to move 150 000 m^3 in one year it would take 50 loads per day using 20 t trucks (equivalent to around one full load every ten minutes and a return trip). The road is a light construction and is used by the local inhabitants of three small villages. Such an increase in the volume of traffic would have a huge impact on the local inhabitants and on the environment.

A good alternative solution was to move the shingle using a large flat top barge which would be towed by an inshore boat. It was estimated that the barge could load, transport and deposit 1500 t (750 m^3) of shingle every 24 hours, i.e. ~ 4500 m^3/week. The only constraints would be bad weather, i.e. a wind over a force 5 would prevent the barge moving up onto the beach.

A piled mooring facility would be constructed from sheet piles where the barge would be tied up. It would be loaded either by conveyor or by loading shovels. At approximately two hours before high water the barge would be towed towards the western end of the site (updrift) where it would either be beached and offloaded using shovels/trucks or if the barge was on station at the point of discharge one hour before high water, the shingle could be pushed off the front using a shovel and then retrieved by land-based plant at low water.

The environmental impacts of the seabourne method are minimal and although the cost per cubic metre is slightly higher than using the 20 t trucks, the whole life costs, i.e. consumption of fossil fuels, repairs to the roadway, etc., would be lower. The construction period would also be around 30% less than for the land-based option.

Figure 5.33. On board an aggregate dredger (courtesy of HR Wallingford)

The environmental impacts associated with beach renourishment include:

- habitat and ecosystem disturbance
- energy consumption from transporting aggregate around the site
- carbon dioxide emissions from heavy plant
- visual impacts during construction
- nuisance effects from the noise created by heavy plant
- dust
- waste water control
- disruption of the local community from traffic.

Aggregate used in beach renourishment provides a habitat for worms and crustaceans, a feeding area for sea birds and a recreation area for the public.

In beach nourishment schemes, the intervals at which beach surveys are conducted to ensure that a beach profile is maintained are generally agreed in the contract. Maintenance operations are then carried out to maintain the beach profile so that it offers an agreed level of protection. Beach maintenance operations may involve the movement of aggregate from one place to another and this is usually carried out using trucks (see Case example 5.4). Ongoing supplies

Figure 5.34. Overflow from dredging operations (courtesy of HR Wallingford)

of appropriate material may be required and this is usually pumped ashore from a barge or delivered by truck.

5.5.6. *Reuse, recycling and disposal*

Most aggregate used in coastal and fluvial construction is used in beach renourishment schemes or in concrete. The recycling of beach materials is a major activity. It may be shifted from one position to another or recycled in a new beach renourishment scheme. However, there are few opportunities for reusing or recycling aggregate from coastal and fluvial concrete structures as waste is very rarely, if ever produced. Instead, original structures tend to be incorporated as they exist within new schemes. This reduces the scale of the new works and saves energy that would otherwise have been used in the disposal of the original structure.

Apart from that used in concrete, very little aggregate is disposed of in landfill.

5.6. CONCRETE

The principal components of concrete, other than water, are cement and aggregate. The life cycles of cement and concrete are discussed in the following sections. The environmental impacts associated with the life cycle of aggregates have been discussed in Section 5.5.

5.6.1. Raw materials and extraction

The principal raw materials used in the production of cement are limestone, shale and sand or chalk and clay. The limestone, chalk and clay are usually won by surface extraction in a quarry. In order to reach the desired materials, other types of rock are blasted and removed. Unwanted material is generally stockpiled with the aim of restoring the quarry once operations cease. When wet chalk is used, as for the wet and semi-wet cement-making process (see Section 5.6.3), blasting is not necessary.

Limestone is blasted from the walls of the quarry and any oversized rocks are crushed. The limestone is transported by truck to the crusher where it is broken down further into rocks of around 150 mm in length. In the Dunbar quarry in south-eastern Scotland the limestone is transported to the crusher in 55 or 80 t trucks and is carried to the raw meal mill by a series of covered conveyors.

The principal environmental impacts from the extraction of the raw materials used in cement production include:

- nuisance effects from noise, dust and the vibrations from blasting, crushing and heavy plant
- habitat disturbance and removal
- the disturbance and removal of topsoil
- carbon dioxide emissions from the burning of fossil fuels during extraction
- energy consumption during extraction operations and the movement of material around the quarry
- visual impacts
- the interruption of ground and surface water flows
- the production of solid waste
- the depletion of raw material reserves.

It should be noted that quarry operators are required to have plans to restore the site of the quarry on completion of the mineral extraction operations.

The principal forms of aggregate extraction for use in concrete include surface extraction and marine dredging. The environmental impacts associated with aggregate extraction are discussed in Section 5.5.1. Aggregate for use in concrete can also be obtained by recycling demolition materials and reusing the waste products of other industries.

It is currently estimated that around 10–15% of the aggregate used in construction is from recycled and alternative sources (CIRIA, 1998). These sources can include blast furnace slag, pulverised fuel ash and demolition waste.

5.6.2. Transport to the processing facility

Cement manufacturing plants are usually located very close to and on the site of the quarry. For this reason, the raw materials are often only transported short distances either on conveyors or in trucks. Sand, a component of the dry cement-making process, is sometimes brought in by road from further afield.

5.6.3. *Production and processing*

Cement

There are four different processes for manufacturing cement. The raw materials available determine which process is used. Relevant information regarding each process is contained in Table 5.3.

The main difference between the wet and dry process, besides the use of different raw materials, is that in the wet process the raw materials are mixed with water to produce a slurry before being pumped into the kiln. In the semi-wet and semi-dry processes water is also added to the raw materials but is driven out in presses and by heating before the materials enter the kiln.

The principal environmental impacts from the manufacture of cement include:

- energy consumption (mainly during the heating and drying phases)
- carbon dioxide, SO_x and NO_x emissions from the burning of fossil fuels (predominantly ground coal)
- the production of solid wastes (mainly alkaline kiln dust)
- particulate emissions into the air.

Concrete

Concrete can be manufactured and poured on-site or manufactured off-site and delivered in its plastic state. It can be poured into moulds of various shapes and sizes and is compacted to remove entrapped air.

Concrete is manufactured by mixing aggregate, cementitious material and water in specific quantities. The mix proportions vary widely depending upon the required properties. These amounts are typically as follows:

- 10–20% portland cement, pfa or ggbs
- 7–8% water
- 25–35% fine aggregate (sand)
- 45–55% coarse aggregate (gravel/crushed stone).

The principal environmental impacts from the manufacture of concrete include:

Table 5.3. Information on cement manufacturing processes (information provided by the BCA in 1998)

Process	Raw materials	% of cement produced in UK	Energy consumed (GJ/t)
Dry	Limestone, shale and sand	46	3·4
Semi-dry	Limestone, shale and sand	15	3·5
Wet	Chalk and clay (sand, iron oxide and pfa may be added)	15	5·7
Semi-wet	Chalk and clay (sand, iron oxide and pfa may be added)	24	5·2

- particulate emissions to air and water
- solid and liquid wastes containing alkali.

5.6.4. Transport from the processing facility to the construction site

Concrete or its components are generally transported to the construction site by road. It either arrives precast in the form of units such as blocks or slabs, as a readymix which is poured in situ or it arrives as separate components, namely sand, cement and aggregate and is mixed on-site. Transport distances vary depending on the form of concrete used and the availability of the raw materials. Typical energy usage values for each mode of transport are given in Table 5.1.

5.6.5. Construction, use and maintenance

Concrete has many applications in coastal and fluvial construction. It can be used in seawalls, jetties, wharves, quays and in control structures or bank protection along rivers. Other uses include armour units or caissons in breakwaters or as blocks or fill for geotextile mattresses in bank protection. Examples of different coastal and fluvial structures containing concrete are shown in Figures 5.35 – 5.42.

Coastal and fluvial construction involving concrete has a number of environmental impacts. These include the following:

- excavated material can temporarily upset the sediment balance causing damage to fishing, recreation and conservation interests (mass concrete structures need good foundations if they are to be durable and generally require deeper structural foundations and more excavation than other materials)

Figure 5.35. Precast concrete fish-tailed groyne, New Brighton, Wirral (courtesy of HR Wallingford)

Figure 5.36. Dolos, precast concrete interlocking armour units, Penmaen Head, A55 trunk road, North Wales (courtesy of HR Wallingford)

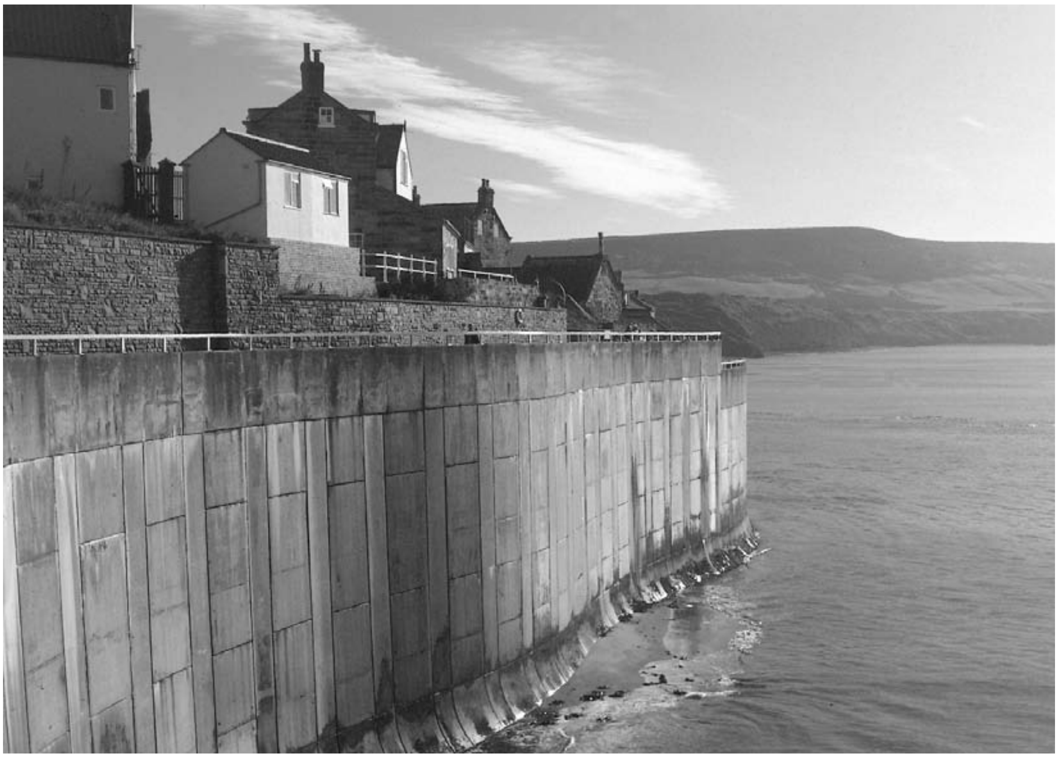


Figure 5.37. Concrete vertical seawall, Robin Hoods Bay, North Yorkshire (courtesy of HR Wallingford)

Figure 5.38. Concrete stepped seawall, Prestatyn, North Wales (courtesy of HR Wallingford)

Figure 5.39. Breakwater, masonry blocks with concrete decking, Hartlepool, Durham (courtesy of HR Wallingford)

Figure 5.40. Concrete caissons, Oosterschelde Barrier, Zeeland (courtesy of HR Wallingford)

Figure 5.41. Cellular concrete revetment, Staines Bypass Channel outfall to River Thames (courtesy of the Environment Agency — Thames Region)

Figure 5.42. Large precast concrete culvert units, Staines Bypass Channel (courtesy of the Environment Agency — Thames Region)

- temporary stockpiles of materials can extend beyond the construction site affecting terrestrial species and local inhabitants
- risk of wind and water-borne pollution from stockpiles of aggregates, sand and cement (when concrete is to be mixed on-site)
- nuisance effects from the noise of mixing, transporting and placing plant and if piling equipment is required there can be further impacts from vibrations
- disruption of the local community from delivery traffic
- a low risk from accidental spills of fuel and lubricants
- energy consumption from heavy plant
- carbon dioxide emissions from the burning of fossil fuels by heavy plant.

Concrete structures with a suitable finish can provide areas for the anchorage of algae and crustaceans. They can also provide areas of recreational value for walking and fishing. When used in riverbank protection, concrete is generally less aesthetically pleasing than natural materials, such as rock and timber, as it tends to restrict the natural regeneration of the riverbank. The use of cellular concrete blocks, surface textures and exposed aggregate finishes can reduce this disadvantage.

Concrete structures are generally perceived as being low maintenance. They can, however, suffer from a number of problems. Reinforcing steel inside concrete can corrode through the penetration of salt water or the diffusion of carbon dioxide and this can result in the spalling or crumbling of the surrounding concrete. The most common causes of spalling are sulphates migrating from surrounding soil, aggregates, groundwater and fill. Water penetration can lead to ion migration resulting in the appearance of voids and a weakening of the structure. If there is shingle present then concrete structures can suffer from abrasion. A suitable mix design can alleviate this problem. All of these problems are well understood and solutions such as the appropriate choice of mix proportions and constituents are used. When used properly, concrete in coastal and fluvial structures should last at least as long as other construction materials.

In failure, concrete can be one of the most difficult of all materials to cope with (Orbell-Durrant, 1992). Maintenance work on concrete structures can be as disruptive as the original construction. The most common situations involve failure of the foundations or degradation of the concrete. This means that the old structure has to be removed and replaced. These operations are likely to cause as much disruption as the original construction with the addition of vibration and noise from the concrete-breaking operations (Orbell-Durrant, 1992).

5.6.6. Reuse, recycling and disposal

Over 10 million tonnes of concrete waste is produced from demolition sites across the UK every year. This amount accounts for around 50% of the total demolition debris produced annually (CIRIA, 1995a).

Unlike other construction materials in civil engineering generally, few opportunities exist for reusing concrete components. However, in coastal and fluvial engineering, new schemes often incorporate old concrete structures, such as seawalls, within them (see Case example 5.5).

There are also increasing opportunities across civil engineering generally to recycle concrete components. The largest potential area for recycling concrete waste is to crush it to produce recycled aggregate.

Demolition techniques can be employed to produce aggregate that is suitable for high grade applications but it is best suited for replacing primary aggregate in lower grade applications, such as bulk fill or as hardcore for temporary roads. This minimises more expensive processing and durability risks. Howard Humphries and Partners (1994) estimate that only around 4% of concrete waste is sorted, crushed, graded and used as an alternative to primary aggregates in construction projects around the UK. Case example 5.5 describes concrete recycling in sea defences at Minehead.

Mobile crushing plant can be brought to the site of the demolition works and rapidly convert concrete waste into a usable material (see Figure 5.43). This plant can also separate out contaminant materials, such as steel reinforcing, through the use of strong magnets. Contact details for companies that supply mobile crushing plant can be found in Chapter 7. The principal environmental impacts from recycling concrete include the consumption of energy and the production of carbon dioxide from the use of fossil fuels during crushing operations.

