Defra/Environment Agency
Flood and Coastal Defence R&D Programme

Engineering materials in flood and coastal defence

– Review of current knowledge

Technical Report W5A-069/TR/1

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ENGINEERING MATERIALS IN FLOOD AND COASTAL DEFENCE

- Review of current knowledge

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 ISBN: 1 8443 2292 0

Dissemination Status
Internal: Released to Regions and Areas
External: Released to Public Domain

Statement of use
This document provides a review of current knowledge on materials available for use in flood and coastal defence. Its principal purpose is to define and prioritise future research needs. It also summarises key references and information thus providing a useful overview for practitioners.

Keywords
Materials, flood defence, coastal defence, engineering properties, resilience, durability

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SUMMARY

Well informed and effective uses of materials are key factors in improving the sustainability of flood and coastal defences. A number of studies have been carried out to provide guidance on individual materials, but no comprehensive review has been done of the overall sector. This review examines both primary materials and recycled and secondary materials in order to indentify key gaps in knowledge available to flood and coastal defence practitioners.

Materials are considered in terms of (a) physical issues – strength, weight, durability etc; (b) economic issues – availability, whole life cost, adaptability (including buildability, maintainability, replaceability); and (c) environmental and social issues (compatibility with existing structures and natural features, social acceptance, ecological impact, and sustainability of use). Key references are given for each area and material type. These sections are written so as to be also informative to practitioners.

Future research needs are summarised in Section 5. Two key reference manuals are proposed on concrete and masonry. Other related work in proposed on pilot projects, particularly on recycled materials which will not be fully utilised unless improved standards and performance data are made available. The proposed research in this document will be considered with other potential funders in establishing the Joint Flood and Coastal Defence R&D Programme for 2005/06.

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1. BACKGROUND AND CONTEXT OF REVIEW

1.1 Introduction

Informed use of materials is a key factor in improving the sustainability of flood and coastal defences. In some areas, it is apparent that research is needed to support informed use of existing, novel and recycled materials. Such research is important not only to achieve practical engineering solutions (for example better fitness for purpose and durability) but also to support initiatives in reducing whole life costs and improving the environmental sustainability of engineering solutions. This review identifies the gaps that exist in present knowledge and guidance and indicates where future research and /or dissemination-cum-training activities are needed.

The review is the first of three parts of an initial phase of work on Engineering Materials commissioned with HR Wallingford as a Centre of Expertise in materials for flood and coastal defence tasked with co-ordinating the work of key experts in individual subject areas from other organisations. Its objective, as defined in the Work Plan for the Engineering Theme of Joint Defra/Environment Agency (EA) R&D Flood and Coastal Management, is to provide an overview / reference paper on engineering materials in flood and coastal defences that will both:

(a) inform practitioners, and
(b) identify gaps in current knowledge or available information requiring future research

The research methodology for this work was a combination of literature review and networking with key individual and organisations in order to identify:

- areas of need for guidance, some of which could be met by better collation and dissemination of, or training in, existing tools and techniques, and
- areas where new technologies and approaches held out the potential for improved practice if supported by appropriate R&D

The other two elements of this initial phase of work, which are being reported separately, are being carried out collaboratively with other national organisations:

1. A framework for prediction of performance (durability) of rock armour blocks in coastal defence structures, and related acceptance criteria for test results. (Whilst many of these issues have been encompassed within the work which has led to the preparation of BS EN 13383: Armourstone, the group preparing this accept that it has serious limitations, particularly in respect of testing for block “integrity” – the resistance to a susceptibility to failure along pre-existing planes of weakness.)

2. Provision of guidance to industry on the sustainable use of timber in coastal and fluvial construction. (This work is covered by a joint industry/government funded project under the DTI Construction Directorate “Partners In Innovation” programme.)

The overall Engineering Theme Objectives and Work Plan set the broader context of this review. In particular, it sets out seven technical objectives for the Engineering

Theme Work Plan, taken directly from the Rationale and Objectives (ROAME A statement) for the theme. Five of these objectives will potentially be impacted by materials research:

Objective 1: Understanding performance of defences to improve design, construction, operation and maintenance.
Objective 2: Improved design and management techniques to match performance of defences with their intended standard of service and potential loading conditions.
Objective 3: Reduced whole-life costs of defences.
Objective 4: Improved quality and efficiency of construction, minimising adverse environmental impact.
Objective 6: Improved flood resistance of buildings.

The research also links to that on performance and risk being carried out under the Risk Evaluation and Understanding of Uncertainty (REUU) Theme.

1.2 Materials typology

A conceptual breakdown of materials into the following principal categories has been adopted for the review following discussion with researchers and industry.

- Existing conventional inert materials, including:
  - rock,
  - masonry and dressed stone,
  - steel,
  - aggregates,
  - concrete (including precast units),
  - asphalt,
  - geotextiles, geogrids and membranes,
  - plastics

- Naturally growing materials and systems, including:
  - cut timber,
  - live willow,
  - faggots and woven material,
  - grass

- Reclaimed or recycled materials (Section 75(2) of Environmental Protection Act):
  - construction and demolition waste (including concrete units i.e. kerb stones, railway sleepers, other prefabricated forms, and forms made from ‘return concrete’, e.g ‘ecoblocks’),
  - railway track ballast,
  - china clay by-products, slate waste, and colliery spoil / minestone waste,
  - maintenance dredged material
  - fired ceramic wastes and spent foundry sand,
  - plastic
  - scrap tyres*
  - glass cullet*

- blast furnace slag, basic oxygen furnace steel slag, and electric arc furnace steel slag*
- pulverised fuel ash, and power station furnace bottom ash*
- municipal solid waste incinerator bottom ash*

(*may be used in ‘Primary’ concrete manufacture)

- Connections, joint fillers, sealants, coatings and treatments:

These are important materials in flood and coastal defence structures as their integrity can significantly influence the overall life and the maintenance costs of the system or structure of which they form a part. These are generally best dealt with as part of the best practice and guidance related to the principal structural materials or systems to which they relate.

1.3 Systems/structures within which materials are typically used

It is always important to understand the context in terms of a system or structure within which a material is being used. There are a wide number of these which are significant to coastal and river engineering, but it is possible to group them into two main categories, namely **composite materials**, such as steel-reinforced concrete and glulam (glued-laminated timber) and **structural systems**. Systems encompassed by the latter include:

1. Revetments, and rubble mound breakwaters (rock, concrete units, asphalt, geotextiles)
2. Multi-functional reefs (geotextile filled bags, rock, recycled plastic tubes, concrete units for fishing and other reefs)
3. River and channel bank protection and toe boarding (masonry, rock, revetment systems, gabions, timber, plastic planking, willow, natural and synthetic grass, and high-void concrete units.) Scour protection at outfalls similarly.
4. ‘Thin’ groyne type structures (timber, steel, concrete, recycled plastic)
5. Vertical sea walls (Primary materials: stone and concrete blockwork, concrete caissons, sheet piling, masonry, rubber tyre bales. Secondary materials can be significant here, e.g. void and crack fillers, surface protection systems.
6. Beach recharge materials – primary materials and alternative beach void fills using secondary and recycled materials
7. Scour protection (rock, timber, artificial grass)
8. Temporary flood protection barriers (structures and membranes)
9. Access steps and ramps –structures for access to beaches offer a particular challenge for durability against abrasion.
10. Walkways and railings (timber, steel, plastic)

Also of interest to the Defra / EA R&D Programme, but not addressed in this review are:

1. Mechanical and electrical / moving equipment (pumps, turbines for hydropower, sluices, lockgates, wave energy devices.) Materials for such equipment are so closely integrated with their overall design and maintenance, that it is more appropriate to get a qualified M&E design engineer to address these separately.
2. Geotechnics and soil properties. These relate principally to embankments and are covered in a separate review of good current practice.

3. Materials for drainage systems (plastic and concrete pipes, granular fill for infiltration and treatment trenches, impermeable and permeable geotextiles as separators/liners)
4. Flood-proofing systems for houses (dealt with separately in R&D outputs on Local Flood Protection).

1.4 End-users and their needs

The key users of improved knowledge from materials research will be those organisations which have an interest in providing flood defence, land drainage and coastal protection in England and Wales. Flood defence is the responsibility of the Environment Agency, Internal Drainage Boards and Local Authorities as Flood Defence Operating Authorities.

Private frontagers and riparian owner form a small but significant group of end users as regards lower risk river bank, coastal or shoreline protection.

Coastal or shoreline protection is provided by a wide range of bodies, including Maritime District Councils, Port and Harbour Authorities, infrastructure authorities (e.g. Highways Agency, County Councils, Railtrack), utility companies. Most of these users are represented on the various Regional Coastal Groups which have been set up around the country. The chairmen of these groups meet regularly under the umbrella of the Institution of Civil Engineers, and also occasionally with Defra Flood and Coastal Defence Division.

In general, these various bodies identify the need for works and/or warning systems, carry out maintenance works and secure the necessary resources for now or improvement works. Detailed design of the latter is unusually carried out by consultants on their behalf, and the research needs of these consultants have to be considered.

These are the client organisations, which plan works, and set standards, and need not only to be aware of future research, but also to have an influence on the direction of that research. The Agency's Framework Consultants form an important group under these client organisations as they effectively work in partnership with the Agency.

All client organisations generally utilise consultants, who work to the client's briefs to carry out the detailed work involved in implementing flood defence improvement works. Thus the research needs of consultants may have a slightly different emphasis to those of their clients'. For work directly relating to properties, it is likely that developers and their consultants (engineers and architects) will be the key users, perhaps under the umbrella of the HBF (House Builders Federation) and NHBC for new properties.