Research conducted in Belgium and the Netherlands has shown that up to 20% of the primary aggregate in concrete can be replaced by high-grade recycled concrete aggregate (RCA) without any adverse effects on its properties. Research

Case example 5.5. Recycling concrete in the sea defences at Minehead (information courtesy of the Environment Agency)

Minehead sea defences comprise 1·8 km of new raised wall, rock groynes and nourished beach. The scheme was constructed between 1997 and 1999 at a cost of £12 million.

Environmental considerations were major drivers in both the design and construction processes. One of these considerations related to the reuse of existing materials and to minimising disposal off site.

The existing seawall needed to be demolished to allow construction of the new wall. The decision to recycle the old wall was driven primarily by economics — the cost of bringing a crusher to the site and reusing the material as a sub-base in the new works was over £50 000 cheaper than disposing of the material off site and importing new aggregate. About 10 000 t of material was recycled in total. Figure 5.43 shows the concrete being crushed.

The process required a little forward planning and cooperation between the client, designer and contractor, however, no difficulties were encountered and the operation was a success. The obvious advantages relating to sustainability, economics and public relations flowed from the decision to recycle.

Another major consideration was minimising the environmental impacts from transporting the 70 000 t of primary rock armour and core rock and the 30 000 t of additional aggregate required for the scheme. By road, this would have involved around 5000 return journeys with obvious impacts on the environment. The Environment Agency took a proactive role and investigated the possibility of transporting the materials by rail. A new railway siding was constructed within the contractor's compound and the rock was sourced from two quarries in the Mendips which benefited from existing rail heads. The materials were delivered by rail in 500 t units and this proved to be a reliable and cost-effective method with significant environmental benefits. Delivery of the primary rock armour by rail can be seen in Figure 5.44.

The finished scheme is illustrated in Figure 5.45.

Figure 5.43. Crushing concrete from the old seawall into aggregate for use as a sub-base (courtesy of the Environment Agency)

Case example 5.5. continuted

Figure 5.44. Delivery of primary rock armour by rail (courtesy of the Environment Agency)

Figure 5.45. Minehead sea defences on completion of the works (courtesy of the Environment Agency)

is also currently underway to quantify the effects that different crushing methods have on the properties and characteristics of the RCA.

There are a number of concerns associated with the use of RCA. Some of these include contaminant levels and the homogeneity in strength and durability of the finished concrete. Centralised recycling facilities can sometimes guarantee a homogeneous supply due to the volume of material that they process. Another barrier to the use and acceptance of RCA is the difficulty in producing a material that conforms to existing standards (CIRIA, 1999).

Concrete can be made using other reclaimed and recycled materials. They can be incorporated into concrete mixes to partially replace the cement and aggregate components. Ground granulated blastfurnace slag (ggbs), a waste material from the steel production industry, and pulverised fuel ash (pfa), a waste material from the power supply industry, can be used in specified amounts to replace Portland cement.

Both ggbs and pfa have also been used in different forms along with other materials such as china clay sand, glass and slate waste to replace primary aggregate in concrete (CIRIA, 1999).

Recycling waste concrete into aggregate and incorporating other recycled materials into new concrete has several benefits — raw materials and energy are conserved, less material is dumped at landfill sites and carbon dioxide emissions and costs are lower. These benefits are based on the assumption that transport distances for the recycled materials are short.

Readymix concrete can be wasted during routine cleaning operations or as a result of cancelled orders. Systems for reclaiming the component materials from readymix waste are now available. The waste concrete undergoes a washdown process from which clean aggregates and sand are segregated and can be returned to production. The water is then recycled through the washing system or sent for treatment to be used in the production of new concrete. The system enables significant quantities of aggregates to be reclaimed making it unnecessary to send waste to landfill. Contact details for the company that supply this system can be found in Chapter 7.

5.7. STEEL

5.7.1. Raw materials and extraction

The principal raw materials used in the production of steel are iron ore, scrap steel, coal and limestone. The iron ore is imported predominantly from Australia, Canada, Brazil, South Africa and Mauritania and has a yield of around 49–65%. It is extracted generally by open cast mining and undergoes a series of crushing and grinding operations. It is estimated that there are enough reserves of iron ore to last for at least another 200 years if current levels of demand continue (CIRIA, 1995c).

The coal used in the steelmaking process within the UK is imported from EC countries and North America. The limestone is quarried in the UK.

The major environmental impacts arising from the extraction of the raw materials include:

- habitat disturbance and removal
- acid mine drainage and heavy metal pollution
- carbon dioxide emissions from the burning of fossil fuels
- energy consumption at the extraction site
- accelerated release of ground methane
- production of solid and liquid waste
- nuisance effects from noise, dust and vibrations
- interruption of ground and surface water flows
- visual impacts
- disturbance and removal of topsoil
- depletion of raw material reserves.

5.7.2. *Transport to the production facility*

Iron ore mines are often located in remote areas and as a consequence the ore may have to travel appreciable distances, usually by rail, before being loaded onto bulk sea carriers ready for export. This, coupled with the large distances between the UK and the countries that supply the iron ore and coal means that the energy consumption and CO_2 emissions attributable to the transport of the raw materials are high.

In the UK, the iron ore and coal arrives by sea and is unloaded at deepwater harbours close to the four integrated steelworks at Teeside, Scunthorpe, Llanwern and Port Talbot. The iron ore and coal are transported by conveyor belt to stockyards where it is blended and stored. The limestone is quarried in the UK and usually arrives at the steel manufacturing plant by road or rail.

5.7.3. *Production and processing*

In the UK, the majority of steel is produced at integrated steelworks. There are two different processes for producing steel: the Basic Oxygen Converter (BOC), which uses raw materials predominantly, and the Electric Arc Furnace (EAF), which uses recycled materials predominantly.

Relevant information regarding each process is contained in Table 5.4.

Unfortunately, despite its environmental advantages, there is currently insufficient scrap steel to allow new steel to be manufactured by the Electric Arc Furnace process alone.

A range of processes are employed to adjust the composition and properties of the steel once it has been poured from the EAF or the BOC into the secondary steelmaking vessel or ladle. The molten steel then enters the continuous casting process or the ingot route where it is formed into slabs, blooms and billets ready for rolling. Surface finishes and coatings can also be added.

Table 5.4. Information on the steelmaking processes

Process	Raw materials	% produced in UK*	Energy consumed (GJ/t)†	Carbon dioxide produced (kg/t)†
Basic Oxygen Converter	Iron ore, coal, limestone and 10–30% scrap steel	76	26–30	2800–3600
Electric Arc Furnace	Predominantly scrap steel (iron carbide and pig iron can also be used)	24	8–10	1200–1500

* Figures provided by the Iron and Steel Statistics Bureau from 1998.
† Figures provided by the International Iron and Steel Institute from 1999.

The principal environmental impacts from the production of steel include the following.

- High energy consumption from the burning of fossil fuels.
- High carbon dioxide emissions from the burning of fossil fuels.
- A substantial emission of SO_x and NO_x from the burning of fossil fuels.
- Small amounts of other pollutants may escape, including iron oxides, lead, cadmium, mercury, cyanide, zinc, chromium, copper, nickel, coal dust, oil, carbonyl, fluoride, alkali fume, dust and resin fume, sulphur, H_2S, HCN, ammonia and CO.
- The production of solid waste. (Around 500 kg of solid wastes are produced per tonne of liquid steel from integrated primary steelmaking. Roughly 16% of this is recycled for its metal and fuel value, about 50% of the unrecycled waste is sold to the cement and road building industries while around 35% of the waste is sent to landfill (CIRIA, 1995c).)
- Large volumes of water are used. (The water may become contaminated with heavy metals, ammonia and inert suspended solids through operations such as quenching and cooling, dust settling, flue gas scrubbing and machining. These days, most of the water passes through recirculating systems many times before being discharged. This means that roughly 3 m^3 of water is removed from the water system for every tonne of steel produced.)

It should be noted that exhaust gases that are not recycled are treated with bag filters, wet scrubbers and electrostatic precipitators to control emissions within consent limits. Other pollutants are also controlled, using industrial effluent plant, to within consent limits.

Steel recycling greatly reduces the negative impacts on the environment.

5.7.4. *Transport from the processing facility to the construction site*

Steel is transported to the construction site predominantly by road unless the location is near a rail link.

Owing to the high strength of steel and the relatively low volume required to perform similar functions to larger quantities of bulkier materials, the environmental impacts from this stage can be less than for other materials as fewer journeys are required (Gorgolewski, 1998).

The estimated energy use for different modes of transport are given in Table 5.1.

5.7.5. Construction, use and maintenance

In coastal and fluvial engineering, steel is used predominantly in sheetpiling, tubular piling, concrete reinforcement and gabions. Examples of different structures containing steel are shown in Figures 5.46 – 5.50. Steel used in gabions can be seen in Figures 5.6, 5.8, 5.9 and 5.13.

Steel is likely to be a favoured choice of material where there is a requirement to minimise the environmental impacts during the construction phase. The use of steel in construction requires little or no excavation, the components can be stockpiled easily and there is very little wind-borne pollution.

Coastal and fluvial construction involving steel has a number of environmental impacts. These include:

- nuisance effects from noise and vibrations if piling equipment is used
- disruption of the local community from delivery traffic
- energy consumption from the burning of fossil fuels during the installation of steel components
- carbon dioxide emissions from the burning of fossil fuels during the installation of steel components
- a low risk of accidental spills of fuel and protective coatings.

Figure 5.46. Steel sheet piling, concrete and reinforcing steel at Sandbanks, Poole Bay, Dorset (courtesy of HR Wallingford)

Figure 5.47. *Steel sheet piling using a rig that avoids vibration and minimises noise, Wraysbury River at Staines (courtesy of the Environment Agency — Thames Region)*

Figure 5.48. *In-situ concrete structure with large steel gates, River Medway, Tonbridge Flood Storage Reservoir (courtesy of David Hockin)*

Figure 5.49. Reinforced concrete construction of a new control structure at Tanhouse Farm, Colnbrook, on the Colne Brook (courtesy of the Environment Agency)

Figure 5.50. Reinforced concrete construction utilising a large amount of temporary steel piling, Lagan Weir, Belfast (courtesy of A. T. Pepper)

Steel structures do not generally provide habitats for local flora and fauna in the same way as those constructed from rock and timber.

The wastage associated with steel in construction is generally small owing to the fact that most of the steel that arrives at the construction site is prefabricated. This also enables it to be installed relatively quickly. In an extensive study carried out to assess wastage on construction and demolition sites, steel was shown to be one of the best materials (CIRIA, 1999).

In service, steel can require more maintenance than rock or concrete and it can sometimes pose hazards to the public in the form of projecting steelwork and corroded piling. The durability of steel structures along the coast and inland waterways can be compromised severely if there is a failure to prevent corrosion by good design and/or effective maintenance. Maintenance activities can include painting and the replacement of damaged elements. The environmental impacts from maintenance activities are usually minimal. Steel can be susceptible to damage from abrasion, chemical attack and storm damage, especially where maintenance is lacking. In some areas, steel is susceptible to accelerated low-water corrosion.

5.7.6. Reuse, recycling and disposal

Scrap steel has a high commercial value and this provides an incentive for its collection and recycling. The UK steel industry currently recycles over 7 million tonnes of ferrous scrap each year. More than 80% of scrap steel is recycled and over 40% of the steel produced in the UK is recycled steel (Steel UK, 1999).

Reusing materials is more beneficial to the environment than recycling. Steel components, such as piling, can be in good condition when they are extracted and opportunities for their reuse should be investigated. A number of examples of the reuse of steel piling are outlined in Case example 5.6.

Steel recycling technology is well established. The magnetic properties of steel mean that it is easily separated from other waste materials by powerful magnets. It can be sorted into different grades and qualities and can be cleaned and stripped of any non-ferrous coatings (Gorgolewski, 1998). The extraction of scrap steel only

Case example 5.6. Reusing steel piling in Welmore Sluice, Cambridgeshire (information courtesy of the Environment Agency)

During the construction of Welmore Sluice, unpainted steel sheet piling was used to form a temporary 46 m diameter circular cofferdam and this can be seen in Figure 5.51. Once the work inside the cofferdam was completed, the majority of the cofferdam piles were extracted and the site was allowed to flood.

The extracted piles were taken away from the site, cleaned, any damaged ends were trimmed off and they were painted. The piles were returned to site where they were used in the permanent works to form wing walls to the new sluice structure. No particular problems were encountered as a result of reusing the piles.

Figure 5.51. Temporary cofferdam used during the construction of Welmore Sluice (courtesy of the Environment Agency)

requires general demolition equipment. Steel reinforcement is sold to scrap merchants for reprocessing for around £10 – 30/t (CIRIA, 1999).

Scrap steel is the primary feedstock into the Electric Arc Furnace and also forms around 10 – 30% of the feedstock in the Basic Oxygen Steelmaking vessel. There are large energy savings to be made from recycling steel. Significant reductions in carbon dioxide and acid gas emissions are also possible (see Table 5.4). Recycling and reusing steel can reduce greatly the pressure on the raw materials needed for its production.

5.8. RECYCLED PLASTIC

5.8.1. Raw materials and extraction

Over 80 million tonnes of plastics are produced around the world every year. The UK construction industry is a major consumer of these utilising over 534 000 t of PVC, polyethylene and polystyrene in 1990 (CIRIA, 1995d).

For the purposes of recycling, plastic polymers have been divided into seven types, each identified by a code number (see Table 5.5).

A plastic product or package is usually marked with the code number (as identified in Table 5.5) enclosed by a recycling triangle to identify the polymer type from which it is made.

There are two main sources of plastic waste available for the production of recycled plastic products:

- post-consumer (plastic retrieved after it has served the use for which it was intended)
- pre-consumer (waste from the plastic manufacturing process).

Pre-consumer plastic is generally easy to recycle as it is clean, dry and easily sorted into different polymer types. Post-consumer plastics, or those collected from the domestic waste stream, can be dirty, wet and of mixed origin making them more difficult to recycle. Post-consumer plastic waste is either collected from bins located at convenient places, such as shopping centres, or it is collected

Table 5.5. Plastic types and code numbers

Plastic type	Code number
Polyethylene terephthalate (PET)	1
High density polyethylene (HDPE)	2
Polyvinyl chloride (PVC)	3
Low density polyethylene (LDPE)	4
Polypropylene (PP)	5
Polystyrene (PS	6
Other plastics (including acrylic and nylon)	7

as part of a kerbside recycling program. In order to produce a manufactured product there is a need to select suitable source material.

5.8.2. *Transport to the processing facility*

Plastic waste is usually transported by road for further processing.

5.8.3. *Production and processing*

After collection, plastic waste is sorted into different polymer types, baled, ground and washed. The flakes are then dried in heated air, melted, filtered and formed into pellets through the extrusion process. There is little information on the environmental impacts from processing plastic waste into pellets ready for conversion into recycled plastic products. The main impacts are likely to be the production of carbon dioxide and the energy usage from burning fossil fuels from each of the stages mentioned above and also from the transport phase between each processing stage.

5.8.4. *Transport from the processing facility to the construction site*

Some recycled plastic products are currently imported from the United States by ship and others are manufactured in the UK. All are generally transported to the construction site by road or rail. When used in port construction, plastic piling can be shipped directly to the point of use thus reducing the impacts on the environment. Typical energy usage values for each mode of transport are given in Table 5.1.

5.8.5. *Construction, use and maintenance*

Traditionally, the coastal and fluvial construction industry has used very few plastic materials. With the shift in emphasis towards utilising recycled materials, minimising the impacts on the environment and eliminating the disposal of materials to landfill, recycled plastic is now being considered as a viable alternative to traditional construction materials.

Plastic is currently recycled into a number of forms suitable for use in coastal and fluvial construction projects. It can be extruded continuously into square or circular cross-sections and it can be transformed into lumber, the plastic alternative to timber, or turned into piling, providing an alternative to steel. Recycled plastic lumber and piling is available from a number of different companies in the UK. Contact details for some of these are provided in Chapter 7.

Some recycled plastic products, such as ‘Seapile’ and ‘Seatimber’ as manufactured by SEAWARD, are reinforced with poltruded fibreglass rods. The reinforcement can be adjusted in diameter and number to engineer the product to meet a wide range of stiffness requirements. Co-extrusion of a high density outer skin provides abrasion resistance and incorporates protection from ultraviolet degradation by the incorporation of stabilisers and pigments. The properties of these materials can be engineered to offer superior performance to traditional materials.

Recycled plastic has been used in coastal and fluvial construction projects in countries such as the United States for a number of years. Examples of applications to date include:

- toe boarding
- piling
- revetments
- groynes
- pier cladding
- dolphins
- training walls
- bridge protection
- navigation and marker piles
- geotextiles
- fendering
- pipe outfalls
- camels
- decking
- lock gates.

Some of these are illustrated in Figures 5.52 – 5.56.

In the UK, recycled plastic has not been used extensively. Some examples of its use are as follows.

Figure 5.52. Recycled plastic timber used in a guide wall on the Port Allen Lock on the Mississippi River (courtesy of SEAWARD)

Figure 5.53. Installing recycled plastic piling (courtesy of SEAWARD)

Figure 5.54. Composite marine piling installed as a replacement to a traditional wood fender pile (courtesy of SEAWARD)

- Piling has been used as navigation markers in the Solent.
- Trials have been carried out by the Environment Agency using recycled plastic lumber as toe protection in Edgware Brook (see Case example 5.7).
- Sheet piling has been used in groynes at Cleethorpes (see Case example 5.8).
- There are currently plans to use recycled plastic for an outfall support structure in Portsmouth.
- Recycled plastic has been used in railings in Bournemouth and Felpham.

Case example 5.7 describes the use of recycled plastic piles and boarding in the bank protection at Edgware Brook.

Case example 5.7. Using recycled plastic in the bank protection at Edgware Brook, Edgware, North London (information courtesy of the Environment Agency)

In March 1995 the Thames Engineering Group was asked to investigate various alternative solutions for the problems of collapsed revetments and banks in Edgware Brook. A number of the proposed solutions used recycled plastic piling and toe boarding. Each solution was trialled along a stretch of the bank.

No difficulties were encountered in procuring the works. Plastic toe boarding was found to be easy to work with and light to handle but the plastic piling did not drive very well and proved difficult to keep on line. Figures 5.55 and 5.56 show the recycled plastic toe boarding four years after installation.

Figure 5.55. Recycled plastic toe boarding, Edgware Brook, North London (courtesy of the Environment Agency)

Case example 5.7. continued

Figure 5.56. Recycled plastic toe boarding, Edgware Brook, North London (courtesy of the Environment Agency)

Some of the advantages and disadvantages of using recycled plastic materials in the Edgware Brook trials are outlined below.

Advantages of using recycled plastic toe boarding included:

- perceived durability
- easy to handle
- aesthetically pleasing
- flexible to work to the profile of the river
- similar price to hardwood timber
- meets Environment Agency objectives on environmental issues.

Disadvantages of using recycled plastic toe boarding included:

- flexed a bit too much and had to be tied back to the existing bank
- limited cross-sectional profiles available at the time
- design properties not well defined by the suppliers.

Advantages of using recycled plastic piling included:

- lightweight and easy to handle, cut and drill.

Case example 5.7. continued

Disadvantages of using recycled plastic piling included:

- limited pile cross sections were available at the time
- piles were difficult to drive and some piles split on top
- colour limitations.

After experiences from the trials, the Environment Agency concluded that it would use recycled plastic toe boarding again in other projects but would pay closer attention to its design properties, particularly in bending. The Environment Agency would not, however, use the same type of recycled plastic piling in other projects owing to the difficulties encountered and the poor overall results.

Some of the engineering benefits of using recycled plastic products, as given by the manufacturers, include the following:

- not subject to corrosion or rot
- impervious to marine borers
- absorbs impact energy without damage to either party (e.g. fenders)
- requires no coating system
- resistant to abrasion
- maintenance free
- does not splinter
- readily worked with conventional equipment
- permanent colour
- available in custom lengths
- waterproof
- non-leaching
- resistant to most acids and chemicals.

Some of the constraints on the use of recycled plastic products in the UK include the following:

- industry standards are not yet developed
- there is a range of products with differing performance standards
- they are not widely available
- there is little experience of their use among engineers, designers and contractors
- unreinforced extruded or moulded plastic may experience thermal movement and deformation
- plastic manufactured in combination with materials that have different thermal properties, e.g. steel, can experience stress and may crack.

Case example 5.8 describes the use of recycled plastic in the groyne field at Cleethorpes.

Case example 5.8. Use of recycled plastic in groynes at Cleethorpes

Recycled plastic timbers were used in the construction of groynes in the coast protection scheme at Cleethorpes in 1996. No problems were encountered during installation. Constructing the groynes using recycled plastic was found to be similar to using Douglas Fir. Owing to a restriction in the availability, timber was used for the 5 m piles and recycled plastic was used for the 3 m piles. At the time, recycled plastic was slightly more expensive than the equivalent amount of Douglas Fir.

Table 5.6. Typical properties of products containing recycled plastic

	Recycled plastic products		
Property	Plaswood*	Seatimber†	Seapile‡
Density (kg/m^3)	883	600–730	710–870
Modulus of Elasticity, *E* (Mpa)	780	517	3963
Maximum stress in bending (Mpa)	–	5·9	33·8

* 3 in. × 3 in. — no reinforcement (Dumfries Plastic Recycling Ltd)
† 8 in. × 12 in. — no fibreglass reinforcement (SEAWARD)
‡ 30 mm diameter using 8 Nr × 32 mm diameter reinforcement (SEAWARD)

Some of the engineering properties of recycled plastic materials are quoted in Table 5.6. The quoted values are meant as a guide only and may vary depending on the stress ranges and load durations tested. Further, more detailed information, can be obtained from the manufacturers.

The design life of recycled plastic products is quoted by manufacturers as being greater than 30 years. As this is a new material in coastal and fluvial construction, the historic information is not available to verify this. The life of recycled plastic materials in the outdoor environment is very dependent on the use of ultraviolet stabilisers as plastics are susceptible to degradation by sunlight. Carbon black is often used to colour the plastic and to prevent sunlight from penetrating the material. Recycled plastic used in the ground, as is the case with piling, can be expected to last longer than plastic exposed to the sun.

There is no information currently available on the embodied energy of recycled plastic products. It would seem that the energy consumed during the transport phases would be a large contributing factor.

5.8.6. Reuse, recycling and disposal

The majority of plastic materials can be recycled repeatedly without any degradation of the polymer. However, difficulties in collecting, sorting, cleaning and reprocessing mean that at present it is only viable to recycle a few types from post consumer sources. The three most commonly recycled plastics are PET, HDPE and PVC, i.e. code numbers 1 to 3 (see Table 5.5). Thermosetting plastics such as bakerlite cannot be readily recycled.

It is possible to incinerate plastic waste under controlled conditions in high temperature incinerators to recover the inherent energy. Research conducted in 1995 by the British Plastics Federation indicated that energy recovery from plastic waste is an environmentally acceptable option. The trials suggested that plastic waste could be combusted in a modern Energy from Waste plant within current emission limits (Recycling World Magazine, 1996). This is the most common way of disposing of plastic in the United States.

Recycled plastic materials are inert generally and pose few environmental hazards if disposed of at landfill sites. However, there are potential environmental impacts from leachates that may result from reactions between chlorine bearing plastics and codisposal industrial wastes. Little research has been conducted in this area to date.

Incineration and disposal to landfill are regarded as the least desirable options for the environment and opportunities for reuse and recycling should be investigated first.

5.9. RUBBER TYRES

5.9.1. *Raw materials and extraction*

Around 60–70% of the rubber consumed worldwide is used to produce tyres (CIRIA, 1999). In 1996 around 37 million car and truck tyres (~380 000 t) reached the end of their first lives in the UK. They were put to the following uses (Environment Agency, 1999):

- 31% — retreaded
- 27% — energy recovery
- 26% — landfill or stockpiling
- 11% — material recovery in the form of granulate
- 5% — physical reuse.

A proposed European Commission Directive to ban the disposal of whole tyres and tyre crumb to landfill sites by 2003 and 2006 respectively, means that new uses for the 26% of tyres currently disposed of in this way must be found.

5.9.2. *Transport to the processing facility*

Rubber tyres can be processed into bales by mobile balers and in this case it may not be necessary to transport them to a processing facility. Tyres used to produce rubber crumb are generally transported by road or rail to the processing facility.

5.9.3. *Production and processing*

There are three main ways that rubber tyres can be reused, recycled and utilised in coastal and fluvial engineering projects. These are:

- direct reuse, e.g. bank protection, breakwaters, fenders and artificial reefs (see Case examples 5.9 to 5.11) — the tyres require no further processing
- compressed and baled into blocks using a mobile tyre baler and used in bank protection and dam wall construction
- processed into rubber crumb and used in landscaping, soil conditioning, concrete and asphalt.

5.9.4. *Transport from the processing facility to the construction site*

Reclaimed tyres or recycled rubber materials are usually transported to the construction site by road. The bulky nature of tyres means that transport impacts and costs are potentially higher than for other materials. Typical energy usage values for each mode of transport are given in Table 5.1.

5.9.5. *Construction, use and maintenance*

Direct reuse of rubber tyres

Whole tyres have been successfully used to construct artificial reefs, revetments and breakwaters in low-energy wave environments in numerous countries around

Case example 5.9. Floating tyre breakwater, Port Edgar, Lothian (Motyka and Welsby, 1983)

The floating tyre breakwater, shown in Figure 5.57, was built in Port Edgar, Lothian from truck tyres in 1979. The structure successfully reduced wave action in the harbour. Waves with periods of up to five seconds were damped significantly. The major problem encountered at this site was the growth of marine organisms on the structure causing a loss of buoyancy. This required regular maintenance.

This floating tyre breakwater is still operating effectively to this day.

Figure 5.57. Floating tyre breakwater

the world, including Australia, the United States and Israel. There are few examples of their use in the UK. Case examples 5.9 to 5.11 describe a number of applications in which whole rubber tyres have been used.

Case example 5.10. Tyre and post revetment, Oak Harbour, Washington, USA (Motyka and Welsby, 1983)

The tyre and post revetment in Oak Harbour, shown in Figures 5.58 and 5.59, consisted of two lines of vertical posts driven into the beach. Car tyres filled with gravel were laid over the posts and a filter cloth was placed between the tyres and the backfill. The structure performed successfully but the gravel fill inside the tyres was lost.

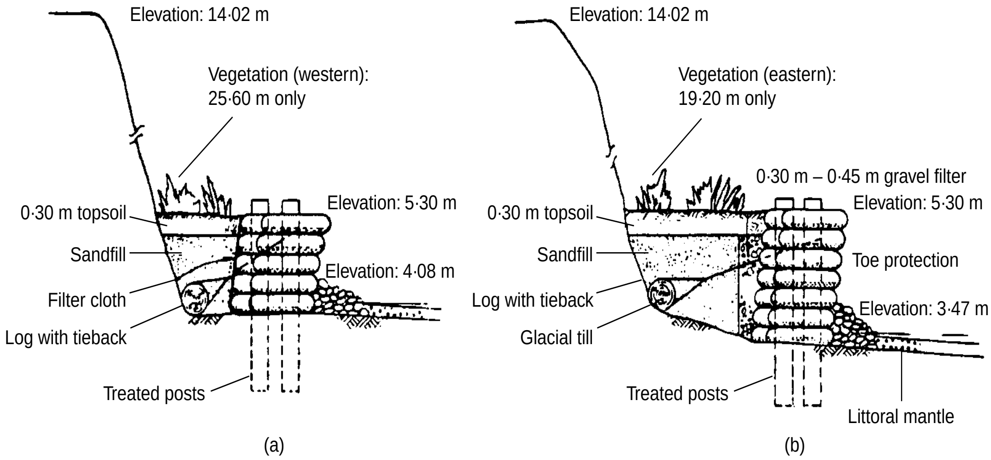


Figure 5.58. Tyre and post revetment (side view) (Motyka and Welsby, 1983)

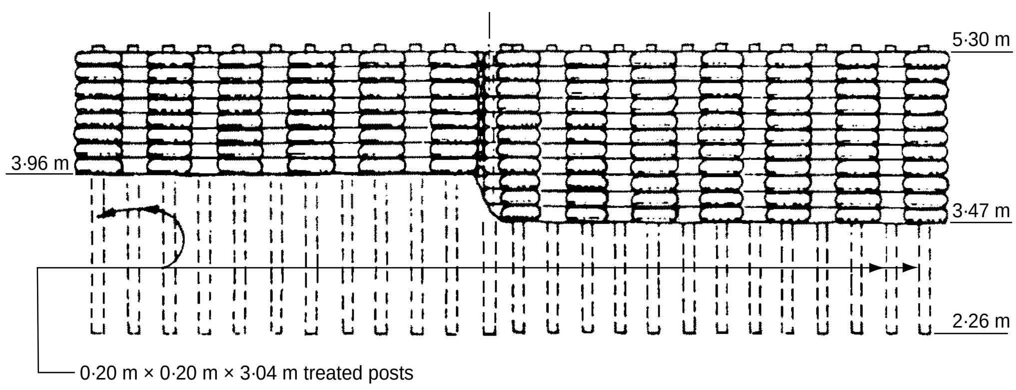


Figure 5.59. Tyre and post revetment (front view) (Motyka and Welsby, 1983)

Case example 5.11. Rubber tyre vertical defence in the River Bure, Norfolk (Environment Agency — Anglian Region)

The Environment Agency has used rubber tyres in bank protection along the River Bure. This was carried out as part of a trial along with other methods of bank protection and proved to be successful. However, it did prove difficult to install the tyres underwater as horizontal connections could not be obtained and backfill material was lost owing to the movement of the tyres under wave attack. The structure can be seen in Figures 5.60 and 5.61.

In a recent inspection, the tyres had partially filled with silt and had good reed growth behind.