Designers of flood and coastal defences require sufficient information that will persuade them that they can improve their efficiency of resource use in terms of consumption of primary materials for construction. This means providing viable option choices for selecting recycled, secondary or alternative materials. At present many of these option choices are not viable because they are not well classified or defined, and those that are, are not sufficiently well documented and disseminated.

1.5 Researchers

The scope of research on materials is such that a wide range of researchers are currently involved (or may be involved in the future.) These researchers include universities (perhaps funded in part by Research Council grants), research organisations such as BRE, TRADA etc and research associations such as CIRIA. Indeed the variety of different organisations and individuals involved means that drawing together relevant information is a key issue.

HR Wallingford has been asked by Defra / EA to help to co-ordinate the programme – with its specific skills and experience in civil engineering hydraulics related to scheme design and in technology transfer from the researcher to the field. It is expected to call on experience from disciplines outside flood and coastal defence to provide benefits from lessons learned in other sectors. Examples include experience from related fields such as chemical industry, ports and waterways as well as specialists in individual materials such as concrete, steel, timber, geotextiles, etc.

It is also expected that on individual research and development projects, "reality checks" will be required from a number of sources. These will include the following: the Agency's Framework Consultants (with their practical experience in day-to-day strategic planning, design and management practice); the Agency's framework contractor's (practical experience of scheme implementation and maintenance); in-house work forces with their special understanding of environmental and durability issues; and those involved in implementing government policy within Defra and the Operating Authorities.

1.6 Current Good Practice

Material choice is dependent on a wide range of factors as outlined in the following sections. Some or all of these may apply to any material under consideration.

1.6.1 Primary materials

There are many examples of good practice with primary materials, which have been extensively researched, tested and evaluated for their role in construction generally. Their application in coastal and fluvial works has been developed within the construction industry over many years governed mainly by trial and error, testing, scientific evaluation, and examination of case history.

In most situations this experience has been captured by guidance documents which either exist or are in the process of being prepared. However, in many cases guidance is in need of updating/rewriting, and needs to reflect the changing composition of the engineering resource now available, as experienced engineers are being lost from the industry and new issues such as sustainability and whole life costs come to the fore. All these need to be captured and brought into a robust framework for the selection and use of materials. In some cases the guidance does not exist at all in any usable form. This project seeks to examine where the gaps in provision and updating occur.

1.6.2 Recycled and secondary materials

Construction is the largest consumer of natural resources in the UK, with over 90 percent of non-energy minerals extracted in the UK supplying the construction industry with materials. This represents, on average, nearly 300 million tonnes per year of primary materials (Smith, Kersey & Griffiths, 2002), the majority of which (some 214 million tonnes per year) is in the form of aggregates. If the demand for aggregates in the UK increases by the 1 percent per annum, as presently expected, then by 2012 an extra 20 million tonnes of aggregates will be needed annually (www.aggregain.org.uk). There are growing concerns for the environmental consequences and the long-term sustainability of providing this large amount of construction material.

In response to these current levels of use, the Government introduced an Aggregates Levy in April 2002 as an environmental tax on the commercial exploitation of aggregates in the UK. Presently set at £1.60 per tonne, the aim is to reduce the demand for primary aggregates and encourage the use of alternative materials (see www.hmce.gov.uk/ business/othertaxes/agg-levy.htm).

The UK is already a leading user of alternative materials in Europe and can be proud of the fact that it has already established large and successful markets for alternatives to primary aggregates. In England alone, some 50 million tonnes of construction materials per annum are already derived from recycled or secondary sources (see www.aggregain.org.uk). Increasing the use of alternative, and recycled construction materials could provide a more sustainable option for meeting future demands. In addition to being a major consumer of natural resources, the construction industry is also one of the largest generators of waste in the UK, producing approximately 150 millions tonnes of waste per annum (Smith, Kersey & Griffiths, 2002). This, coupled with limited available landfill space, has contributed to the Government's introduction of the landfill tax and the waste strategy to help secure changes to behaviour and to meet new waste targets (see: www.hmce.gov.uk/business/othertaxes/landfill-tax.htm and www.defra.gov.uk/environment/waste/strategy/cm4693). However, some inert construction and demolition (C&D) materials are still going into landfill. Increased recycling of such materials would further reduce the demand for primary aggregates for new construction projects.

Unfortunately the use of alternative, reclaimed or recycled materials in coastal and river engineering applications has so far been limited to low cost 'sacrificial' schemes and as opportunistic utilisation for low grade and bulk fill purposes (accepted under so called '*fit for purpose*' standards). Subsequently these materials have not been investigated and tested to the same degree as primary materials.

Without proper investigation of properties and testing of characteristics, alternative, recycled and reclaimed materials have been perceived in the industry as inferior in quality to primary materials. This lower value has not proven necessarily to be the case when investigated. If utilisation is to improve, then a concerted effort needs to be made to prove to the industry that there are valuable benefits to be had in terms of cost, performance and sustainability.

Where material characteristics and performance are proven to be similar and within acceptable "application-determined" parameters, selection should be made on other criteria including environmental impacts and socio-economic costs and benefits. Guidance is required in the utilisation of the range of tools available to the end-user that will allow him/her to make an informed decision on such a choice of material(s).

Environmentally driven initiatives such as landfill tax, aggregate tax and indeed many European directives, together with the expectations of society, are leading to considerable pressure in the UK for the use of such materials. Their use is being hampered by:

a) poor understanding of the potential uses of such materials;
b) lack of good engineering guidance e.g. strength/durability properties; guidance on detailing; and
c) a regulatory framework (Environmental Protection Act, Waste Management Licencing Regulations, Waste Management Directive, forthcoming Landfill Directive etc) which is perceived to make the adoption of some of these materials bureaucratic and slow.

Each of these issues will need to be addressed and user-guidance identified that will enable the Agency simultaneously both to fulfil its regulatory role and to act as a best-practice construction client and thus to move towards achieving its environmental vision. In this regard, it may be necessary to identify activities that could enable learning from other leading nations. Dutch practice, in particular, may offer an interesting mix of vision and practicality.

1.6.3 Science Base/Technology Transfer

Whilst much of the knowledge on existing materials exists within the flood and coastal defence sector, it has become clear that useful existing information can be found elsewhere.

For the major construction materials, it should be unnecessary to go beyond the existing research institutes (e.g. TRADA for timber, BCA for concrete, SCI for steel etc) and a few key universities who have often linked in with these. However for some proprietary materials such as geotextiles, prefabricated revetment systems, coatings, composites and sealants it will be worth linking in with the relevant trade associations, particularly those that have a more independent technical stance (e.g. the International Geosynthetics Institute).

1.7 Format of report

Whether or not a material is suitable for use in any flood or coastal defence application depends on its ability to perform the desired function over a period of time. This in turn is dependent upon its physical, chemical and sometimes biological characteristics, its performance under the range of conditions that are likely to be encountered or typical of the application in question, its social and aesthetic acceptability / compatability, its environmental / ecological impact in terms of pollution or contamination potential and also its resource sustainability.

Conceptual extent of area covered by materials. Following Thomas & Hall (CIRIA "Seawall Design") materials issues can be divided up as follows.

A. **Physical** issues – strength, weight, durability etc
B. **Economic** issues – availability, whole life cost, adaptability (including buildability, maintainability, replaceability)
C. **Environmental and social** impact (compatibility with existing structures and natural features, social acceptance, ecological impact) to which must now be added **sustainability** of use.

Obviously issues in this broad classification can be interconnected. Each of these issues is addressed in turn in the following three chapters, starting with a general introduction to the subject and followed by a summary of key references, available research and future research needs.

The report concludes with a description of a proposed forward research programme and a bibliography of other reference material.

2. PHYSICAL (DESIGN AND DURABILITY) ISSUES

2.1 Introduction

Before starting to think about materials and structures, it is important to have some form of conceptual framework and hierarchy as to how flood and coastal defence systems and structures perform. This has been explained in detail in the draft FCDPAG6 (Defra Policy Appraisal Guidance on Performance Evaluation). However from the materials perspective, structures can be summarised as consisting in the following hierarchy:

1. Structural position (geography)
2. Structural profile (geometry)
3. Structure composition
4. Structure element composition

Guidance on materials cannot address any one of these levels in isolation, but needs to address strength, durability and other issues across the full range of the hierarchy, focussing primarily on levels 3 and 4. For this reason, manuals on materials are generally best constructed to cover both materials and structures in the one document.

Different characteristics will of course be more important at each of the different levels and, for each of these, information will need to be gathered and evaluated to inform the designer about likely structural and functional performance. Examples of the kinds of characteristics (dependent on the material type and its intended purpose) that may be important include the following:

Level 2: Structural profile (geometry)
- Slope stability,
- Surface durability / erodibility,
- Frost heave

Level 3: Structure composition
- Density,
- Porosity / permeability / water absorption,
- Strength,
- Hardness,
- Durability ,
- Grading,
- Plasticity / elasticity,
- Coefficient of friction and adhesion,
- Geotechnical parameters - shear strength, angle of friction and cohesion,
- Optimum moisture content and maximum dry density
- Susceptibility to chemical or biological attack,
- Resistance to heat

Level 4: Structure element composition
- Density,
- Solubility,
- Particle size,

- Strength,
- Hardness,
- Durability,
- Flakiness,
- Grain compression / tension,
- Coefficient of friction and adhesion,
- Susceptibility to chemical or biological attack,
- Resistance to heat / uv degradation

This is not a comprehensive list, but does give an indication of the level of scientific investigation required to establish the physical material characteristics for design and construction purposes. Additional characteristics will be required in order to assess the environmental impact of a particular material choice (see Chapter 4)

2.2 Recycled and secondary materials

Recycled materials are those derived from reprocessing materials previously used in construction. Examples include recycled hardwood timbers, construction and demolition waste material and railway ballast.