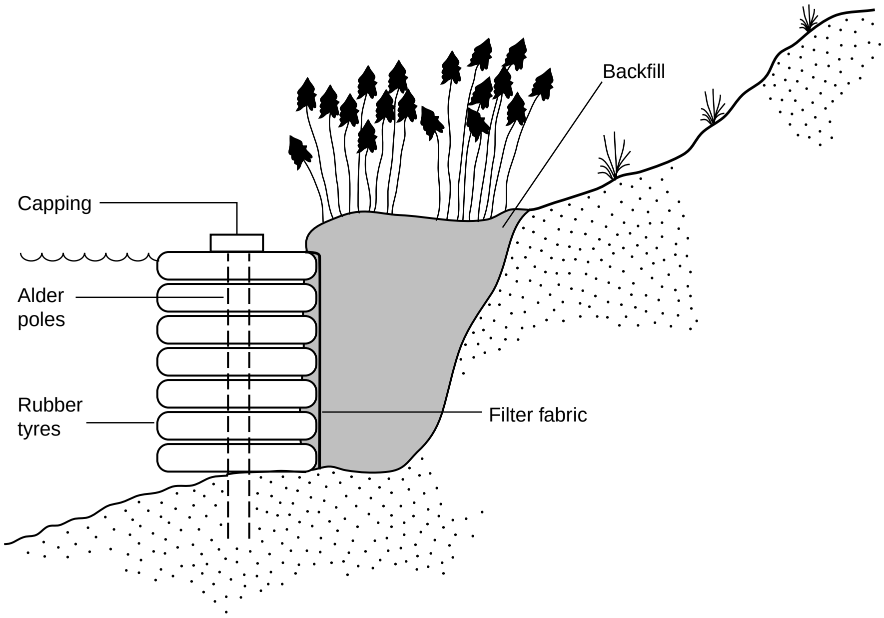


Figure 5.60. Tyre and post bank protection (schematic)

Figure 5.61. Tyre and post bank protection

Processing of tyres into rubber crumb

Twenty mm long rubber shreds made from (preferably) lorry tyres are used in an asphalt mix which is then used to fill a geotextile, e.g. Enkamat A20 or Geomat DM20. Three per cent rubber shreds are included in the asphalt mix.

The matting is 20 mm thick and is supplied as pre-fabricated rolls on a spindle. It is used for erosion protection in areas of limited wave and current attack, and is permeable. Grass seed is placed under the matting and grows through to make the construction acceptable aesthetically.

Tyres have traditionally been used as cheap fenders in ports and harbours around the UK.

Some of the problems commonly encountered with structures built from scrap tyres include (Motyka and Welsby, 1983):

- loss of buoyancy in floating structures owing to the growth of marine organisms (this requires regular maintenance)
- difficulties with tyre to tyre connections
- shifting of anchors
- trapping of debris
- loss of backfill material.

Many of these problems can be addressed and maintenance aspects, such as the removal of marine growth, should be considered at the design stage.

Reusing whole tyres in coastal and fluvial engineering can have a number of drawbacks and environmental impacts. Some of these include:

- the tyres can be rendered unsuitable for other methods of recycling and energy recovery
- there are potential environmental risks from leachates (little research has been conducted in this area to date, some research is currently being undertaken at both the University of Southampton and the University of Hertfordshire)
- they are generally not aesthetically pleasing (especially if the structures are damaged and tyres are washed onto beaches or down river systems — this can be mitigated through careful design)
- degradation of the rubber compound resulting in crumbling of the rubber and exposure of the wire reinforcement (no information is available as to the time period over which this occurs)
- potential fire hazard from vandalism.

Tyre baling

The technology is now available to compress and bale whole scrap tyres into cubes that can be used in sea defences and bank protection. Each cube has the following characteristics:

- weighs around 800 – 900 kg
- contains around 100 passenger car and light truck tyres
- has dimensions of approximately 30 in. × 50 in. × 60 in.
- has a density of around 544 kg/m^3.

Some of the advantages of the baler, as described by the manufacturer, include:

- it is relatively inexpensive when compared to shredding systems
- two operators can produce up to six bales an hour
- bales are easily handled with a forklift, front-end loader or grappler
- bales are stacked easily due to their uniform shape
- fire risk is reduced due to decreased surface area and lack of air.

Tyre bales have been used to stabilise the bank of the Pecos River in New Mexico. This is discussed further in Case example 5.12.

The environmental impacts associated with using tyre bales are similar to those from using whole tyres as discussed in the previous section.

Case example 5.12. Using tyre bales to stabilise the bank of the Pecos River in New Mexico

Tyre bales were used in 1997 to stabilise the bank of the Pecos River in New Mexico in the United States of America. There was bank erosion due to the wave action caused by passing water traffic. Around 700 000 recycled scrap tyres were utilised in the project.

The river was drained and the tyre bales were placed in a trench about 1 m deep along the river's edge. They were placed on a concrete foundation containing steel reinforcing bars and were encapsulated in concrete. A concrete block retaining wall was constructed on top of the bales and fill was placed behind. The process is illustrated in Figures 5.62 and 5.63.

More information on the uses and properties of the tyre bales can be obtained from Encore Systems. Contact details can be found in Chapter 7.

Figure 5.62. Placing the tyre bales in the trench (courtesy of Encore Systems)

Figure 5.63. Constructing the retaining wall above the concrete coated tyre bales (courtesy of Encore Systems)

Processing of tyres into rubber crumb

Tyres can be processed to produce a rubber crumb. This material has many applications, some of which include asphalt, fill or backfill, sports surfaces, landscaping, bollards, manhole covers, carpet backing and bumpers. In 1996, 11% of waste tyres were converted into tyre granules in the UK (Environment Agency, 1999).

There are currently limited uses in coastal and fluvial engineering for products made from tyre crumb. Low grade applications such as fill, mulch or soil conditioning may be viable if concerns over the potential for chemical leachates can be addressed.

The properties of recycled rubber are not as good as virgin rubber as it has already been vulcanised. For this reason using recycled rubber limits the properties of the finished product.

There is a possibility that products, such as lumber, similar to those made from recycled plastics may appear in the future.

There is limited information available on the environmental impacts of the use of tyres in the hydraulic environment. The major current concern in the UK is the potential for chemical leachates. Laboratory studies have found evidence of zinc leachates when tyres are placed in saline conditions. In Canada, studies have shown that tyres immersed in freshwater produce a leachate that is toxic to fish. The toxicity was shown to decrease once the tyres were submerged for a period of around three months. As tyres degrade over time, leachate concentrations can increase once more.

Studies conducted in America show that metals are leached most readily at low pH and organics are leached most readily at high pH. For this reason it is recommended that shredded tyres are used in environments with a neutral pH. Field studies have shown that tyre shreds used as fill can leach manganese, iron and organics in low levels when used below the water table. Further research is needed to determine whether the levels are high enough to be of concern (American Society for Testing and Materials, 1998).

The conclusions of other research conducted into leachates from tyres are inconclusive and additional research is required in order to quantify the potential hazards.

Other environmental impacts from the use of tyres in coastal and fluvial engineering include:

- visual impacts
- energy consumption during transport
- carbon dioxide emissions during transport
- potential fire risks from vandalism.

Constraints on the use of recycled rubber tyres include:

- concerns over leachates
- visual impacts
- lack of products
- little application to date.

5.9.6. *Reuse, recycling and disposal*

Tyres that have been reused are generally rendered unsuitable for further reuse and recycling. There are, however, opportunities to reclaim their energy value.

There are a number of ways in which the energy value of tyres can be reclaimed. Some of these include:

- incineration to provide electricity
- as a fuel in cement kilns
- undergoing controlled pyrolysis to provide gas, oil, carbon and steel.

Tyres have a high energy content and a calorific value greater than coal and have been incinerated for energy recovery for over 20 years in the UK. The Environment Agency regulates emissions from plants utilising scrap tyres as a fuel and ensuring that they are within consent limits. In addition to providing energy, a number of materials can be recovered from the process including steel, zinc oxide and calcium salts.

Tyres disposed of in landfill sites can cause instability at the site and can pose a fire hazard. There are also concerns over the potential for chemical leachates. The conditions at landfill sites can sometimes trigger uncontrolled pyrolysis of the tyres producing a complex mixture of chemicals.

5.10. OTHER SECONDARY MATERIALS

Information on the potential for using secondary materials in low grade applications can be found in other publications. For this reason, they are not discussed in any detail in this manual. Further information on the uses and properties of materials such as bricks, china clay waste, colliery spoil, blastfurnace slag and pulverised fuel ash can be found in *The reclaimed and recycled construction materials handbook* (CIRIA, 1999).

5.11. COMPARISON OF PRIMARY MATERIALS

This section aims to provide the reader with an overview of the information on the environmental impacts and considerations associated with the various construction materials presented in Sections 5.2 to 5.8. This is achieved by a series of checklists which can be used to ensure that the environmental impacts throughout the life cycle of each material have been considered.

The environmental impacts covered by the Ecopoints estimator spreadsheet are indicated in the checklists in italics. A description of how to use the Ecopoints estimator spreadsheet and a full list of the impacts considered in the calculations are provided in Appendix 6.

The checklists cover the following.

- Environmental impacts from the extraction of raw materials (Checklist 5.1).
- Environmental impacts from production and processing (Checklist 5.2).
- Environmental impacts from the transport of materials (Checklist 5.3).
- Environmental impacts from construction (Checklist 5.4).
- Identifying potential opportunities for reuse and recycling and considering potential environmental impacts from disposal (Checklist 5.5).

Checklist 5.1. Potential environmental impacts from the extraction of raw materials (impacts in italics are included in the Ecopoints estimator spreadsheet)

Carbon dioxide emissions
Energy consumption
Impacts upon climate
Production of solid waste
Production of liquid waste
Alteration of water tables
Impacts upon water quality
Heavy metal pollution
Interruption of groundwater flows
Habitat disturbance
Loss of biodiversity
Depletion of raw material reserves
Visual impacts
Noise
Vibrations
Loss of potential medicines
Impacts on native people
Impacts on topsoil
Acid mine drainage
Particulate emissions to air
Particulate emissions to water
Interruption of surface water flows
Damage to commercial fisheries
Disturbance of benthic flora and fauna
Impacts on coastal processes
Resuspension of sediments/contaminants

Checklist 5.2. Potential environmental impacts from production and processing (impacts in italics are included in the Ecopoints estimator spreadsheet)

Carbon dioxide emissions
Emissions of SO_x and NO_x
Energy consumption
Impacts upon climate
Production of solid waste
Production of liquid waste
Impacts upon water quality
Heavy metal pollution
Visual impacts

Noise
Particulate emissions to air
Particulate emissions to water
Potential hazards from preservatives and treatments

Checklist 5.3. Potential environmental impacts from transport (transport impacts in italics are accounted for in the Ecopoints estimator spreadsheet and account for transport during raw materials extraction, production and processing and transport to the construction site)

Carbon dioxide emissions
Emissions of SO_x and NO_x
Energy consumption
Noise
Disturbance to local communities
Particulate emissions to air
Particulate emissions to water
Potential hazards from fuel spillages

Checklist 5.4. Potential environmental impacts from construction and use (these are not accounted for in the Ecopoints estimator spreadsheet)

Carbon dioxide emissions
Energy consumption
Production of solid waste
Production of liquid waste
Impacts upon water quality
Vibrations
Noise
Visual impacts both during and after construction
Particulate emissions to air
Particulate emissions to water
Potential hazards from preservative or fuel spills
Excavation can upset sediment balance
Habitat disturbance
Disruption of the local community from delivery traffic and heavy plant
Temporary material stockpiles can extend beyond the site
Potential for toxic leachates
Potential fire hazards

Checklist 5.5. Identifying potential opportunities for reuse and recycling and considering potential environmental impacts from disposal

Can the material be reused?
Can the material be recycled?
Can the material be incinerated for energy recovery?
What are the environmental impacts from disposal to landfill (toxic leachates, occupying valuable landfill space)?

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6

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Further information

7

7. Further information

This section contains contact details, Internet addresses and further references of relevance to this manual.

7.1. CONTACT DETAILS

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Website: www.bl-pegson.com

Prospector Concrete Recycling Systems
Pepper House
Market Street
Nantwich
Cheshire
CW5 5DQ
Tel: 0800 7311800
Fax: 01270 624994

Recycled plastic suppliers
Commercial Marine & Piling Ltd (UK Distributor for Seaward)
Second Floor Office Suite
Lynes House
6 Lynes Lane
High Street
Ringwood
Hampshire
BH24 1DA
Tel: 01425 489600
Fax: 01425 489606

Seaward International, Inc.
PO Box 98
3470 Martinsburg Pike
Clearbrook
VA 2264-0098
USA
Tel: (540) 667 5191
Fax: (540) 667 7987
Website: www.seaward.com

Dumfries Plastics Recycling Ltd
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DG2 0BU
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Tel: 01387 247110
Fax: 01387 247109

Timber companies and organisations
Recycled Greenheart Developments
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SGS Forestry
Oxford Centre for Innovation
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OX2 0JX
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Recycled tyres
Encore Systems
PO Box 247
585 NW 3rd Street
Cohasset
MN 55721
Tel: (218) 328-0023
Fax: (218) 328-0024
Email: baler@northernnet.com

Tyre Casings Ltd (UK Distributor for Encore Tyre Baler)
Unit 1051
Tattersett Business Park
Sculthorpe
Fakenham
NR 21 7QZ
Tel/Fax: 01485 528080

Certification bodies
SGS United Kingdom Ltd
Yorkshire House
Chapel Street
Liverpool
L3 9AG
Tel: 0151 255 1115
Fax: 0151 258 1511
Website: www.sgs.co.uk

Soil Association Woodmark Scheme
86 Colston Street
Bristol
BS1 5BB
Tel: 0117 929 0661
Fax: 0117 925 2504

Miscellaneous

T.J. Recycled Materials
22 Highwood
61 Shortlands Road
Bromley
Kent
BR2 0JJ
Tel/Fax: 0181 464 2602

7.2. FURTHER REFERENCES OF RELEVANCE

Clough, R. and Martyn, R. (1995). *Environmental impact of building and construction materials. Volume D — Plastics and elastomers*. CIRIA Project Report 14.

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Appendices

Appendix 1.
The role of the organisations responsible for flood and coastal defence

A1.1. FLOOD AND COASTAL DEFENCE LEGISLATION AND RESPONSIBILITIES

Coastal and fluvial defence is defined as the reduction in risk to land from erosion or inundation by sea or fresh water.

Coastal defences, with a primary design function of preventing or mitigating erosion are referred to as coast protection. Initial responsibilities emanated from the Coast Protection Act 1939 which has now been superseded by the 1949 Act.

Coastal defences with a primary function of preventing or mitigating flooding from the sea (sea defences), and alluvial defences designed to reduce the risk of river flooding and tidal inundation, are referred to as flood defence. Traditionally, these have been encompassed within land drainage law which has a long history (see *Land drainage and flood defence responsibilities* [ICE, 1996] for more details).

The present law is contained principally within:

- Coast Protection Act 1949 (CPA 1949)
- Water Resources Act 1991 (WRA 1991)
- Land Drainage Act 1991 (LDA 1991), as amended by the later Acts of:
  - Land Drainage Act 1994 (LDA 1994)
  - Environment Act 1995 (EA 1995)

A particular feature of coast protection and flood defence responsibilities is that they are both dependent on permissive powers rather than mandatory legal duties. The provision of coastal and flood defences in England and Wales is a partnership between the Government and local operating authorities (as shown in Figure A1.1). In Scotland, the Unitary Councils and the Scottish Office are responsible for the provision of flood defences.