Secondary materials, by contrast, are usually by-products of other industrial processes not previously used in construction. Examples include china clay waste, used foundry sand, metallurgical slags and post-consumer tyres.

For many recycled or secondary materials there have not been sufficient quality testing methods and controls in place to allow for their application with any great confidence. This problem has only served to reinforce the misconception that all 'waste' materials are of inferior quality to primary materials. Certainly some may require some treatment, but many are of comparable quality and some have uniquely beneficial characteristics of importance in particular engineering solutions.

> *In 1997, a technical committee was set up to establish a means of controlling the quality of aggregates produced from processing material previously used in construction. Then in 1998 the Quarry Products Association (QPA) together with the Highways Agency and the DETR reviewed the Specification for Highway Works to identify and remove any impediments to the use of recycled aggregates that could not be technically justified. A consensus view by these two initiatives was achieved and reported as a quality control protocol of recycled aggregates for sale as construction materials, or as constituents in a product such as concrete or asphalt.*
>
> *The aim of the use of this protocol is to give adequate assurance that the products conform to the relevant technical specifications or certified characteristics. The protocol is available via* www.viridis.co.uk

Until recently all primary materials were classified and defined via established (British) standards that were well known and routinely used in the industry. The equivalents for non-primary materials are still being formulated, but not apparently in a coherent manner. However, this work has been overtaken by the advent of European (EN) standards in the UK replacing the British Standards Institute (BSI) framework.

The policy for EN standards to permit any secondary or recycled materials that comply with the requirements for primary materials will result in better usage for non-primary materials. This should (in theory) increase the likelihood of wider utilisation. However, an appraisal of these new standards needs to be made to establish where these additional (non-primary) materials now stand in this context and, subsequently, what future work needs to be done. The problem arises because of the (potentially unknown) environmental impact of such materials through leachates etc, and the standards only contain general phrases about this at present and refer to national legislation.

Some material sources (e.g, slate, C&D waste, colliery spoil) can be highly variable in terms of their quality. Guidance is required on what measures may need to be taken (or are possible) to ensure consistency of quality of material supply; whether this includes grading, sorting, crushing or other processing. Some indication of costs involved should also be given (see Chapter 3) as this will affect not only raw material costs but the scoring of the material choice in environmental (see Chapter 4) and socio-economic testing. These considerations are especially important when materials from old stockpiles are a potential option.

New tested and proven design options utilising a wider variety and mix of materials are needed if more efficiency in the use of resources is to be achieved. These options need to be well-documented and reinforced with appropriate **case histories of pilot projects** and **innovative schemes**. Testing of material function(s) in designated structures needs to be conducted to establish and highlight any potential hazards that might arise and thus reduce the risk to future construction schemes and projects. With today's concerns over professional liability and litigation, designers and engineers will always revert to a 'better safe than sorry' approach if there is even the slightest doubt as to how a material may or may not perform under any particular condition. The material must be declared 'fit for purpose' by reliable and proven tests and methods before risk is accepted as being low enough to assume particular performance characteristics.

Clients (who frequently claim to strong environmental credentials) must support end-users in becoming informed about what potential there is for them to substitute primary materials with alternatives, preferably with examples, case studies, designs and guidance. It is very difficult to "learn on the job" if the industry generally is not encouraging research and use of recycled and secondary materials. Such information may be collated from the wider construction industry where application specific examples in coastal and river engineering are not available. Widely disseminated examples of innovative and sustainable schemes are likely to encourage others to do likewise, or at least adapt and develop the described material use and/or designs.

2.3 Zones of loading

When considering material behaviour, it is important to consider the zones of loading to which materials and structures are subject. As these vary so much they have a big impact on processes such as:

- the direct static or [hydro-] dynamic loading
- the general physical, chemical and biological environment which can affect the performance and durability of materials by processes such as abrasion, corrosion, chemical degradation, freeze-thaw and biological attack. This is particularly important with defences that are only occasionally subject to extreme storm loading.

Zones can typically be distinguished both in a vertical and horizontal direction.

In the vertical direction, the following zones can be distinguished for coastal and estuarial engineering:

- The **atmospheric** zone lies above the splash zone and behaviour is controlled by the general climate, particularly by factors such as:
  - the duration and frequency of moisture film contact
  - atmospheric humidity
  - the rate at which the surface dries
  - the build-up of aggressive sea-salts (e.g. chlorides) on the structure surface
  - the level of pollutant gases and contaminants present in the surrounding atmosphere
  - the degree of exposure to wind and rain.

- The **splash** zone lies between mean high water level (MHWL) upward to the bottom of the atmospheric zone. The splash zone range depends on the average height of the waves present at the site. Abrasion may be significant here.

- The **tidal** zone is the area between the mean low water level (MLWL) and high water level (HWL). This zone is repeatedly immersed in seawater and then exposed to air by the ebb and flow of the tide. Abrasion may be significant here and scour of vertical wall structures may be important.

- The **low water level** (LWL) zone – the area between a point approximately 0.5m below LWL and MLWL which appears to be particularly significant for accelerated low water corrosion of steel.

- The **continuously submerged** zone – the area from mud line (sea bottom) up to LWL (note that this zone does not exist in those locations where the mud line is above the MLWL).

- The **buried** zone – the area of total burial in soil or sediment.

For river engineering, these zones can be simplified:

- The **atmospheric** zone lies above the splash zone and behaviour is controlled to a large extent by the factors referred to above (except those relating to sea-salts).

- The **splash** zone lies between high water level upward to bottom of the atmospheric zone. The splash zone range depends on the average height of the waves present at the site and the degree of turbulence in the flow.

- The **flow** zone is the area between the normal low water level and the normal high water level. The latter may be defined as the Mean Annual Flood water level (ie average of the highest water levels that occur in each year). This zone is immersed in water and exposed to air by the change in river flow. The normal river level tends to be closer to the low water level than the high water level, and part of this zone can be exposed for very long periods (months or even years). Abrasion and scour may be significant here, particularly at high river flows.

- The **continuously submerged** zone – the area from river bed up to low water level.

- The **buried** zone – the area of total burial in soil or sediment.

It should be noted that the splash zone and atmospheric zone can be inundated during larger flows than the Mean Annual Flood. Note also that for both coastal and fluvial flood embankments, the soil mass experiences very different conditions of groundwater regime in the continuously submerged and the occasionally submerged zones.

In the horizontal direction, various zones can be distinguished depending on the cross-shore or cross-river profile being considered. This kind of zonation can be illustrated by a couple of examples:

A typical beach profile includes the following:

- **Zone offshore** of wave breaking
- **Wave breaking zone** where waves start to break because of depth limitation
- Surf zone with significant wave-generated current and sediment transport processes in it
- The **swash zone** where the waves meet the beach and rush up and down it and the area in which bed load sediment transport and associated abrasion processes dominate for shingle beaches
- The **back-shore** which is only occasionally affected by any wave action, but may also be affected by aeolian processes (e.g. in dune formation)

A typical river profile would include:

- The **river channel** that normally contains water all the time. Some rivers dry up completely in dry periods. High sediment loads can occur in high flows.
- The **river bank zone**, where turbulent flow can lead to bank erosion and a variety of ecosystems exist according to the degree of saturation.
- The **floodplain zone**, which is only inundated during flood events which exceed the channel capacity.

A further factor to take into account is the wide geographical variations which exist for example in:

- rainfall,
- wind,
- water quality,
- temperature (especially risk of freezing and thawing)

2.4 Key references, available research and research needs

2.4.1 Materials and structures generally

Many of the key manuals have been developed with both structural systems and materials in mind. This is positive, because it encourages the engineer to think in an integrated way. However, cross-referencing of information is always needed, and the best guidance on a particular topic is not always in the most likely place. Good examples of existing guidance manuals which cover both structures and materials include

Budd M, John S, Simm J, and Wilkinson M. (2003) Coastal and marine environmental site guide. Construction Industry Research and Information Association (CIRIA). Publication C584. London.

Coventry S, Woolveridge C and Hillier S.(1999). The reclaimed and recycled construction materials handbook. CIRIA Publication C513. London.

Crabb, G and Reid, M. (2003) Protocols for alternative materials in construction: Final Report. Viridis. Crowthorne Business Estate, Old Wokingham Road, Crowthorne, Berkshire.

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Escarameia, M. (1998) River and channel revetments – a design manual. London: Thomas Telford.

Hemphill RW and Bramley ME (1989) Protection of river and canal banks: a guide to selection and design. CIRIA Water engineering report, Butterworths, London.

Lee, EM and Clark, AR (2002) Soft cliffs: Prediction of recession rates and erosion control techniques: Examples and publication. Available at www.defra.gov.uk/science/project_data/DocumentLibrary/FD2403/FD2403_500_FRP.pdf

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May, R, Ackers, J, Kirby, A (2002) Manual on scour at bridges and other hydraulic structures. CIRIA Report C551 London

McConnell, K. (1998) Revetment systems against wave attack – a design manual. Thomas Telford Ltd, London.

PIANC (1992) Guidelines for the design and construction of flexible revetments incorporating geotextiles in marine environments. Report of Working Group no 21 of the Permanent Technical Committee II, Supplement to Bulletin Nos. 78/79, Brussels, Belgium.

River Restoration Centre (1999/2002) Manual of River Restoration Techniques available at www.therrc.co.uk/manual.php

US Army Corps of Engineers (USACE). 2002. Coastal Engineering Manual. Engineer Manual 1110-2-1100, US Army Corps of Engineers, US Army Coastal Engineering Research Center, US Government Printing Office, Washington, DC (in 6 volumes).

If there is a materials **research need** in this general area, it is for a better integration of thinking across different materials and structures options. This is probably best achieved via the development of thinking in the areas of whole life costs and sustainability, which are discussed in the next two chapters.