In England, local operating authorities are responsible for identifying the need for defences, for examining the range of options within a consultation framework and for selecting a scheme that meets the Ministry of Agriculture Fisheries and Food's technical, economical and environmental criteria. These bodies are also responsible for the construction, maintenance and operation of the scheme.

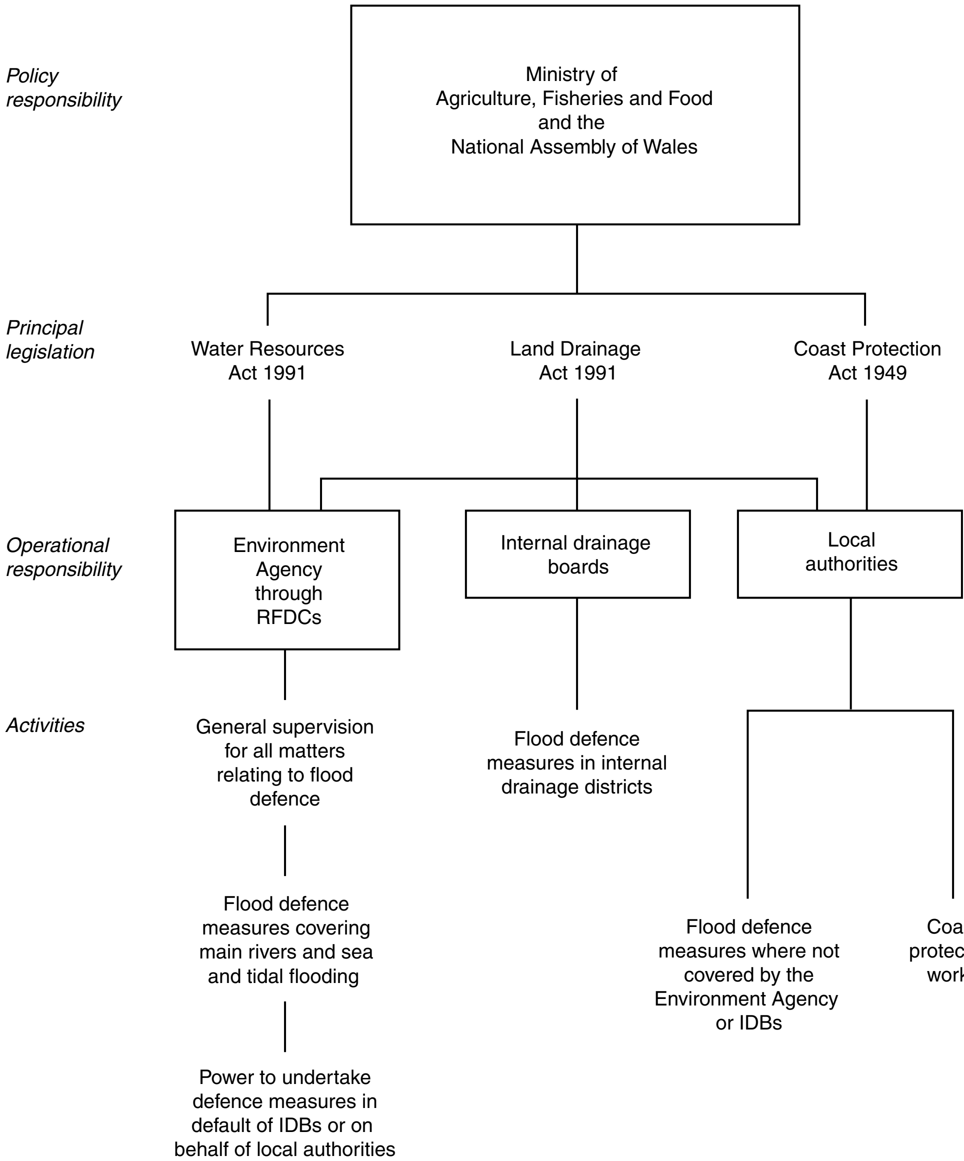


Figure A1.1. Flood and coastal defence organisation in England and Wales

In practice, the responsibilities of the District Council and the Environment Agency on any particular frontage overlap and local agreements are in place to avoid duplication. In many areas, it has been agreed that where the land behind the defences is generally above the mean high-water level (MHWL) responsibility lies with the District Council and where protected land is below the MHWL the Environment Agency are responsible for the defences.

The organisation of responsibilities associated with coastal and fluvial engineering in England and Wales is shown in Figure A1.1.

A1.2. GOVERNMENTAL RESPONSIBILITY

In England and Wales, the Ministry of Agriculture, Fisheries and Food (MAFF) and the Welsh Office have policy responsibility from the Government, overall administrative responsibility and a supervisory role with respect to land drainage, flood and coastal defence matters. MAFF's role in flood defence is to set national priorities and to provide guidance on the technical, economic and environmental criteria to be applied. MAFF also provide grant aid to the local operating authorities for proposed schemes that meet these criteria and they provide funding for research and development work.

Under the LDA 1991 and the WRA 1991, MAFF has a number of statutory powers and duties in overseeing the Environment Agency for England and Wales and also the internal drainage boards and local authorities when they act within their land drainage capacity.

MAFF has similar powers and duties under the CPA 1949 with regard to maritime district councils (councils, including unitary authorities, which have a sea frontage).

A1.3. THE ENVIRONMENT AGENCY

The Environment Agency was established under the Environment Act 1995. The Environment Agency took over the land drainage and flood defence duties and powers of the National Rivers Authority and has the overall duty to provide 'a general supervision over all matters relating to flood defence'. The responsibilities of the Environment Agency are defined mainly within the EA 1995 and the WRA 1991. The Environment Agency has the power to maintain and construct new drainage works and flood defences (both fluvial and coastal). It also has the power to consent to new structures crossing main rivers (whether in, under or over) and on any aspect likely to affect the flow of water in a watercourse.

Under the EA 1995, all of the Environment Agency's functions relating to flood defence are overseen by regional flood defence committees which have executive powers. Local flood defence committees are established in areas where they are deemed necessary.

A1.4. INTERNAL DRAINAGE BOARDS

The responsibilities and functions of the internal drainage boards (IDBs) were set out in the LDA 1991 and were established in areas where flood protection is required to sustain low-lying land for agriculture and developed land purposes. There are about 250 IDBs in England and Wales and their function relates mainly to land drainage and watercourses other than main waterways. The main function of an IDB is to exercise supervision of all aspects relating to the drainage of land within their area and to conduct work on waterways to maintain and improve existing works and construct new works.

A1.5. LOCAL AUTHORITIES

Local authorities have responsibilities and powers similar to those of internal drainage boards under the LDA 1991. The local authorities also have responsibilities relating to flood prevention and the mitigation of damage caused by flooding. This includes the power to maintain and improve existing defences and to construct new works (both fluvial and coastal). Consent for new works is normally required from the Environment Agency.

Under the CPA 1949 the council of each maritime district in Great Britain was made a coast protection authority with permissive powers in connection with the protection of the coastline in their area. Each maritime district council has the powers to promote, construct and maintain coastal defence works along their frontage and to generally exercise supervision of all aspects of coastal protection.

Appendix 2. International standards and initiatives aimed at improving environmental performance and sustainability

A2.1. ENVIRONMENTAL MANAGEMENT SYSTEMS (BS 7750)

Environmental management systems (EMS) are management approaches that aid an organisation to identify, monitor and control its environmental impacts. The first standard that set out the requirements of an environmental management system was BS 7750: *Specification for environmental management systems* (BSI, 1994).

The concept is similar to ISO 9000 (ISO, 1994) for quality systems. The standard only provides the framework for the development and assessment of an environmental management system with the methods to be used left to the organisation to define. The basis of BS 7750 is the Environmental Policy. This should be fully supported by senior management and should outline the policies of the company to both staff and the general public. The policy should clarify how the organisation conforms to relevant environmental legislation and should include a commitment to continual improvement. The various steps involved in the development of an environmental management system are outlined below (CIRIA, 1995e).

- Confirming commitment and undertaking an initial review.
- Defining the scope of the company's products, services and activities.
- Defining environmental policy.
- Defining organisation and responsibilities.
- Compiling a register of regulations and effects.
- Setting objectives and targets.
- Implementing control, recording and reviewing systems.
- Refining a policy and targets in the light of these reviews.
- Having performance audited.

BS 7750 is now designed to be compatible with the European Community's Eco-Management and Audit Scheme and the International Standard ISO 14001 (ISO, 1996) (see below).

A2.2. ECO-MANAGEMENT AND AUDIT SCHEME

The Eco-Management and Audit Scheme (EMAS) is a European initiative that encourages industry to manage its environmental effects and to report to the public on its environmental achievements. EMAS can be seen as an extension to environmental management systems (such as BS 7750) where the emphasis is on continual environmental improvement and on informing the public rather than the main concern being an organisational management system. As such, EMAS tends to be site based rather than organisation based.

EMAS is voluntary and, at present, is currently available only to industries in the manufacturing, mining, power generation, recycling and waste disposal sectors but it will be extended to a much wider range of sectors in due course.

The steps involved in getting EMAS registration are set out in Box A2.1.

A2.3. ISO 14000

The ISO 14000 series is the new international standard (ISO) environmental management system based on BS 7750. Its aim is to provide a coherent standard that covers the range of environmental management, auditing, eco-labelling and other standards that had been developed by various countries. The relationship between ISO 14001 and EMAS is still not exactly clear as the wording of ISO 14001 does not exactly meet the prescriptive requirements of EMAS

The ISO 14000 standard is designed to cover the whole area of environmental issues for organisations. This can be separated into two principal areas: those with

Box A2.1. EMAS registration route

1. Prepare an *environmental policy*. This sets the environmental priorities of the company and must include a commitment to:
   - comply with relevant environmental regulations
   - continuous improvement of environmental performance.
2. Undertake an *environmental review*. This looks at the current environmental performance of the site, including issues such as waste, raw materials use and energy consumption, and identifies to the site management how the performance can be improved.
3. Develop an *environmental programme* that contains specific objectives and targets for improving the site's environmental performance.
4. Put in place an *environmental management system* (such as BS 7750 or ISO 14001) to ensure the successful implementation of the policy and programme. This ensures that members of the workforce know who is responsible for achieving specific goals.
5. Carry out periodic *audits* to check the environmental performance against the goals that have been set to improve performance.
6. Prepare a concise *environmental statement* that sets out the environmental performance of the site and explains how the site's environmental impacts are being managed.
7. Have the environmental statement, and the systems and policy of the site, *validated* by an independent verifier to ensure that the information is accurate and that the requirements of the scheme are being met.

Table A2.1. The ISO 14000 series

Standard	Title/description
14000	Guide to environmental management principles, systems and supporting techniques
14001	Environmental management systems — specification with guidance for use
14010	Guidelines for environmental auditing — general principles of environmental auditing
14011	Guidelines for environmental auditing — auditing procedures — Part 1: auditing of environmental management ssystems
14012	Guidelines for environmental auditing — qualification criteria for environmental auditors
14013/15	Guidelines for environmental auditing — audit programmes, reviews and assessments
14020/23	Environmental labelling
14024	Environmental labelling — practitioner programs — guiding principles, practices and certification procedures of multiple criteria programs
14031/32	Guidelines on environmental performance evaluation
14040/43	Life Cycle Assessment general principles and practices
14050	Glossary

an organisational focus that have EMS standard (ISO 14001) as the basic guidance document and those with a product focus that have the ISO 14040 (ISO, 1997) series on Life Cycle Assessment (LCA) as a basic guidance document.

The EMS standards were published in 1996 with the LCA standards due to be published in 1998. The list of standards is provided in Table A2.1.

A2.4. ECO-LABELLING

The EU Community Eco-labelling scheme involves identifying those products with the lowest environmental impact in a product range. The principal aims of the eco-labelling scheme are to:

- promote the design, production, marketing and use of products that have a reduced environmental impact during their entire life cycle
- provide consumers with better information on the environmental impact of products.

In practice, the scheme involves three general phases: the establishment of criteria; the award of the label to products; and the revision of the criteria. The scheme is based on Life Cycle Assessments (see Chapter 3) of each of the products in a product group. However, agreement on the process and comparison methods has proved difficult to date.

The eco-labelling scheme requires each of the Member States of the EU to set up a Competent Body that is independent and neutral and which will coordinate and promote the development of schemes for different product groups, and award the label. The label allows the product to display the Eco-label logo (daisy) and is valid in all EU Member States and in Norway, Iceland and Liechtenstein. At present, there are approximately twenty eco-labelling schemes worldwide.

The scheme aims to provide guidance to consumers, and as such is consumer and not industry related. At present, there are no primary construction materials that have undergone the eco-labelling process.

Appendix 3.
Life Cycle Assessment

Life Cycle Assessment (LCA) is basically a decision support tool. It is a comparative analysis process that evaluates the direct and indirect environmental burdens associated with a product, process or activity. Used correctly it can ensure that choices made by an organisation are environmentally sound at all stages of the particular life cycle. However, LCA or associated methodologies should not be used to claim that a particular product is *environmentally friendly* but should be used to determine the relative performance against a specified set of criteria.

Life Cycle Assessment techniques can contribute to environmental management systems and they are a requirement for many environmental labelling schemes (see Appendix 2). They are also an integral part of the ISO 14000 standard that is currently being developed. The ISO 14000 series can be separated into two particular areas: the environmental management system standard (ISO 14001), as the foundation document, and the ISO 14040 series on LCA, which has a product focus. As such, the majority of the life-cycle studies that have been conducted have had a customer rather than an industry focus.

The following summary is based on the methodologies and terminology provided by the ISO environmental management systems, tools and standards of LCA (note that some of the parts are still under development). The SETAC guidelines (SETAC, 1991), the Nordic guidelines on LCA (Lindfors, 1995) and the summary provided in a report on LCA for the European Environment Agency (Jensen *et al*., 1998) are also used.

The techniques described in the following sections complement other environmental management initiatives such as Design for the Environment (DfE) and Green Procurement and these initiatives are summarised in more detail in Appendix 5.

A3.1. LIFE CYCLE ASSESSMENT: METHODOLOGICAL FRAMEWORK

There is no standard way of conducting a Life Cycle Assessment and the technique can be applied using various degrees of complexity (see Section A3.6). The important aspect is to retain the life cycle approach to assessing choices (known as Life Cycle Thinking). Common to all LCA is a general framework, but the particular tools and methodologies can be selected depending on the particular application.

The SETAC guidelines (SETAC, 1991) defined three components of an LCA to provide the information required to result in environmental improvement:

- Life Cycle Inventory
- Life Cycle Impact Analysis
- Life Cycle Improvement Analysis.

These are described in more detail below.

This has since been extended to include goal and scope definitions (ISO, 1997). The technical framework is shown in Figure A3.1.

The following description of the methodological framework for conducting an LCA is based on the report by Jensen *et al.* (1997), which provides a detailed introduction to LCA. Further, more detailed information can be provided by reference to this text, to the ISO 14040 series or to the Nordic guidelines (Lindfors, 1995).