However, better integration of thinking and use of existing research could also be achieved by ongoing capturing of experience and best practice. This could include:

- development of a more formalised process of piloting and trialling of new ideas and learning lessons from these pilots and from other experience,
- research on how designers **actually** do it, including their evolution of designs and details, will remain an important part of developing and maintaining guidance. In this regard the indicators from the recent Defra 'Concerted action on performance evaluation', for example in understanding the learning cycle and the differences between 'espoused theory' and 'theory in practice' will be particularly important.
- setting up a 'single point of expertise' to which people can refer in the first instance for guidance on materials aspects.

A first step along this road could be achieved by a programme of **training workshops or seminars** to present to staff and consultants explaining:

- the full range of tools that are currently available, and
- how to use the currently available guidance and how to work between the different types of manual available when developing project options and designs.

This would reinforce more formally the ongoing process of gathering feedback on future needs and requirements. The exact format of these workshops would be a matter of available time and money, but it would be important to include within them an opportunity for brainstorming and discussion of future needs.

2.4.2 Beach and dune materials

Key references in this area are the following guides:

Simm JD, Brampton AH, Beech NW and Brooke JS (1995) Beach management manual. CIRIA Report 153, London

Humphreys B, Coates T, Watkiss, M and Harrison D (1996) Beach recharge materials – demand and resources. CIRIA Report 154, London.

SNH (2002) Guide to managing coastal erosion in beach/dune systems. Scottish Natural Heritage, Edinburgh

These guidance documents have all proved to be extremely useful and the CIRIA beach management manual is known to be widely appreciated and used. It is however felt that the documents will need updating in the near future and discussions have been held with CIRIA in regard to the timing of this. It is particularly important to incorporate the large amount of work that is now being driven by concerns about sea level rise. Currently it is considered that:

- Revision of the beach management manual should commence at about the time that revision of the Rock Manual is complete (i.e. in 2005) and should build on the experience of beach nourishment schemes completed and monitored since the manual was published in 1995.
- Revision of the demand and resources study should be done in the medium term in discussion with the wider construction industry and in response to developing views of society and current thinking on Sustainable Development. It should also take account of the recently completed CIRIA project RP687 "Potential use of alternatives to aggregates in coastal and river engineering"

2.4.3 Armourstone and Aggregates

Key references in this area are the following guides:

Herbert DM, Lovenbury HT, Allsop NWH and Reader RA (1995) Performance of blockwork and slabbing protection for dam faces. Report SR 345, HR Wallingford in association with CIRIA, Wallingford, UK.

CIRIA / CUR (1991) Manual on the use of rock in shoreline and coastal engineering. CIRIA SP083 / CUR Report 154, London, commonly referred to as the 'Rock Manual'

CEN (European Committee for Standardization) (2001). European Standard: Armourstone - Part 1: Specification, prEN 13383-1.

CEN (European Committee for Standardization) (2001). European Standard: Armourstone - Part 2: Test methods, prEN 13383-2.

A DTI Partners in Innovation (PII) and Environment Agency funded partnership project with industry contributions has now commenced to completely revise and update the Rock Manual. The project will deliver good practice guidance on the use of rock for erosion and flood control at coasts and rivers. The update will incorporate the significant advances in knowledge that have occurred over the past twelve years, including the implementation of the new European Standard EN13383. It will also take the opportunity to widen the scope of the manual to include all aspects of the use of rock in hydraulic engineering, and in particular to provide more information on form and appearance of rock structures from the societal / amenity viewpoint. It is intended that application of the guidance in the report will help to achieve a long-term improvement in the use of rock and will promote conservation of natural systems in balance with the proper protection of human life and property.

The manual is being updated by a joint UK, French and Dutch team represented by CIRIA, CETMEF and CUR respectively. In the UK, the project is led by CIRIA with HR Wallingford as Lead Research Contractor. Imperial College and Halcrow are also providing technical expertise to the project. The project commenced in May 2003 and will end with open publication of the manual in September 2005. The manual will be published in English, French and (probably) Spanish, with a CD-Rom version included and will also be available to download from the web.

A separate project, due for completion by the end of 2004, is examining the development of a method to quantify the integrity of rock armour blocks – their ability to remain intact as large blocks under loading. The research is examining both destructive and non-destructive testing options.

2.4.4 Masonry and building stone

Some very useful information on building stone materials can be found in:

> Smith, MR (ed) (1999). Stone: Building stone, rock fill and armourstone in construction. The Geological Society, Bath.

and on designing masonry structures in:

> BS 5628-2: 2000 Code of practice for the use of masonry. Structural use of reinforced and pre-stressed masonry.

Further useful information on masonry can be obtained from the Brick Development Association http://www.brick.org.uk and from specialists at BRE.

As usual however, the difficulty is finding reports or guides which deal adequately with the structures commonly encountered in coastal and river engineering. One landmark report which attempted to move the subject forward with some success was:

> Bray, RN and Tatham, PFB (1992). Old waterfront walls - Management, maintenance and rehabilitation. CIRIA, London.

However, it is felt that this report does not address all the issues facing designers. Many **existing walls** are significant in both size and age. Unresolved issues include:

- The overall stability of walls, in particular the reasons why walls with factors of safety against overturning or sliding less than 1.0 do not fail. Many factors may be involved here, but a procedure for evaluating these factors would be helpful. This would enable evaluation of the significance of wall movement causing load relief and the significance of basement structures - for example where masonry river walls comprised parts of now-demolished warehousing.
- The appropriate use of lime mortars with masonry, learning lessons from the heritage sector.
- Guidance on the significance of the internal vs the surface structure of the walls, including understanding the significance of surface pointing and why this might cause or be the cause of internal failure.

The significance of this problem to **coast protection** can be gauged from the fact that a quick search on databases held by one consulting engineer suggested that up to 50% of hard man-made protection works might be masonry in some areas (based on Pembrokeshire, North Tyneside and Berwick.)

Designing **new walls** can be problematic and here a key issue is ensuring a robust interface between surface masonry and the concrete or permeable back fill. For example any air gap between the masonry and the wall can risk failure under load.

Brick culverts pose an ill-defined long-term maintenance problem in many of our cities.

It is proposed that an appropriate team of experts be put together to address these and other issues and to update and extend the present guidance, making it more practically directed toward implementation.

2.4.5 Concrete

The only comprehensive guide known to be available is:

> Allen, RTL (ed) (1998) Concrete in coastal structures. London: Thomas Telford

This guide is unfortunately only a compilation of various papers written by different authors. Whilst it sought to cover the main topics, it lacks the integration required of a true manual and also now needs some very significant updating to take account of the following:

- New concrete materials technologies, including those to:
  - provide strength whilst avoiding use of conventional reinforcement,
  - mitigate chloride-related corrosion of reinforcing steel, and
  - deliver concrete that is resistant to abrasion, particularly in the coastal zone.
- New European Standard methods for specifying concrete
- Guidance on precasting of a variety of elements, including parts of larger structures, wave return walls, armouring units for wave energy dissipation

Note that on the societal / amenity front, provision of durable access steps across coastal structures remain a major problem for coastal engineers. Various solutions have been proposed for improving abrasion resistance including use of selected harder aggregates. Recycled glass is the most recent of these and apparently offers other useful durability properties when used as fine aggregate, sand or filler in concrete.

It is proposed that a team of experts be put together, possibly under the auspices of CIRIA, to compile a comprehensive guide on the use of concrete in coastal (and river) engineering. The approach could take lessons from the format and approach used in other CIRIA concrete guides such as:

- C577 Guide to the construction of reinforced concrete in the Arabian Peninsula

- C559 Freeze-thaw resisting concrete – its achievement in the UK

Support in principle for a collaborative research project for a new guide has already been forthcoming from the Concrete Centre. The Concrete Centre is a new pan-industry umbrella organisation set up with the support of the concrete industry to promote concrete as a material and to ensure dissemination of best practice (see www.concretecentre.co.uk.) (Key partners in the Concrete Centre include the British Cement Association, British Precast Concrete Federation, the Concrete Society and the Institute of Concrete Technology, as well as a range of component materials suppliers.)

2.4.6 Steel sheet piling

Steel sheet piled walls are used for coastal defences and as back protection in estuaries in urban or industrialised areas. Methods for designing steel sheet piled retaining walls are well established and appropriate design guides can be obtained from the Steel Construction Institute or steel production companies such as Corus. These include some software packages to assist with design.

The major problem of concern with steel piling at present, which is probably of most significance in estuarial waters, is that of Accelerated Low water Corrosion (ALWC). This issue is currently being addressed by CIRIA project RP693 "Management of ALWC in steel marine structures."

2.4.7 Geotextiles

The difficulty in this area is the lack of a completely independent integrated guide. There are a number of conference proceedings and collections of papers, for example:

> Koerner R M. (ed.) (1992) Geosynthetics in filtration drainage and erosion control. Elsevier Advanced Technology.

There are also some useful guides that are now out of print:

> Rankilor, PR (1992) UTF geosynthetics manual. Belgium: UCO Technical Fabrics NV.
>
> Veldhuijzen van Zanten, R (1986) Geotextile and geomembranes in civil engineering. AA Balkema, Rotterdam
>
> Geosynthetic Institute (1998) Designing with Geosynthetics (Fourth Edition) . Folsom, PA 19033-1208, USA

Other than these, it is suggested that reference is made to the Thomas Telford published guidance manuals on revetments and the CIRIA (1991) Manual on the use of rock in coastal and shoreline engineering (see Section 2.2.1 above on materials and structures generally).

2.4.8 Asphalt and bituminous materials

The original key reference here is the following publication from the Netherlands

> Technical Advisory Committee on Water Defences (1985) The use of Asphalt in Hydraulic Engineering. Communication 37. Rijkswaterstaat Communications. The Hague, The Netherlands.