A3.2. GOAL AND SCOPE DEFINITION

The goal and scope has a strong influence on the magnitude and level of sophistication of the resulting LCA, and the intended use and audience for the results. This phase covers the following main areas (Jensen *et al.*, 1997):

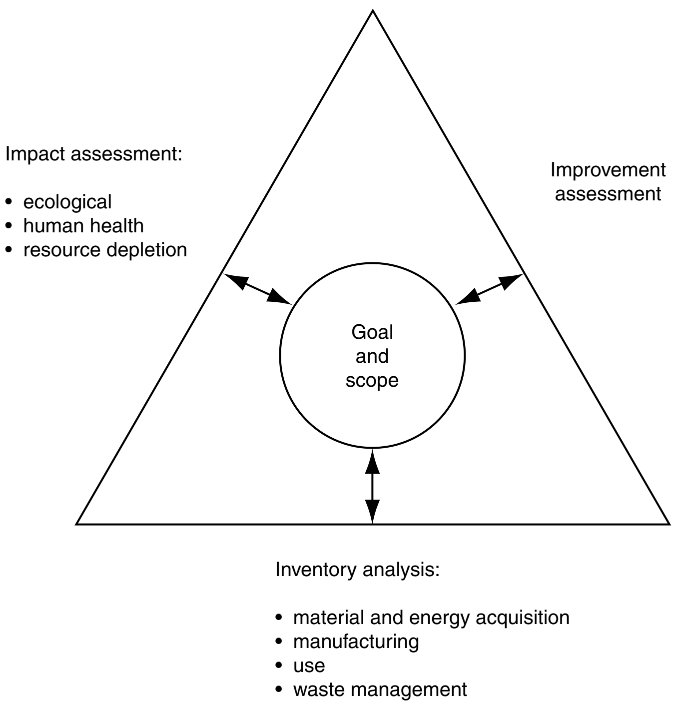


Figure A3.1. Life cycle assessment—technical framework (Jensen et al. *(1997) based on Consoli* et al. *(1993))*

- goal
- scope
- functional unit
- system boundaries
- data quality
- critical review process.

Goal

The definition of the goal of an LCA is an important part of the overall process, as it will determine the required level of sophistication for the study. It should include:

- the intended application and the reasons for carrying out the work
- the intended use of the results and the intended audience for the results.

Scope

The scope of the LCA sets the boundaries for the study, i.e. what is and what is not included and what methodologies are to be used.

The definition of the scope of the Life Cycle Assessment sets the borders of the assessment — what is included in the system and what detailed assessment methods are to be used.

Functional units

The functional unit is the basic performance measurement used to normalise input and output data and to compare products or systems within the LCA. The result of an LCA study will define the environmental burdens associated with the functional unit. In the context of waste management, common functional units include:

- per unit weight of municipal solid waste
- per unit number of 'household equivalents' of solid waste collected
- the quantity of solid waste collected from a given geographical area.

System boundaries

The system boundary defines a process or operation and the inputs and outputs identified for that particular process (see Figure A3.2).

This analysis is normally concerned with the systems that produce products rather than the particular product. As such, the system is defined as the operations that perform some defined function (SETAC, 1991). However, the definition of system boundaries can be more subjective and include aspects such as geographical boundaries. In a particular system three areas of operation are required to be identified (SETAC, 1991).

(*a*) The main processing sequence — the operations associated with production, that use transportation and the disposal of the product.
(*b*) The production of ancillary materials — for example, packaging or equipment required to process raw materials that are input into the main processing sequence.

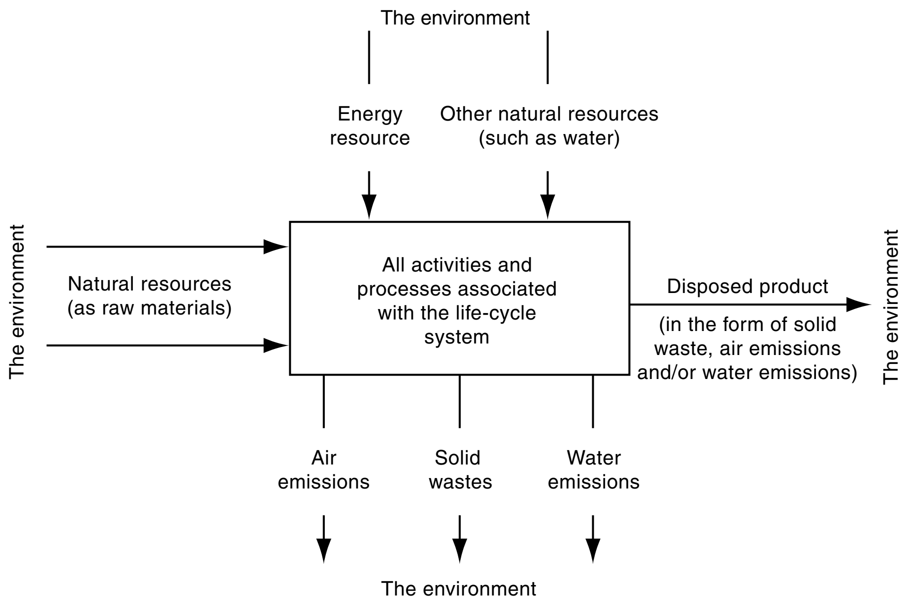


Figure A3.2. Illustration of life-cycle system concept (Boguski, 1996)

(*c*) The fuel production industries — i.e. the energy input needed to drive the system.

The system boundary (and LCA) would generally exclude things such as:

- the manufacture and maintenance of capital equipment
- the maintenance of manufacturing establishments, i.e. heating and lighting
- factors common to each of the products or processes under consideration (where different products are being compared).

The performance of a system is assessed by breaking the overall system into a series of sub-systems at such a level that each of the sub-systems represents a physical operation involving inputs and outputs. In essence, each of these sub-systems can be considered a system in its own right with an input of energy and materials, and an output of a usable product and environmental releases including all inputs and outputs associated with ancillary processes and materials.

It is unlikely that all sub-systems can be adequately included within the study, for example owing to data, time or cost constraints. In defining the system boundaries, the level of detail needs to be decided upon and the assumptions and process used to define the boundaries should be identified clearly.

Data quality

The goal and scope of the study define the requirements with regard to the quality of the data used, e.g. whether qualitative information, generic or specific data are used. ISO 14040 (ISO, 1997) suggest that the data quality should consider:

- time-related coverage
- geographical coverage
- technology coverage
- precision, completeness and representativeness of the data
- consistency and reproducibility of the methods used throughout the LCA
- sources of the data and their representativeness
- uncertainty of the information.

Critical review process

The review process within the LCA has not yet been developed to include certification or accreditation by external parties (such as in quality assurance or environmental management schemes). However, a critical review of the study can be conducted by either internal or external experts, independent of the study, or by an interested party that can include stakeholders.

A3.3. LIFE CYCLE INVENTORY (LCI)

Much of the work involving LCA has traditionally concentrated on assessing the inventory stage. This stage is concerned with collating data to quantify the inputs (e.g. energy and raw materials) and the outputs (effluents, wastes and other releases) throughout the life cycle of the particular product. The inventory stage is summarised in Figure A3.3. In general, each of the six stages involves the use of materials and energy (inputs) and results in both usable product(s) and wastes, effluents or emissions (outputs).

Within the context of Figure A3.3, the inventory stage considers the following main areas (Jensen *et al*., 1997):

- data collection
- refining system boundaries
- calculation
- validation of data
- relating data to the specific system.

Data collection

Collation of data for LCA is often the most labour-intensive part of the whole process. Data can either be in the form of *site-specific* data, e.g. from specific organisations, countries, etc., or more *general* data, e.g. industry averaged data and governmental data. Average data can also be found in the literature from previous studies of a similar nature or from data published by trade organisations.

Data need to be collated for all systems (or sub-systems) identified within the life-cycle process but depending on the level of the LCA, the data can also be either qualitative or quantitative. The quality of the data is a vital part to the overall credibility of the LCA (see above).

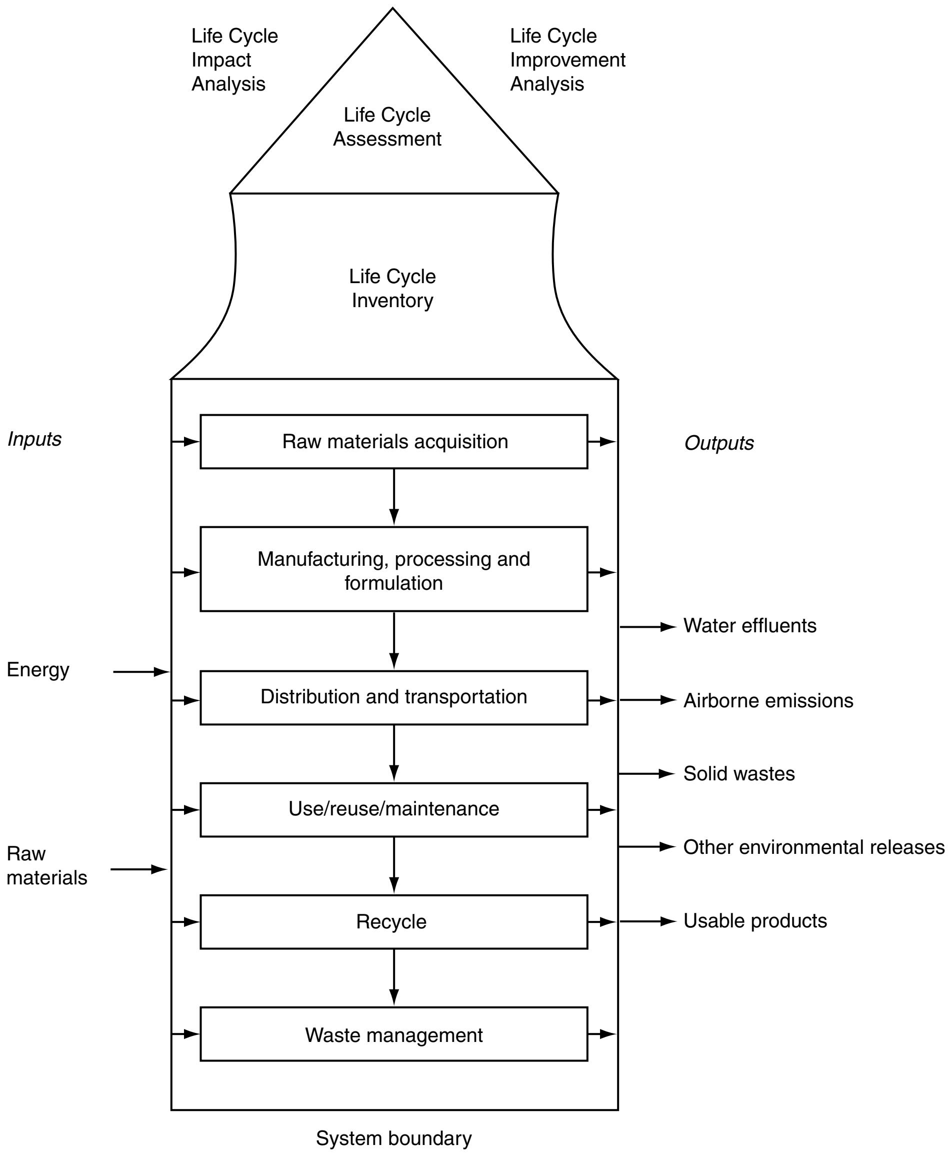


Figure A3.3. Relationship between the inputs, outputs and the six stages of a Life Cycle Inventory (SETAC, 1991)

Refining system boundaries

An inventory analysis is an iterative process. As data are collated, the system boundaries can be revised by including new processes that have been shown to be significant, or conversely, excluding insignificant processes.

Calculation

The complexity and volume of data collated will determine the method of calculation. The calculation procedure involves quantifying the energy flows associated with each system and where there are multiple products, assessing the relative allocation of energy usage and waste production for each product.

Relatively simple LCA studies can be conducted using a spreadsheet. However, there are many software programs written specifically for Life Cycle Assessment. For example, LCA software reviews have been conducted by, among others, Menke *et al*. (1996) and de Caluwe (1997).

Validation of data

Data validation is an iterative process to identify where data quality may need to be improved or where data should occur in other processes.

Relating data

The data collected during the study may not be related to the required reference energy flow or functional unit for the particular product under assessment. For example, the data may be in the form of energy consumption/machine/timescale or total quantity of wastewater for the entire site. These data need to be related to the particular functional unit for the system under assessment.

A3.4. LIFE CYCLE IMPACT ASSESSMENT

The impact assessment aims to use the results obtained during the inventory analysis to determine the significance of potential environmental impacts. The potential contribution of each system input and output to each impact category is estimated. As in the inventory stage, the level of detail will depend on the goal and scope of the study. ISO 14040 (ISO, 1997) identifies that the following elements could be included at the impact assessment stage:

- classification (grouping together the inputs and outputs of the inventory stage into categories)
- characterisation (translation of the inventory classification into impact descriptors)
- weighting (if possible, assessing the relative impacts of different categorisations).

Data collected during the inventory is classified into a number of impact categories in order to define the particular impacts. These impact categories can be placed on a scale based on the magnitude of their geographical impact, i.e:

- global impacts
- continental impacts
- regional impacts
- local impacts.

There have been a number of different lists of impact categories and these are summarised in Jensen *et al*. (1997). ISO 14040 defines the impact categories as shown in Table A3.1.

Table A3.1. Description of ISO 14040 impact categories (adapted from Jensen et al.*, 1997)*

Impact category	Description	Scale
Abiotic resources	Deposits, e.g. fossil fuels, mineral ores, aquifers, sediments, clay, peat, gravel, etc. Funds, e.g. groundwater, surface water, soil Natural flow resources, e.g. air, water, solar radiation and ocean currents	Global
Biotic resources	Fauna (fish, etc.) and flora	Global
Land use	Land as a resource for humans, e.g. area for food production Land use related to ecosystems and landscape degradation, landscape fragmentation, desiccation, habitat alterations and impacts on, e.g., biodiversity	Local
Global warming	Influence of increasing temperature in the lower atmosphere	Global
Stratospheric ozone depletion	Decomposition of the stratospheric ozone layer causing increased incoming UV radiation	Global
Ecotoxicological impacts	Effect of ecosystems of exposure to and effects of chemical and biological substances	Global, continental, regional, local
Human toxicological impacts	Effect on humans of exposure to and effects of chemical and biological substances	Global, continental, regional, local
Photochemical oxidant formation	Degradation of organic compounds (VOCs) in the presence of light and nitrogen oxide resulting in photochemical ozone formation ('smog' as a local impact and 'tropospheric ozone' as a regional or continental impact)	Continental, regional, local
Acidification	The effect on terrestrial and aquatic ecosystems due to acidification effects (e.g. acid rain)	Global, continental, regional, local
Eutrophication	Enrichment of aquatic ecosystems with nutrients leading to increased production of plankton algae and higher aquatic plants leading to a deterioration of the water quality and a reduction in the value of the utilisation of the aquatic ecosystem	Continental, regional, local
Work environment	Human toxicological effects due to exposure to chemical or biological substances such as: • acute toxicological effects • irritation	Local

Table A3.1. continued

	• allergenic reactions
	• genotoxicity
	• carcinogenicity
	• neurotoxicity
	• teratogenicity
	• non-chemical effects caused by working conditions:
	  ◦ hearing impairment
	  ◦ psychological damage
	  ◦ pain in muscle
	  ◦ pain in joints.