However, the asphaltic technology aspects have been significantly updated and expanded in:

> Schonian, E. (1999) The Shell Bitumen Hydraulic Engineering Handbook. Thomas Telford, London

Hydraulic design methods using asphaltic materials are presently best captured in:

> McConnell, K. (1998) Revetment systems against wave attack – a design manual. Thomas Telford, London.

> Escarameia, M. (1998) River and channel revetments – a design manual. Thomas Telford, London

Interest in asphaltic revetments seems to have waned in the UK over recent years, with the move to softer engineering. This is probably a pity as asphaltic construction can offer a useful additional option for the coastal and river engineer in certain situations. The most recent applications seem to have been restricted to reservoir embankments in Scotland. Asphaltic grouting to upgrade existing substandard rock revetments remains a useful design approach. At present, further research in this area does not seem to be justified until there is a little more project experience.

2.4.9 Timber

The original design guide for the use of timber was

> Oliver, AC (1974). Timber for marine and fresh water construction. Timber Research and Development Association (TRADA).

Until recently there was little progress in this area. The following research report was never published because of concerns about its limitations

> TRADA (1993). Specification and use of timber for marine and estuarine construction. R&D Note 133. National Rivers Authority, Bristol

This situation has now been rectified with the forthcoming publication of a new Timber Manual funded by DTI PII, Defra / EA and others in the construction industry.

> Crossman, M P and Simm, J D (in press). Manual on the use of timber in coastal and river engineering. Thomas Telford, London. (This will also be available as an e-publication on the Defra / EA webpages).

For more general information on timber design, this publication might be helpful

> Ozelton, E C and Baird J A (2002). Timber designers' manual. Blackwell Science, Oxford.

The new Timber Manual should provide a comprehensive design tool covering properties of timber, its environmentally sensitive procurement and all aspects of its engineering application and use. The project did however identify that there were some areas requiring further research:

1. The need to determine the **appropriateness** of the durability and engineering properties **of alternative sustainably-produced hardwoods**. A pilot project commissioned by the EA has examined the durability of some hardwoods to gribble and shipworm attack, but requires some limited further funding. Having completed this, there will be a need to trial some of the alternative hardwood timbers, probably on coastal groynes
2. The need to determine the **extent of shipworm infestation** around the UK coast as the characteristics of our coastal waters have changed significantly since the last survey in the 1960s.

Recycled hardwood timber represents a significant source of material, which some operating authroities are using as a first preference choice on environmental grounds. Such timber will often require removal of ironmongery and re-milling before use. Guidance on the use of recycled timber is provided in the Timber Manual.

2.4.10 Maintenance dredged material

The subject of beneficial uses of dredged material has been heavily researched and good guidance is available. The following reports on the subject are available from HR Wallingford.

> Burt, T N (1996) Guidelines for the beneficial use of dredged material, HR Wallingford Report SR 488.

> Burt, T N and Cruikshank, I C (1999). Uses of recycled dredged and other materials in construction: DETR Project 39/5/118. Report SR 555. HR Wallingford

2.4.11 Construction and demolition waste

In 2001 in England and Wales, the construction industry produced an estimated 93.9mt (million tonnes) of construction and demolition (C&D) waste, of which 38.0mt was recycled as aggregate by crushing and/or screening and 7.1mt was recycled as soil. Of the remaining 48.8mt:

- 2.7mt comprised uncontaminated hard C&D waste and heavily mixed and/or contaminated hard C&D waste with varying potential for recycling as aggregate;
- 5.5mt was mixed construction and demolition excavation waste (CDEW), which was primarily soil but mixed with some hard C&D waste. This had limited scope for recycling as aggregate, and,

- 40.6mt was wholly or mainly accounted for by waste soil and excavation waste with little or no scope for recycling as aggregate.

This shows that there is significant potential on nearly all construction sites for reuse of Construction and Demolition (C&D) waste, either as general filling or as aggregates for concrete. In most cases, there is strong pressure now to avoid paying tax on consignments sent to landfill and to avoid the aggregates levy by using recycled aggregates sourced from crushed hard uncontaminated demolition waste. In many coastal and river engineering schemes, there tends to be limited demolition activity; hence the focus on a particular site is probably going to be more towards making use of C&D waste in general land modelling.

Although little more can be said about site specific approaches, the significance of site by site recycling of C&D waste should not be underestimated in UK coastal and flood defence as the cumulative effect will be very significant. All designers need to be encouraged at the outset of any project to incorporate a recycling logic into their thought processes for sustainable construction.

2.4.12 Secondary materials

A wide range of potential secondary materials is available.

CIRIA report RP 687 "Potential use of alternatives to aggregates in coastal and river engineering" summarised the main kinds of applications for which alternative aggregate type materials might be considered. This is reproduced in Table 2.1 overleaf.

In nearly all cases, the materials would be used as a direct replacement for uses as unbound fills or as aggregates in asphaltic or cement bound materials. As the new EN standards arising out of the Construction Products Directive do not distinguish between primary and alternative materials (i.e. the same quality requirements apply to all materials), there is no reason per se to exclude any material unless it fails to comply with the general requirements.

To assist engineers, a wide range of general case study examples can be examined on websites such as www.aggregain.org.uk. In most cases, the decision to use the materials will be driven by economics (Chapter 3), subject to being satisfied that the engineering performance is comparable to that offered by primary materials and that any potentially harmful environmental impacts are negligible (see Chapter 4).

In a few cases materials may offer particular benefits, other than their general role as an aggregate or filler and the following sections illustrate some secondary materials which have emerged with quite focussed advantages. However, the general research and development strategy identified here would be to:

- **collate novel material applications** by a comprehensive enquiry around all operating authorities and from this identify those applications that might offer the greatest advantages, and
- instigate a **programme of pilot projects**, potentially co-funded by WRAP, in which the use and application of new secondary of recycled materials would be carefully monitored and evaluated

Table 2.1: Suitability of alternative materials for common elements of coastal and river engineering schemes

ALTERNATIVE MATERIALS	Concrete Seawalls*		Coastal Revetment/Beach control structures*	Gabions e.g. walls/groynes	Geobags	Beach recharge	Cliff drains	Saltmarsh cheniers	Embankments		Flood walls	Riverbed protection*
	Fill	Prom. surface	Core/Under -layers						Fill	Revet-ment		
RECYCLED AGGREGATES												
Granular materials	✓	C,B	✓	✓	✓	✓	✓	✓	✓	C,B	C	✓
Maintenance Dredgings (muddy)	X	X	X	X	X	✓	X	✓	X	X	X	X
Capital Dredgings (sand, gravel)	✓	C,B	✓	✓	✓	✓	✓	✓	✓	C,B	C	✓
Spent Railway Ballast	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Recycled Concrete rubble	✓	B	✓	✓	X	✓	✓	✓	✓	✓	✓	✓
Kerbstones	X	X	✓	✓	X	X	X	X	X	✓	✓	✓
Railway Sleepers	X	X	X	X	X	X	X	X	X	✓	✓	✓
SECONDARY AGGREGATES												
Burnt colliery spoil	U,C	C	✓	X	?	✓	✓	✓	U,C	C,B	C	C,B
Unburnt colliery spoil	U,C	C	✓	X	?	X	X	X	U,C	C	C	C
Steel slag (EAF/ BOF)	✓	C,B	✓	X	?	✓	✓	✓	✓	C,B	C	C,B
Blast Furnace Slag	✓	C,B	✓	X	?	✓	✓	✓	✓	C,B	C	C,B
Furnace bottom ash (FBA)	C	C	✓	X	?	X	X	X	C	C	C	C
China clay sand	✓	C,B	✓	X	✓	✓	X	✓	✓	C,B	C	C,B
Slate aggregate	✓	C,B	✓	X	✓	✓	✓	✓	✓	C,B	C	C,B
Foundry sand	✓	C,B	?	X	✓	✓	X	✓	✓	C,B	C	C,B
Recycled glass	✓	C,B	?	X	?	✓	✓	✓	✓	C,B	C	C,B
Incinerator bottom ash (IBA)	✓	C,B	?	X	?	X	✓	X	✓	C,B	C	C,B
Recycled tyres (in bales etc.)	✓	X	✓	✓	X	?	?	?	✓	✓	X	?

Pulverised fuel ash (PFA)	✓	C,B	✓	X	X	X	X	X	✓	C,B	C	C,B

Key: ✓ - generally suitable: C –Suitable if bound in concrete, B - suitable if bound in bitumen/ asphalt, U – suitable if unbound, X – Unsuitable.

* Large mass units or structures are required for most exposed locations, e.g. concrete armour units can be made using secondary aggregates. For sheltered locations, some recovered C&D waste may be suitable, e.g. concrete railway sleepers or kerbstones.

Recycled glass

Some useful information is given in:

Edge, BL, Magoon, OT, and Toepfer (2002). Recycled glass for beach nourishment. Proceedings of the 28th ICCE, July 2002 Cardiff

Edge *et al* (2002) examined the use of recycled glass, particularly heat blown glass cullet, for beach nourishment. The poor economics in the UK and availability of much higher value uses suggest that use in routine coastal and river engineering as a fill material should not be pursued, unless the remoteness of the community (e.g. on an island) suggested otherwise.

However, glass offers the possibility of providing abrasion resistant aggregates, sand and filler in concrete, whilst also maintaining other requirements in terms of resistance to chemical and electrochemical attack. This work has been summarised in recent research outputs from the Centre for Concrete Technology at the University of Dundee:

Dhir, RK, Limbachiya, MD and Dyer, TD (2001) Recycling and reuse of glass cullet. Thomas Telford, London

Post-consumer tyres

Once tyres have been compressed and baled, they offer the possibility of low density fill which could be used to reduce the loading from embankments over soft ground. A successful pilot along these lines has been instigated by the Environment Agency near Lincoln where 12,000 bales (approximately 1,200,000 tyres) have been used in the crest widening and reconstruction of the rear face of a 1.5km length of embankment. The supporting research carried out by a team led by HR Wallingford and funded by DTI PII and Defra / EA (see www.tyresinwater.net) has identified relevant engineering properties of these bales. It has also explored their use as primary armour materials, but has concluded that as such they should only be used in steady flow conditions and not where wave action is present. A full guidance report will be available in 2005 on this subject. In the meantime, useful general guidance is provided by the following reference, downloadable from www.viridis.co.uk .

Hylands, KN and Shulman, V (2003) Civil engineering applications of tyres. TRL Ltd., Crowthorne

Colliery spoil

A useful set of reference papers for this material are the following:

Skarzynska, K M (1995a) Re-use of coal mining wastes in civil engineering – Part 1: Properties of minestone. *Waste Management*, Vol 15, No 1, pp 3-42
Skarzynska, K M (1995b) Re-use of coal mining wastes in civil engineering – part 2: Utilisation of minestone. *Waste Management*, Vol 15, No 2, pp 83-126

Recycled plastics, including plastic piling

Recycled plastics offer an unusual option for replacing timber or steel in piling or planking materials. Some significant disadvantages are its tendency to creep under load or the action of heat such as sunlight. However, it has been used successfully in some applications and the best way forward to evaluate its wider use and value might be first to pick it up in a more general questionnaire around the operating authorities as part of the **review of novel materials applications.**

2.4.13 Flood-proofing of buildings

This topic has been the subject of extensive research recently in the wake of the Easter 1998 and Autumn 2000 floods through an ongoing programme of research under the general heading of Local Flood Protection. The result has been the preparation of some extremely useful guidance (see references overleaf).

DTLR (2002) Preparing for floods - Interim guidance for improving the flood resistance of domestic and small business properties. Available at www.environment-agency.gov.uk/floodresearch , see Engineering Theme pages.

CIRIA / EA / BRE / ABI webpages on Repair and restoration of buildings following floods. See guidance and references at www.ciria.org/flooding

CIRIA / EA short guides on Improved guidance and standards for local flood protection. Available at www.environment-agency.gov.uk/floodresearch, see Engineering Theme pages.

Ongoing research is being co-ordinated by CIRIA to prepare better guidance on achieving whole-building floodproofing and to provide the underpinning information on water penetration through brickwork to clarify what might be covered in Building Regulations on flood resistance.

3. ECONOMIC ISSUES

3.1 Introduction

A key user-need is broad information on **sources** of materials other than those that may be initially, regularly or preferentially considered. Such information might clarify whether those sources are regular arisings, old stockpiles, in decline, renewable or exhausted, recycled, reclaimed, mixed, contaminated, accessible, etc.

The **volume availability** distribution (i.e. where and in what amounts around the country materials are located) is an important factor as coastal and flood defences often require very significant volumes of material. For example millions of cubic metres of beach material for beach recharge or earth fill for reconstruction / new build of flood embankments might be needed in a single flood or defence scheme. Thus, the costs involved in the transportation or provision of these large volumes becomes a crucial factor when considering material options for a scheme.

Some material sources (e.g, slate, C&D waste, colliery spoil) can be highly variable in terms of their quality. Guidance is required on what measures may need to be taken (or are possible) to ensure consistency of quality of material supply – for example grading, sorting, crushing or other processing. Some indication of costs involved should also be given as this will affect not only raw material costs, but also the scoring of the material option in environmental and socio-economic testing. These considerations are especially important when materials from old stockpiles are a potential option.

As previously mentioned, the options available for transporting material can be an important consideration. Coastal schemes often utilise sea transport as this is the cheapest method for high volume requirements. Materials may be sourced from the sea bed as sea won dredged aggregates. The dredging area may even be the closest source of the required material especially if it is dredged for the maintenance of navigation which is mainly in close proximity to the coast, within estuaries, and obviously along inland waterways.

River engineering schemes may, at least partially, be able to utilise river barges for transportation of their materials whilst bulk rail transportation over long distances where necessary could prove to be a cost effective and viable option for some.

Circumstances have arisen with some material sources where special transport infrastructure has been created or extended to facilitate the efficient supply and transportation of that material. Examples are: the Port of Par development in the South West of England for China Clay waste transportation by sea; and, the consideration for the construction of new rail heads at slate quarries in North Wales for slate waste distribution and utilisation throughout the UK. These two materials are particularly significant because they offer the overwhelming largest part of the existing reserves of secondary materials in the UK (see Table 3.1 overleaf).

End-users should be informed enough about these attributes of availability distribution, quality, consistency of supply and transport costings to be able to employ the hierarchy of material sourcing options, also required to minimise environmental impact (See Box 1 in Chapter 4).

Table 3.1: Tonnages of some key secondary materials in England, Wales (2001) and Scotland (1998)

Resource Type	Material	Annual Arisings		Potential Aggregate Portion		Actual Aggregate Use		Non-Aggregate Use		Stockpiles	
		England & Wales	Scotland	England & Wales	Scotland	England & Wales	Scotland	England & Wales	Scotland	England & Wales	Scotland
Metallugical Slags	Blast Furnace Slag	3.0mt	0	3.0mt	not known	0.9 - 1.2mt	90kt	1.8 - 2.1mt	not known	No reliable estimates	0
	BOF Steel Slag	1.0mt	not known	1.0mt	not known	0.98mt	not known	0.02mt	not known	No reliable estimates	0
	EAF Steel Slag	0.28mt	not known	0.28mt	not known	0.28mt	not known	0	not known	No reliable estimates	not known
	China Clay	22.60mt	0	20.01mt	0	2.28mt	0	0	0	45 – 100mt	0
Mine & Quarry	Slate	6.33mt	not known	6.33mt	not known	0.58mt	not known	0	not known	456.5mt	not known
	Colliery Spoil	7.52mt	150 kt	7.52mt	150 kt	0.81mt	65 kt	0	0	10 – 20mt	not known
	Pulverised Fuel Ash	4.87mt	780 kt	4.87mt	780 kt	1.66mt	228 kt	0.83mt	not known	55mt	not known
Other	Furnace Bottom Ash & Clinker	0.98mt	44 kt	0.98mt	44 kt	0.97mt	40 kt	0	0	No reliable estimates	not known
	Incinerated Refuse	0.62mt	not known	0.62mt	not known	0.38mt	not known	0	not known	No reliable estimates	not known
	Spent Railway Track Ballast	1.3mt	102 kt	1.3mt	102 kt	1.24mt	77 kt	0	not known	No reliable estimates	not known
	Spent Foundry Sand	0.9mt	not known	0.9mt	not known	0.09 - 0.18mt	not known	0	not known	No reliable estimates	not known
	Glass Waste	2.20mt	not known	2.20mt	not known	85kt	not known	0.65mt	not known	20 – 30kt	not known
	Fired Ceramic Waste	100kt	not known	100kt	not known	90 – 100kt	not known	0	not known	Working only	not known
	Scrap Tyres	400kt	not known	400kt	not known	90kt	not known	170kt	not known	~14million tyres	not known

Primary materials have an established **market value** and known **costs**. Some secondary, recycled / alternative materials have also secured market utility through the construction industry. Some are of considerable value as alternatives to aggregates (e.g. ground granulated blast furnace slag (ggbs) and air cooled steel slag) and in several instances all annual arisings are fully 'bought up' and utilised within the industry. Thus demand can and does outstrip supply and the material enjoys a relatively high market value for a 'waste' product. Coastal and flood defence schemes are cost sensitive to the degree that these higher value materials are too expensive to procure for bulk applications other than within concrete or superficial design features of relatively low volume (e.g. bitumous road and footpath wearing courses).

Market prices for some non-primary materials are difficult to estimate as their utilisation is not widespread, and any significant uptake of these materials into the market could alter their value.

A concern for non-primary materials are the potential additional costs associated with treatment(s) to achieve quality requirements or standards. High volume demand, however, should reduce the costs per unit volume / weight of necessary treatment(s) or processing.

Where the cost advantage (under current fiscal controls) for procuring non-primary materials is relatively marginal in comparison to that of procuring primary materials, some effort should be made to assess / value the associated costs and benefits (including externalities) associated with material selection. The full costs of the option choices can then be assessed. This is a crucial aspect if choice is to be governed by the sustainability driver. Guidance and information is needed to enable end users to carry out these evaluations in a consistent and effective manner; (a promising approach is to expand the current ECOPOINTS tool to include whole life cost issues – see below).

'Owners' or procurers of materials further up the utility chain (i.e. before they become waste) need to be made aware of the potential of such materials for further use in construction. This may be particularly relevant to construction and demolition firms where careful prior planning and operation (e.g. segregation of materials) can result in a reduction of volume going to landfill and an increase in volume of higher 'quality' secondary and recycled aggregates for construction. Examples of such potential use in flood and coastal defence are the use of:

- kerb stones as 'rip-rap' – for rock armouring of banks and revetments,
- railway sleepers as components in low cost river or estuarial structures'
- block masonry as fill in crib structures for cliff toe protection, and
- baled tyres as bulk fill in embankments and sea defences.

Greater awareness of these options may be cultivated by increased deliberation between minerals / resource planners, recycling, processing and waste management companies and coastal and marine consultants, engineers and designers.

3.2 Key references, available research and research needs

3.2.1 Whole life costs

Economic appraisal of project options is well established in the process of flood and coastal defence because of the requirement to carry out options appraisals with benefit-cost analysis for grant applications.