Potentially, the most difficult part of the LCA is weighing up the relative environmental impact of the various categories. For example, if product A has higher water usage but lower carbon dioxide emissions than product B, which has the greater impact on the environment? Weighting aims to rank, weight, or possibly aggregate the results of the various Life Cycle Impact Assessment categories in order to arrive at the relative importance of the various category impacts. Weighting can be achieved by applying scientific-based analytical techniques (both qualitatively or quantitatively). It can also be based on other factors, such as political, social or ethical values. A summary of various methodologies is provided by Jensen *et al*. (1997) and de Caluwe (1997).

There are no standard methodologies for conducting Life Cycle Impact Assessments, i.e. associating data collected during the inventory with environmental impacts. This is an area that is still being developed and any method adopted needs to be defined clearly. An explanation of the weighting methodology employed by the BRE in the UK is explained in Section 4.4.2.

A3.5. LIFE CYCLE INTERPRETATION

The Life Cycle Interpretation stage brings together the inventory and assessment stages to develop the conclusions and recommendations of the study. The interpretation stage is conducted in conjunction with the other stages, e.g. if the results of the inventory or impact stages do not meet the objectives set out in the goal and scoping stage, then the inventory or impact assessment is revised or improved. The resulting aim of the interpretation stage is to identify the key results of the inventory and impact stages to inform the decision-making process.

The interpretation stage consists of the following issues (ISO, 1997).

Identification of significant environmental issues

The first part of the interpretation stage is the identification of the key environmental results. This is normally based on the impact categories identified during the impact assessment. The scale of the environmental issues considered will depend upon the level of complexity defined at the goal and scope stage.

Evaluation

The objective of the evaluation stage is to determine the confidence in the results by conducting at least three of the following elements (ISO, 1997d).

- Completeness check — qualitative check of the data selected to ensure that the environmental issues identified are adequate in representing the data collected from the inventory and impact assessment.
- Sensitivity check — the estimation of the sensitivity of the results to variations in the input parameters. This is normally done by using established uncertainty simulations, e.g. Monte Carlo simulations).
- Consistency check — qualitative check normally conducted during comparative studies to ensure that all methods, procedures, etc., have been conducted in a consistent manner. Jensen *et al*. (1997) suggest the following items need to be checked for consistency:
  - regional and/or temporal differentiations
  - system boundaries
  - allocation methods
  - differentiation between foreground and background processes
  - valuation/weighting methods.

The evaluation stage may also be supplemented by the following:

- uncertainty analysis
- data quality assessment
- conclusions and recommendations.

The reporting of the conclusions and recommendations of an LCA are much the same as for any other study.

A3.6. APPROACHES TO CONDUCTING A LIFE CYCLE ASSESSMENT

The previous section has outlined the methodological framework for conducting an LCA based largely on the ISO 14000 guidelines and the ongoing work conducted by SETAC. Life Cycle Assessments can be conducted in a number of ways, all of which should be applied within the methodological framework outlined above. However, the purpose of the LCA should dictate the approach (i.e. the complexity) to be adopted (which should be defined at the goal and scope stage). In addition to the purpose, there are a number of other issues that may also need to be considered when selecting the appropriate approach:

- the required and available data quality
- the decision-making timescale
- the value of additional data
- who the intended target audience is.

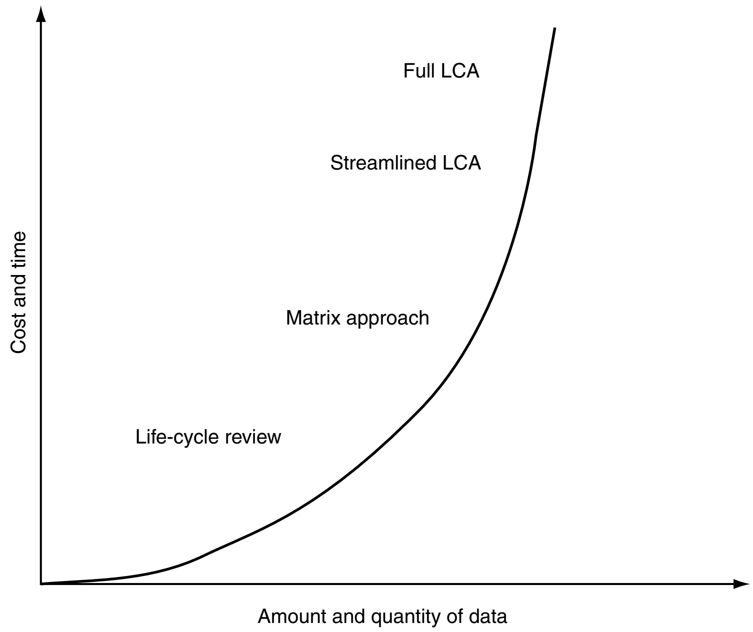


Figure A3.4. Different approaches to LCA

The cost and time required tends to increase exponentially with increased LCA complexity. This is illustrated in Figure A3.4.

The main approaches to LCA (Christiansen, 1997) can be summarised as:

- Life Cycle Thinking or conceptual LCA
- streamlined or bottleneck LCA
- full quantitative LCA.

These approaches are outlined below. It should be noted that there is no distinct point where one approach finishes and another starts. Instead, the approaches should be considered as a continual increase in detail.

Life Cycle Thinking or conceptual LCAs

The SETAC EUROPE LCA Screening and Streamlining Working Group uses the term Life Cycle Thinking (Christiansen *et al*., 1997) to describe a mainly qualitative approach to identifying stages of the life cycle and/or the most significant environmental impacts. The Life Cycle Thinking approach is applied by a design or engineering team to account for the potential environmental impacts, both upstream and downstream, of a product. Data used within this approach is based typically on qualitative statements or very general quantitative information. The main benefit of the approach is that it begins to focus consideration of the full life cycle of the material or system for minimal cost and can provide an overall understanding of the relative environmental advantages, disadvantages and areas of uncertainty of a particular product, material or service.

The basis of Life Cycle Thinking (as with all LCA) is a simple flow chart or process tree showing all of the main stages and components in a product's life cycle. This will help to identify system boundaries where material and energy flows into the life cycle and where wastes and a particular product are released. Such a process may also help to identify what processes are worth including in a more detailed study and what can be left out without having a major impact on the results, for example:

- limiting the inventory by omitting one or more stages of the life cycle
- by concentrating on fewer parameters, for example considering only the energy used (see Section 3.3 on embodied energy), or considering particular emissions only.

The results of a conceptual LCA can be presented either qualitatively, e.g. via statements, or by using simple scoring systems, such as matrices, to indicate which materials or which step in the life cycle has the largest environmental impacts and why. Further details of approaches to conceptual LCAs are provided in Section 3.4.

Streamlined, bottleneck or simplified LCAs

A streamlined, bottleneck or simplified LCA is a limited LCA where the aim is to obtain similar results to a full quantitative LCA but with much reduced cost and time. This is achieved by simplifying or omitting areas of the LCA that do not significantly affect the overall result (streamlining) or by concentrating on a particular critical part of the life cycle (bottleneck).

The SETAC EUROPE LCA Screening and Streamlining Working Group summarises simplified LCA as (Christiansen *et al*., 1997):

> an application of the LCA methodology for a comprehensive screening assessment, i.e. covering the whole life cycle but superficial, e.g. using generic data (qualitative and/or quantitative), standard modules for transportation or energy production, followed by a simplified assessment, i.e. focusing on the most important environmental aspects and/or potential environmental aspects and/or stages of the life cycle and/or phases of the LCA and a thorough assessment of the reliability of the results.

Jensen *et al*. (1997) summarise three stages of a simplified LCA.

(*a*) Screening. This involves identifying the systems, stages or flows (i.e. material or energy entering or leaving the system) that are important or have limited data. For example, identifying the areas that have maximum environmental impact or the areas where a particular emission is released. Screening should cover all parts of the life cycle to ensure that all the key issues are covered but if necessary coverage can be relatively superficial.

(*b*) Simplifying. Based on the screening assessment, further work can be focused on the important parts of the life cycle, system or elementary flows ensuring that the critical environmental impacts can be identified.

(*c*) Assessing reliability. A check of the whole simplified LCA process should be conducted to ensure that the simplifications adopted are not detrimental to the overall result.

Data used within a simplified LCA can be either (or a combination of) qualitative and quantitative (both specific and generic) information and data. For example, specific data is often collected for the acquisition and processing or manufacturing stages but generic data is often used for transportation or waste disposal stages. An important aspect of a simplified LCA is to ensure that the limitations adopted are explicitly defined.

Quantitative or comprehensive LCA

A full LCA is usually quantitative, relying on specifically measured and calculated data collated over the entire life cycle of a product. The completeness and quality of the available or collated data is normally the determining factor in the extent of the LCA. Data sources can be primary (such as site-specific data) or secondary (such as published reports) and can include (Lewis, 1996):

- industry reports (internal and external)
- laboratory test data
- government reports
- journals, books and patents
- databases
- trade associations
- consultants
- related Life Cycle Assessments.

The most common source of data for full LCA studies is site-specific company data.

A full LCA should address all aspects required by the methodological framework of an LCA. It should collate appropriate data for all significant system processes identified and it should assess the accuracy and precision of this data. Uncertainty or sensitivity testing should also be conducted to assess the influence of the various input parameters. The study methodology should also be consistent throughout the entire study and reproducible.

Full LCA studies require a great deal of time and expenditure. For LCAs associated with consumer items the costs can often run into millions of pounds.

Appendix 4. Embodied Energy Analysis: methodological framework

Treloar (1996) identified four main methodologies for Embodied Energy Analysis:

- process analysis
- input–output analysis
- statistical analysis
- hybrid analysis.

A brief outline is provided below. Further, more detailed descriptions of the various methodologies are provided by Treloar (1996).

Process analysis

The methodology of a process type analysis is similar to that used in an LCA where system boundaries are established. The main aim is to derive an energy intensity for each specific material. The main steps in process analysis consist of the following.

(*a*) Definition of the main process. This involves the identification of a system boundary around a particular process. Four conventions of defining a particular process were proposed by the International Federation of Institutes for Advanced Study (1974):

(i) basing the energy analysis on only one significant output from the process
(ii) basing the energy analysis on the financial value of the outputs of the system
(iii) basing the energy analysis on the physical parameter that best characterises the output of the system
(iv) basing the energy analysis on the energy requirements according to the savings that could be made by making one less of the product (rarely relevant to the energy analysis of construction materials).

(*b*) Measurements of all direct energy requirements and the output of the process, over a reasonable period of time.

(*c*) Identification of inputs of other products required by the main process.
(*d*) Determination of embodied energy in each product required by the main process.

Energy analysis using the process analysis method can often be incomplete owing to the heavy requirement of detailed data. Many studies have been conducted previously where only the most significant parts of the process have been studied in detail thus limiting the completeness within the system boundary.

Statistical analysis
This methodology uses general industry or government statistics to derive a national or regional energy intensity value for a national or regional industry. The method is general and does not provide the necessary detail to accurately determine the embodied energy of a particular construction material, for instance, largely due to local effects caused by the variability in the sourcing, processing and manufacturing part of the life cycle.

Input – output analysis
An input – output analysis is a development of the statistic analysis based on input – output matrices (which provide relationships between complex systems). In many Western countries such matrices are compiled by governments to map the flow of goods and services, normally in financial terms, between sectors of the economy. The direct energy intensity of a particular sector can be obtained from the input – output coefficients associated with the sales of a particular energy supply sector and the national average unit cost of that energy. Indirect energy can also be assessed using the input – output matrices. As the input – output analysis method again uses general data, it is generally not as accurate as the process analysis method but does not require the detailed level of data required in a process analysis.

Hybrid analysis
In a hybrid analysis, process and input – output analysis methods are merged, combining the benefits of both techniques and minimising their respective limitations. The direct energy and quantities of goods and services are obtained for critical aspects of the process under consideration by process analysis, with the energy intensities of goods and services further upstream obtained using input – output analysis.

A4.1. USE OF EMBODIED ENERGY ANALYSIS

There has been a wide range of studies analysing the embodied energy associated with particular materials or products. In construction, the methodology has been applied most commonly to construction products associated with buildings with organisations in the UK, USA, the Scandinavian countries, Australia and New Zealand having conducted much of the work. A good literature review on significant work conducted in this field is provided by Treloar (1996) although this is biased to the Australian market. Information on work conducted in the UK, within the context of the construction industry, is provided in Chapter 4.

Embodied Energy Analysis of construction materials or complete structures is often conducted in conjunction with other assessments (which can also be part of an LCA), for example:

- primary material usage
- CO_2 emissions
- air pollution (e.g. sulphur dioxide, nitrous oxides, methane, particulate and volatile organic compounds)
- solid waste generation
- water pollution
- water usage
- environmental cost.

Appendix 5. A description of the simplified tools used within Design for the Environment

A5.1. NEGATIVE CHECKLISTS

Negative checklists are lists of materials to be avoided in a particular product owing to some environmental impact during the life cycle of a product. The checklists are simple to use but do not provide any method of comparing environmental impact between two materials, e.g. whether a larger quantity of a particular material has less of an impact than a smaller quantity of an alternative material. Checklists can be found in the appendices of the book *Industrial ecology* (Graedel & Allenby, 1996) and *Excluded materials: an industry survey* (CIRIA, 1996).

A5.2. MATRIX BASED APPROACHES

A matrix based approach is a common tool used in conceptual LCAs. It relies largely on professional judgement rather than the use of collated quantitative information on the inputs and outputs of a particular system or stage in the life cycle. There is a large number of different matrix based approaches available that have been developed to suit particular requirements. Almost all follow the same pattern of environmental concern along one axis and life-cycle stages or system boundaries along the other axis. For example, a common approach is to classify the environmental impacts at the various stages under material usage, energy and toxic emissions. A qualitative or quantitative scoring system can be developed to identify the stages in the life cycle where the largest environmental impacts occur or to provide a general qualitative overview of the relative performance of different materials. The matrices can be as complex or as simple as required.

A5.3. INDICATORS AND PRE-DEFINED WEIGHTING INDICES

Indicators can be selected to represent the overall environmental impact of a product. Potential indicators can include quantities or ratios of materials, energy consumption, transportation distances, percentage recyclability and waste generation. Generic indicators, such as 'total hazardous material emitted', should not be used as this can be misleading. For example mercury emissions are much more toxic than similar volumes of other metals.

Pre-defined weighting indices, commonly known as Eco-indictors, are values that express the total environmental load or process in a single figure. The most common method has been developed by Prè in 1995 but other methods are also available, e.g. ECOPOINTS by the BRE. The approach allows a comparison between different products based on the environmental impact of the various materials and processes for a particular product.