Defra appraisal guidance has focussed primarily on the evaluation of benefits on the assumption that costs are well understood. However, as the importance of **whole life costing** has emerged, the significance of obtaining better information on costs has become more apparent. The following reference summarises best practice in whole life costing and illustrates the process by use of a series of case studies:

> Masters, N and Simm, JD (2003) Whole life costs and project procurement in port coastal and river engineering. Thomas Telford, London.

3.2.2 Unit cost data

Capital works

The Environment Agency is building up a Unit Cost database for key types of capital works. This should provide a very useful reference source when it is well populated with data. As an interim measure, Masters and Simm (2003) provide data from a study by Halcrow Maritime on the future investment needs of the Environment Agency. This gives a useful indication of unit costs per km for different kinds of defences.

The research by Masters and Simm also attempted to prepare a database of maintenance costs for different types of structures and materials. This is available at www.wholelifecosts.org but mainly contains data from local authority coastal protection projects.

A key reason why data on maintenance costs is difficult to obtain is that it is not systematically recorded in the same way as capital costs are usually are. This was highlighted in the O&M Concerted Action carried out under the Defra / EA R&D Programme. Maintenance is an activity which may be only part of a larger budget (e.g. the leisure budget of a local authority) and unless the costs are separated out at the time of incurring them it is extremely difficult to record them afterwards. Proposals set out in the draft guidance on Performance Evaluation (FCDPAG6) prepared by HR Wallingford recommend that this should be done. Similarly, improved approaches to asset management will not be possible unless there is better data on maintenance costs. It is currently unclear when and how this improved operational management will be implemented.

As thinking about the three so-called “pillars” of sustainability (economic, environmental and social) becomes better developed and integrated, there is scope to integrate whole life cost thinking with materials environmental impact. As explained in Chapter 4, the next step along this road would be to integrate environmental and economic scoring approaches, building on previous work by BRE and HR Wallingford.

3.2.3 Availability of secondary and recycled materials

CIRIA report RP687 on the Potential use of alternatives to aggregates in coastal and river engineering (Section 2.4.12) has picked up on the general nature of the availability of the larger quantities of secondary and recycled materials.

In practice, individual engineers and clients will need to know at a particular point in time whether a particular material is available for use on a particular scheme. There may be some advantage in the Environment Agency and local authorities setting up **specialist materials exchange websites** for some key materials, for example **hardwood timber**.

Where a particular material stockpile or other source offers a significant potential benefit to a scheme, further investigation (e.g. boreholes, sampling) is always likely to be needed to determine the extent and quality of the material.

However, in most cases the way forward will be for the flood defence and coast protection community to make use of the WRAP website (www.wrap.org.uk) or the subsidiary AggRegain website (www.aggregain.co.uk) either to advertise materials they are disposing of or to source recycled materials they require. This website also provides details of those companies that are acting as collectors and reprocessors of waste materials.

4. ENVIRONMENTAL (INCLUDING WASTE MANAGEMENT) AND SOCIAL ISSUES

4.1 Introduction

Too often **specifications** for works are drawn up without sufficient consideration being given early enough in the design process for the efficient and best use of construction materials and resources. Early consideration allows for the extra time that often needs to be spent when dealing with the appropriate authorities and applying for the licenses required in many instances when utilising materials other than primary products. This could be time and effort well spent that is subsequently recovered through more efficient resource utilisation throughout the scheme.

Where recycled or secondary materials are being used, it may be necessary to consider additional parameters and measurements associated with the material, other than those required for consideration of their physical performance. These might include, for example, the following:

- Colour,
- pH value,
- Leachants,
- Nitrates content,
- Redox potential,
- Organic content,
- Total sulphate, acid-soluble sulphate, sulphide and hydrogen sulphide content,
- Chloride ion content,
- Microbial activity index,

Early consideration is imperative for some schemes. For instance applications for a Food and Environmental Protection Act licence to deposit materials on the foreshore (i.e. beach replenishment / renourishment) are considered on a case by case basis. Thus there is no guaranteed consistency of acceptance of a material choice between schemes or locations for the same use of material. Early consideration of all material options and good guidance as to their appropriateness can reduce time and money spent otherwise by trial and error licence applications.

Box 1 Hierarchy of material sourcing options (adapted from Masters, 2001)

1. **Suitable materials available on-site** from a previous scheme or structure.

2. **Locally sourced alternative materials** appropriate to fulfil the functions identified in the functional analysis of the project.

3. **Alternative materials** from further afield that can be delivered to site predominantly **by sea or rail or locally sourced primary materials**.

4. **Alternative 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**.

End-users, especially Environment Agency regulators and those who interact with them, do require some knowledge of potential environmental impacts that any material may have or has incurred. This is important if full costs and benefits are to be integrated into any project / scheme appraisal or analysis. This should include those impacts 'upstream' (as well as 'downstream') in the resource chain if life cycle assessment costs and benefits are to be realistically represented.

It should be acknowledged that current terminology used to describe and regulate materials in the legal framework is not compatible with the sustainability approach to resource management. This primarily concerns the terminology surrounding by-products of processes being referred to as 'Waste'. 'Waste' signifies to most something that must be disposed of and thus inferior to that which is 'new'. In fact, the approach should be taken that '*waste is not waste until you waste it'*.

Unfortunately, the current legal approach (see Box 2) does not help in encouraging the notion that materials can and should be re-utilised repeatedly wherever possible. It should be noted that legislation pertaining to the status and application of materials is likely to undergo change. End-users should be kept informed of relevant up-coming and new legislation, especially where these changes are to do with exemptions of materials from restrictions, licensing, storing or stockpiling, utilising, transporting, using, applying and disposing.

Box 4.2 Environment Agency definition of 'waste'

The Environment Agency position with regard to the recycling of materials into civil engineering structures is currently that they legally remain waste until incorporated into an engineering structure. It had been thought that a European Court judgement in Arco Chemie (C-418-97 and 419/97) would mean that waste would cease to be waste once partly processed into a material which was directly usable in an engineering structure. (An example of such part-processing might be tyres incorporated into a tyre block held together by strapping.) However, the Agency's position has been reviewed in the light of recent decisions of the European Court of Justice (Abfell Services AG(ASA) C-6/00 and Palin Granite Oy C-9/00). The Agency has now taken a new view with reference to the judgement in Abfell Services AG that "the essential characteristic of a waste recovery operation is that its principal objective is that the waste serves a useful purpose in replacing other materials… ." The Agency has therefore stated that in this context waste will usually only be deemed to have been recovered once it has been put to use and is incorporated into an engineering structure. Until that time partly -recovered products remain waste.

If the waste is going to be incorporated into an engineering structure for flood defence or coast protection purposes, the operation is not a waste disposal operation, but a waste recovery operation. Thus, subject to the nature of the materials involved, a PPC (Pollution Prevention and Control) permit will generally not be required. However, a Waste Management Licence is required for each and every site at which waste is to be stored or recovered. The Environment Agency grants quasi-licenses in the case of work carried out by itself, on the same terms and conditions that it grants licenses to any other party.

Use of some waste materials in construction is an exempt activity for the purposes of the Waste Management Licencing Regulations 1994; (the relevant section of these regulations is Schedule 3, paragraph 19, which refers to construction work involving certain specified wastes.) Whether an exemption is made is a matter for the Government and addition of new wastes requires a change to the Regulations.

End-users however should be informed that much can be achieved "in spite of" the terminology used and its current interpretation, and asked to think again about assumptions they may make about legislative requirements and restrictions. A possible sustainable policy on materials selection for use by operating authorities is set out in Box 4.3 below.

Box 4.3 Policy statement on material selection for use by operating authorities (from Masters, 2001)

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 business involved, harnessing the profit objective of each business but serving environmental and sustainable development objectives
- sets 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.

4.2 Key references, available research and research needs

4.2.1 Estimating environmental impact of materials selection

Despite the above problems, HR Wallingford has compiled a database of maintenance cost information to assist the coastal or river engineer adopt a consistent approach to estimating these costs for port, coastal and fluvial structures. (The database is accessible at www.wholelifecosts.org) It provides an indication of the likely maintenance and monitoring costs associated with groynes, breakwaters, seawalls, jetties, wharves / quays, beaches and revetments (Masters & Simm, 2002).

In addition the "Ecopoints Estimator" has been developed by the Building Research Establishment and HR Wallingford in collaboration with representatives of the construction materials sector. This enables the identification of scheme and material options that have less impact on the environment and are more sustainable. Ecopoints are calculated from the effects on the environment of the extraction, processing and transport components of the life cycle of each material up to the time they leave the factory gate. The details of the approach are given in the following reference:

> Masters, N. (2001) Sustainable use of new and recycled materials in coastal and fluvial construction: A guidance manual. Thomas Telford, London

The Estimator can be used to compliment other methods and processes, such as EIA or the broader CEEQUAL scheme, 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.

This tool is designed to be used by authorities in the project appraisal and tender evaluation process. It may also be appropriate for tenderers to use the Ecopoints spreadsheet to assess the environmental impacts of using alternative sources of materials.

The following environmental impacts are accounted for in the spreadsheet calculations.

- Climate change
- Acid deposition
- Ozone depletion
- Minerals extraction
- Water pollution (human toxicity, ecotoxicity and eutrophication)
- Air pollution (human toxicity and generation of "summer smog")
- Fossil fuel depletion
- Waste disposal
- Water extraction

The relative importance of each environmental impact is accounted for by the introduction of weighting factors. These were chosen using a stakeholder consultation approach, asking industry representatives to judge how important they considered the different impacts to be (Dickie and Howard 2000). There was sufficient consensus across the industry to generate a single set of weightings that can be applied to the environmental data.

To generate the Ecopoints, the environmental impacts are also "normalised" by comparing them to the impacts of one UK citizen for one year. By applying the normalisation factors and weightings, BRE derived a scoring system whereby 100 Ecopoints are equal to the environmental impacts of one UK citizen for one year.

There is always some subjectivity on the relative importance of different environmental effects as there is in any method of this type. It does however allow a quick assessment of the potential environmental effect of a product throughout its life.

The Ecopoints are values that express the total environmental load or process as a single figure. This allows comparison between different products based upon the environmental impact of materials and processes used and conducted to produce them.

The Ecopoint score is used to represent the overall environmental impact of a product. More specific potential indicators can include quantities or ratios of materials, energy consumption, transportation distances, waste generation and percentage recyclability.

For buildings, a new tool, Envest2, is available which combines environmental and whole life costing. A logical step forward in due course would be to extend such a **combined environmental and whole life cost approach** to the infrastructure associated with flood and coastal defence.

4.2.2 Timber procurement and re-use

Many coastal and river structures such as piers, groynes, lock gates, jetties and river bank cladding are comprised either entirely or partially of timber, mostly from tropical forests. Tropical hardwoods have properties which make them attractive for these purposes, however there has been increasing public awareness and concern relating to the environmental damage caused by industrial scale logging of forests and the environmental costs of long distance transport of materials.

The Global Forest Resources Assessment 2000 (FAO 2001) estimates that 14.6 million hectares of natural forest are lost each year and a further 1.5 million hectares are converted to forest plantations. Although the rate of deforestation was slower in the 1990s than the 1980s, most of the losses were in the tropics and it is widely accepted that the rate of destruction is still unsustainable.

Whilst unsustainable logging for export contributes to this degradation of tropical forests, only a comparatively small portion of the timber harvested is actually shipped abroad. Much of the timber is used for firewood, local construction or wood products such as paper in the countries of origin. The responsible specification and purchase of timber can have a significant impact in discouraging illegal and unsustainable practices.

There is clearly an urgent need to encourage the implementation and practice of sustainable forest management world-wide. In recent years, this has resulted in the establishment of a suite of international agreements, government policies and statements and intense lobbying activities from NGOs.

A recently published report (Procurement of timber products from 'Legal and Sustainable Sources' by Government and its Executive Agencies, ERM 2002 – see www.forestforum.org.uk) suggests a basis for public sector timber procurement in the UK. It addresses appropriate sustainability criteria and recognises that it is necessary to adopt a proactive approach to eliminating timber logged illegally and/or unsustainable practices.

In order to identify whether a timber product is legal and sustainable it is essential to have verification of where it has come from. This requires the 'chain of custody' to be recorded and verified through some form of independent auditing. To be meaningful in forestry terms, certification should be complimented by labelling. However, construction materials are often not directly labelled, but the certification reference numbers should be quoted on advice and delivery notes. These can then be verified directly by the recipient with the accrediting organisation (such as the Forestry Stewardship Council), often via the Internet.

It is unlikely however that this certification process is going to be taken up by suppliers overnight or indeed globally, or applied to the full range of timber used in coastal and river engineering structures. A framework for assisting with the procurement process in spite of these difficulties is presented by Crossman & Simm (2004) in their 'Manual on the use of timber in coastal and river engineering'. This framework demonstrates the iterative nature of the design and selection process and intentionally excludes cost criteria. Whilst there may be a cost premium for certified timber, it is likely to form a relatively small element of the overall scheme value.

5. FUTURE R&D PROGRAMME

The user needs and gaps in knowledge have been considered in terms of their potential to be addressed by R&D. A proposed R&D programme in materials for fold and coastal defence is set out in Table 5.1. It is broken down into a series of activity types which have the capability of being carried out in different ways and with different funding routes. The following notes are by way of explanation of the proposed programme.

5.1 Existing research

This section of the programme sets down the known current programme of research to which the Defra/EA R&D programme is contributing. The project funders and research contractors are as follows:

Project short title	Funding arrangements	Research contractor
1. Timber manual	DTI PII project – some EA funding	HR Wallingford
2. Armour rock integrity	UK-French collaborative project – some EA funding	Imperial College (via HR Wallingford)
3. Rock Manual (2^{nd} edition)	DTI PII project – some EA funding	CIRIA, HR Wallingford, Halcrow, Imperial Coll.
4. Re-use of tyres	DTI PII project – some EA funding	HR Wallingford, Southampton University
5. ALWC steel project	DTI PII project – some EA funding	CIRIA/Mott Macdonald

5.2 Proposed research

Most of the following projects would be ideal for collaborative research, involving Defra/EA, the Construction Industry, ports, consultants and contractors. Unfortunately the DTI PII programme has come to an end and it is as yet unclear whether the new DTI research products will provide adequate support to construction research. The situation will hopefully become clearer during 2004/05.

Project short title	Funding arrangements	Possible research contractor
1. Concrete Manual	Collaborative project, some Defra/EA funding	CIRIA, with Halcrow and HR Wallingford
2. Masonry Manual	Collaborative project, some Defra/EA funding	CIRIA, with Posford and HR Wallingford
3. Beach Management Manual (2^{nd} edition)	Collaborative project, some Defra/EA funding	CIRIA, with HR Wallingford and consultant
4. Beach recharge materials – demand & resources (2^{nd} edition)	Collaborative project, some Defra/EA funding	CIRIA, with others including BGS etc
5. Timber – completion of durability testing of new timbers	Defra/EA funding	TRADA
6. Timber – shipworm prevalence around the UK	Ports and Defra/EA funding	TRADA
7. ECOPOINTS 2 – materials environmental impact and whole life costs combined	Collaborative project, some Defra/EA funding	BRE and HR Wallingford

5.3 Pilot projects

The following projects are not seen as being funded principally from the Defra/EA Joint R&D Programme. However, some R&D funds might usefully be "bolted on" for monitoring and review of the projects, if this funding cannot be sourced from elsewhere.

Collaboration with WRAP regarding funding of pilot projects with recycled materials is worth active engagement. This could cover various types of scheme including:

- beach recharge trials using china clay sand, slate aggregate and smaller quantities of recycled aggregate,
- flood embankment construction using various secondary or recycled aggregates, and
- incorporation of recycled or recovered C and D waste, and / or secondary aggregates within revetments, breakwaters or rock groynes / sills.

Project short title	Funding arrangements	Possible research contractor
1. Pilot project(s) with FSC timber	Generally non R&D. May require funding of monitoring	EA framework consultants and contractors
2. Pilot project(s) with asphalt	Generally non R&D. May require funding of monitoring	EA framework consultants and contractors
3. Pilot projects with recycled materials (WRAP supported)	Generally non R&D. WRAP may support, including funding of monitoring	EA framework consultants and contractors

5.4 Training

The exact details of the training requirements will need to be resolved in discussion with Defra/EA. However, based on previous experience, if there is evidence of sufficient demand then the events can be self-funding. However, this is contingent on sufficient training budget being made available from EA and local authorities to support delegate attendance.

Part of the programme is already established in terms of regular events at HR Wallingford such as the armourstone users group and planned events on timber and recycled materials.

Project short title	Funding arrangements	Possible research contractor
1. General workshop	EA/self-funding	HR Wallingford and research partners
2. Topic workshops	Self-funding	HR Wallingford and research partners

5.5 Other initiatives

Various other items that have been identified through this review are listed below.

Project short title	Funding arrangements	Possible research contractor
1. Performance evaluation of projects	Should become a standard part of Defra grant aided projects	Project manager/designer of specific project
2. Case study preparation on use of recycled materials for WRAP web site.	Funded by EA/WRAP as part of the pilot programme	EA framework consultants and contractors
3. Questionnaire on novel material applications	Defra/EA	To be agreed
4. Setting up of single point of expertise enquiry service for materials	Defra/EA	To be agreed

Table 5.1 Proposed R&D programme for materials.

DATE (F/Y)	2004-5				2005-6				2006-7				2007-8			
TOPIC																
A. ONGOING R&D																
1. Timber manual	■	■														
2. Armour rock integrity	■	■	■													
3. Rock manual (2nd edition)	■	■	■	■	■	■										
4. Re-use of tyres	■	■	■	■	■	■	■									
5. ALWC steel project	■	■	■	■												
B. PROPOSED RESEARCH																
1. Concrete Manual			■	■	■	■	■	■	■	■						
2. Masonry Manual					■	■	■	■	■	■	■	■				
3. Beach Management Manual (2nd edition)									■	■	■	■	■	■	■	■
4. Beach recharge materials – demand & resources (2nd edition)									■	■	■	■	■	■	■	■
5. Timber – completion of durability testing of new timbers	■	■	■	■	■	■										
6. Timber – shipworm prevalence around the UK					■	■	■	■	■	■						
7. ECOPOINTS 2 – materials environmental impact and whole life costs combined					■	■	■	■	■	■	■	■				
C. PILOT PROJECTS																
1. Pilot project(s) with FSC timber																
2. Pilot project(s) with asphalt																
3. Pilot projects with recycled materials (WRAP supported)																
D. TRAINING																
1. General workshop																
2. Topic workshops																
E. OTHER INITIATIVES																
1. Performance evaluation of projects																

2. Case study preparation on use of recycled materials for WRAP web site.																
3. Questionnaire on novel material applications																
4. Setting up of single point of expertise enquiry service for materials																

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BS EN 13242 Aggregates for unbound and hydraulically bound materials
BS EN 13383 Armourstone
BS EN 13450 Railway Ballast
BS EN 13055-1 Lightweight aggregate for concrete
BS EN 13055-2 Lightweight aggregate for bound and unbound materials

National Guidance documents

PD 6682-1 Aggregates for concrete
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PD 6682-4 Lightweight aggregates for concrete and mortar
PD 6682-5 Lightweight aggregates for other uses
PD 6682-6 Aggregates for unbound and hydraulically bound materials
PD 6682-7 Aggregates for armourstone
PD 6682-8 Aggregates for railway ballast
PD 6682-9 Test methods for aggregates