The relative importance of different environmental effects is accounted for using weighting factors. The weighting factors were chosen based on a 'distance to target' principle (i.e. it is assumed that there is a correlation between the seriousness of the effect and the distance between the current level and the target level). The weighting factor is expressed as the reduction factor between the two levels.

In all of these indicator methods the assumptions on the relative importance of the various environmental effects is always the subjective part of the analysis. However, the methods do allow a relatively quick assessment of the potential environmental effects of a product's life cycle. The methods require different amounts of knowledge, experience, data and time. In the design process simple, qualitative methods may produce the most significant insights into the impacts of design decisions.

Appendix 6. Using the Ecopoints estimator spreadsheet

The Ecopoints estimator spreadsheet was developed by HR Wallingford and the BRE to enable the comparison of the environmental impacts of different design options at the project appraisal stage using ecopoints. The following environmental impacts are accounted for in the spreadsheet calculations.

Global issues

- climate change
- acid deposition
- ozone depletion
- air pollution (human toxicity and ecotoxicity)
- fossil fuel depletion
- marine water pollution (ecotoxicity and eutrophication).

Local issues

- air pollution (human toxicity and ecotoxicity)
- asthma
- river water pollution (human toxicity and ecotoxicity)
- eutrophication
- black smoke
- minerals extraction
- fossil fuel depletion
- water extraction
- waste disposal
- waste recycling
- transport pollution and congestion (people and freight).

The following explains how to use the Ecopoints estimator spreadsheet.

The Ecopoints estimator is a Microsoft Excel based spreadsheet and the following list of instructions outline the process to be followed.

1. Insert the CD-ROM containing the spreadsheet into the CD-ROM drive.
2. Open the spreadsheet by double clicking on the filename (estimator.xls).
3. A message will appear stating that the workbook contains macros, click on Enable Macros. The opening screen, as shown in Figure A6.1, will now appear.
4. Enter a name for the Ecopoint evaluation in the space provided for project name.

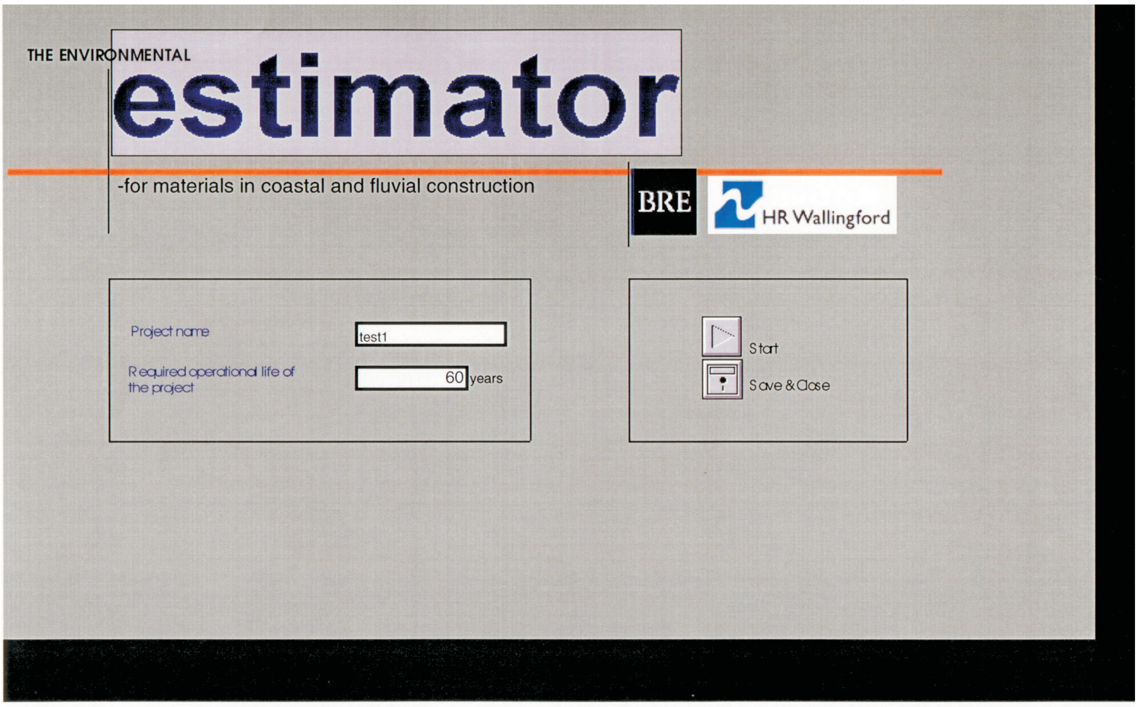
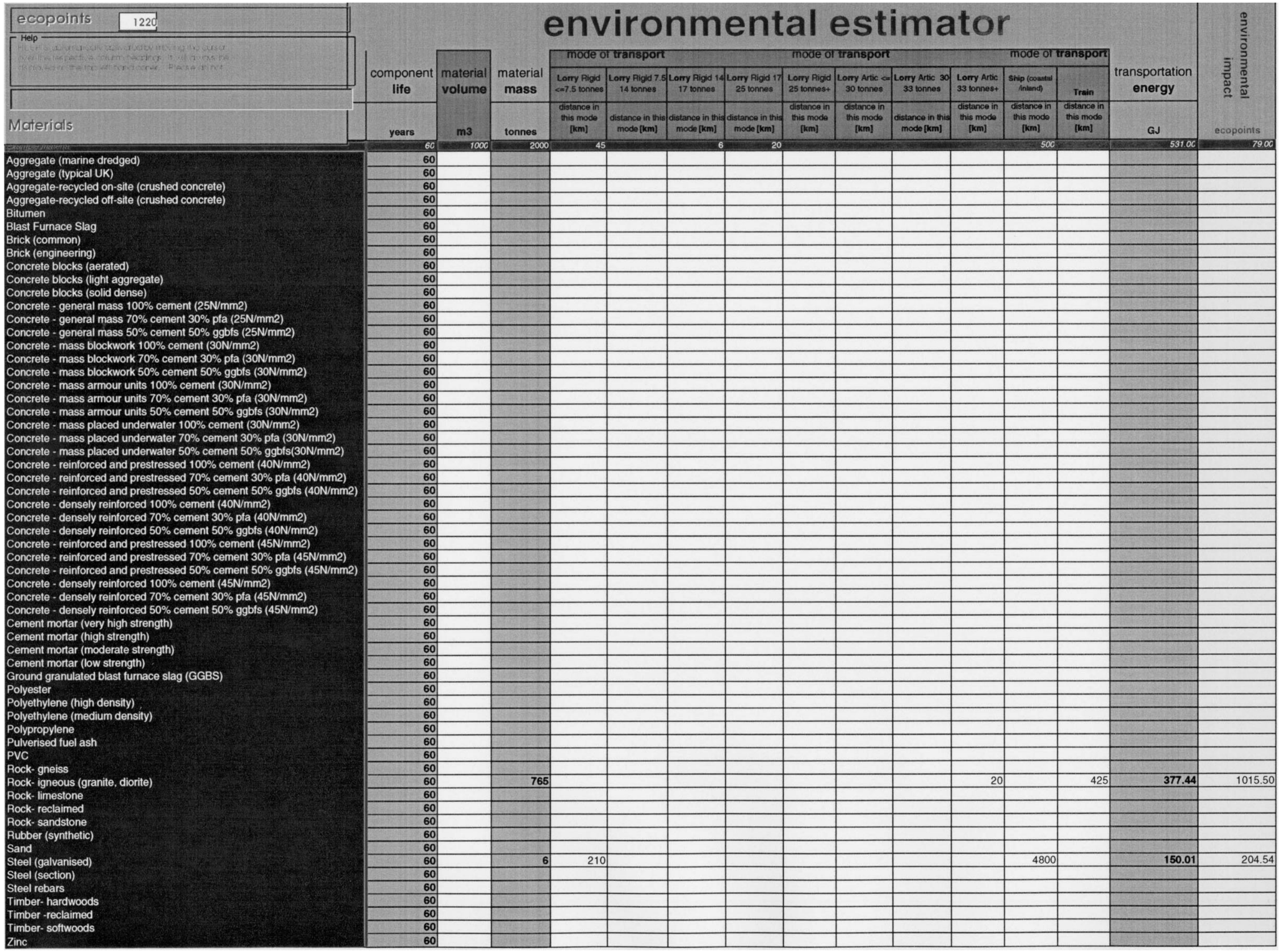


Figure A6.1. Opening screen of the Ecopoints estimator spreadsheet

5. Enter a design life, in years, for the structure to be evaluated.
6. Click on Start. The second screen, as shown in Figure A6.2, will now appear.
7. A warning box will appear stating not to click on the column headings — click on OK to remove this box.
8. If reliable information is available on the expected life of a component material and this differs from the design life of the structure, then enter this value, in years, in column 1 alongside the relevant material. If no suitable information exists then assume that the life of the component material is the same as the design life of the structure.
9. Enter the total amount of the material to be used in column 2 or 3, depending on whether the volume or mass is known. If a volume is entered, a mass will be calculated from an assumed density and will appear in column 3 automatically. Scroll across by clicking on the right arrow at the bottom right-hand corner of the screen. It can be seen that the Ecopoints associated with the upstream life cycle of that quantity of material appear along the same row in column 15. It can also be seen that the Ecopoints total box, located in the top left-hand corner of the screen, keeps a running total of the Ecopoints for all of the component materials in the structure being analysed.
10. Columns 4–13 contain different options for the transport of the material from the supplier to the construction site. (It should be noted that transport impacts during materials extraction and processing are already included in the Ecopoint calculation for each material and need not be included here.)



environmental estimator

ecopoints 1220

Materials	component life	material volume	material mass	mode of transport: Lorry Rigid <=7.5 tonnes	Lorry Rigid 7.5 14 tonnes	Lorry Rigid 14 17 tonnes	Lorry Rigid 17 25 tonnes	mode of transport: Lorry Rigid 25 tonnes+	Lorry Artic <= 30 tonnes	Lorry Artic 30 33 tonnes	Lorry Artic 33 tonnes+	mode of transport: Ship (coastal /inland)	Train	transportation energy	environmental impact
	years	m3	tonnes	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	distance in this mode [km]	GJ	ecopoints
	60	1000	2000	45		6	20					500		531.00	79.00
Aggregate (marine dredged)	60														
Aggregate (typical UK)	60														
Aggregate-recycled on-site (crushed concrete)	60														
Aggregate-recycled off-site (crushed concrete)	60														
Bitumen	60														
Blast Furnace Slag	60														
Brick (common)	60														
Brick (engineering)	60														
Concrete blocks (aerated)	60														
Concrete blocks (light aggregate)	60														
Concrete blocks (solid dense)	60														
Concrete - general mass 100% cement (25N/mm2)	60														
Concrete - general mass 70% cement 30% pfa (25N/mm2)	60														
Concrete - general mass 50% cement 50% ggbfs (25N/mm2)	60														
Concrete - mass blockwork 100% cement (30N/mm2)	60														
Concrete - mass blockwork 70% cement 30% pfa (30N/mm2)	60														
Concrete - mass blockwork 50% cement 50% ggbfs (30N/mm2)	60														
Concrete - mass armour units 100% cement (30N/mm2)	60														
Concrete - mass armour units 70% cement 30% pfa (30N/mm2)	60														
Concrete - mass armour units 50% cement 50% ggbfs (30N/mm2)	60														
Concrete - mass placed underwater 100% cement (30N/mm2)	60														
Concrete - mass placed underwater 70% cement 30% pfa (30N/mm2)	60														
Concrete - mass placed underwater 50% cement 50% ggbfs(30N/mm2)	60														
Concrete - reinforced and prestressed 100% cement (40N/mm2)	60														
Concrete - reinforced and prestressed 70% cement 30% pfa (40N/mm2)	60														
Concrete - reinforced and prestressed 50% cement 50% ggbfs (40N/mm2)	60														
Concrete - densely reinforced 100% cement (40N/mm2)	60														
Concrete - densely reinforced 70% cement 30% pfa (40N/mm2)	60														
Concrete - densely reinforced 50% cement 50% ggbfs (40N/mm2)	60														
Concrete - reinforced and prestressed 100% cement (45N/mm2)	60														
Concrete - reinforced and prestressed 70% cement 30% pfa (45N/mm2)	60														
Concrete - reinforced and prestressed 50% cement 50% ggbfs (45N/mm2)	60														
Concrete - densely reinforced 100% cement (45N/mm2)	60														
Concrete - densely reinforced 70% cement 30% pfa (45N/mm2)	60														
Concrete - densely reinforced 50% cement 50% ggbfs (45N/mm2)	60														
Cement mortar (very high strength)	60														
Cement mortar (high strength)	60														
Cement mortar (moderate strength)	60														
Cement mortar (low strength)	60														
Ground granulated blast furnace slag (GGBS)	60														
Polyester	60														
Polyethylene (high density)	60														
Polyethylene (medium density)	60														
Polypropylene	60														
Pulverised fuel ash	60														
PVC	60														
Rock- gneiss	60														
Rock- igneous (granite, diorite)	60		765								20		425	377.44	1015.50
Rock- limestone	60														
Rock- reclaimed	60														
Rock- sandstone	60														
Rubber (synthetic)	60														
Sand	60														
Steel (galvanised)	60		6	210								4800		150.01	204.54
Steel (section)	60														
Steel rebars	60														
Timber- hardwoods	60														
Timber -reclaimed	60														
Timber- softwoods	60														
Zinc	60														

Figure A6.2. Second screen of the Ecopoints estimator spreadsheet

The distance that the material travels from the supplier to the construction site (in km) should be entered into one, or more (if more than one mode of transport is used), of the transport columns. The energy used during this transport phase can be seen along the same row in column 14. Also, the Ecopoint totals located along the same row in column 15 and in the top left-hand corner of the screen have adjusted to include the impacts from transport.

11. Repeat steps 8 – 10 for each different material contained in the structure.
12. Once all of the information has been entered, a total Ecopoints score for that design option will have been calculated and appears in the Ecopoint total box, which is located in the top left-hand corner of the screen.
13. The result can be seen graphically by clicking on the graph button located underneath the total Ecopoints score box in the top left-hand corner of the screen.
14. To save the results, move back to the first screen and use the Excel menus located at the very top of the screen (*File — Save as*). The results will then be saved in the same location as the spreadsheet.
15. Repeat steps 4 – 14 for each design option to be analysed.
16. To close the estimator, move back to the first screen. Use either the Excel menus located at the very top of the screen (*File — Close*) or click on the Save & Close button located underneath the Start button on the right of the screen.

Please note

This estimator tool is based on LCA data derived in 1999. All LCA data are subject to change and will vary with time and due to on-going research and new data creation. The data contained in the tool are based on available data for generic products as used in the UK. Products from specific manufacturers and sources will have different impacts and the BRE works with manufacturers to produce product-specific Environmental Profiles. The weightings used in the Ecopoints methodology will be revised and updated in the future and will reflect current available data. For further information on other available data, updates and specific data enquiries, please contact the Centre for Sustainable Construction at the BRE on telephone 01923 664307 or e-mail enquiries@bre.co.uk.

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