

Potential use of alternatives to primary aggregates in coastal and river engineering

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Summary

Construction is the largest consumer of natural resources in the UK. More than 90 per cent of non-energy materials extracted in the UK supply the construction industry. This represents, on average, nearly 30 million tonnes per year of primary materials, of which some 214 million tonnes is in the form of aggregates. Concern is growing about the environmental consequences and the long-term sustainability of this resource use. In response, the UK Government is seeking both to reduce the demand for primary aggregates, for example through the Aggregates Levy, and to encourage the use of alternative materials.

This review seeks to identify the potential for using secondary and recycled aggregates, including inert construction and demolition (C&D) waste, in coastal and river engineering schemes. It seeks to reduce the impact of river and coastal construction on natural resources by promoting the use of alternative materials. In addition, it aims to increase the use of alternatives to primary aggregates in the UK (the UK is already a leading user of these materials in Europe), by:

- raising awareness of the potential use of secondary aggregates and recycled/reused materials as aggregates
- reassuring designers and constructors of the appropriateness of using alternatives to primary aggregates
- assisting in overcoming reluctance to the use of alternatives to primary aggregates
- enabling the construction industry to provide more sustainable and cost-effective solutions for river and coastal engineering.

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Following CIRIA’s usual practice, the research project was guided by a steering group, which comprised the following members.

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Glossary

Aggregate	The European Standards for Aggregates provide the following definitions, which should now be regarded as the correct definitions for construction aggregates in the UK and EU.
Aggregate	Granular material used in construction. Aggregate may be natural, manufactured or recycled.
Recycled aggregate	Aggregate resulting from the processing of inorganic material previously used in construction.
Manufactured aggregate	Aggregate of mineral origin resulting from an industrial process involving thermal or other modification.
	In addition to these “standard” terms it is useful here to add two further definitions for aggregates.
Primary aggregate	Construction aggregates produced from crushed rock, and sand and gravel (land and marine won). These aggregates are subject to the Aggregates Levy.
Secondary aggregates	Construction aggregates produced from by-products of industrial processes (manufactured aggregates) such as metallurgical slags, pulverised fuel ash (PFA) and incinerator bottom ash (IBA), plus aggregates produced as by-products from other mineral-extraction processes such that they do not incur the Aggregates Levy, such as china clay sand, and slate aggregates.
Alternative materials	Materials, such as recycled and secondary aggregates, that have not traditionally been considered construction materials.
Armour	Outer protective layer of a sea or river defence usually made of armour units .
Armour stone	Large quarried stone used as primary protection against wave attack.
Armour units	Large quarried stone or specially shaped concrete blocks used as primary protection against wave action.
Beach recharge (or renourishment)	Supplementing the natural volume of sediment on a beach, using imported material (also referred to as beach nourishment/feeding).
By-products	Useful materials that arise as a consequence of processes to create primary products.
Cement-bound material/mixture (CBM)	A mixture of soil or aggregate and Portland cement that generally has a water content compatible with compaction by rolling. After compaction and cement hydration, the mixture hardens to produce a hard, durable and erosion-resistant construction material.
China clay	Commercial term for kaolin, a clay mineral used in the manufacture of whiteware ceramics and in the filling and coating of paper.
China clay sand	Granite sand produced from the processing of waste generated by the china clay industry.
Construction and demolition waste (C&D waste)	Inert waste generated by the construction and/or demolition of buildings and/or civil engineering infrastructure. Materials include concrete, brick, asphalt, unbound aggregates, soil and clay.
Controlled waste	“Household, industrial and commercial waste or any such waste. Such definition includes waste arising from works of demolition, construction and preparatory work thereto” (EPA 1990 and Controlled Waste Regulations 1992).
Core	Material within the defence structure protected by the outer armour or cover layer.
Culvert	A covered conduit for taking a watercourse, drain or sewer under a railway, road or embankment.
Diffuse pollution	Pollution that does not arise from an easily identifiable source (or point source such as a discharge pipe). Usually refers to runoff or leaching from land.

Dioxins	A particularly toxic class of halogenated aromatic compounds, the by-product of the bleaching process used in the manufacture of white paper and the manufacture of other chemicals such as the herbicide Agent Orange and from incomplete incineration of wastes containing chlorine.
Dredging	The excavation and removal of material from the bed of a river, harbour, lake or sea by dredger, dragline or scoop.
Durability	The ability of a material to resist degradation and retain its physical and mechanical properties.
Ecosystem	The plants, animals and micro-organisms that live in a defined space and the physical environment in which they live.
Embankment	Earth structure, often built for flood protection.
Environment	Surroundings in which an organism operates, including air, water, land, natural resources, flora, fauna, humans and their interrelation.
Embodied energy	The quantity of energy required by all of the activities associated with a production process including the acquisition of primary material, transportation, manufacturing and handling.
Estuary	A semi-enclosed body of water in which seawater is substantially diluted with freshwater entering from land drainage.
Gabion	A generally rectangular box or mattress made of wire mesh and filled with stone.
Geotextile	A synthetic fabric used as a filter or a separation layer (can be woven or unwoven).
Groyne	A structure, generally perpendicular to the shoreline or riverbank, built to control the movement of beach material or to arrest erosion.
Hoggin	Sieved or screened gravel.
Hydraulically bound material/mixture (HBM)	Includes CBM and thus soil cement and roller-compacted concrete, but also describes similar products based on the cementitious properties of lime, pulverised fuel ash and hydraulic slag such as ground granulated blast-furnace slag.
Leachate	The liquid generated after a solid is subjected to a leachant.
Lithology	The physical characteristics of a rock or sediment, including colour, composition and texture.
Nutrient	A substance providing nourishment for living organisms (such as nitrogen and phosphorous).
Permeability	The ease with which water will pass into and through the pores in rock, soil, sand or gravel.
Permeameter	An instrument for measuring permeability.
Pollution	The introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structures or amenity, or interference with legitimate uses of the environment.
Pozzolanic	Ability to harden when reacted with lime and water to give a cementitious product.
Pyrolysis	Decomposition of rubber by heat in an oxygen-free atmosphere.
Primary aggregates	See Aggregate above
Primary materials	Materials extracted from virgin natural reserves.
Porosity	Ratio of voids of a material to its total volume.
Quarry	A site from which natural rock is extracted.
Ramsar site	A site designated by government as a Wetland of International Importance (Ramsar site) under the Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the Ramsar Convention, 1973).

Recycling	System of collecting, sorting and reprocessing old material into usable raw materials.
Recycled aggregates	See Aggregates above.
Resource	A concentration of materials from which extraction of a commodity may be possible.
Reuse	The employment of an article or item once again for its original purpose, or for a different purpose, without prior processing to change its physical or chemical characteristics.
Revetment	One or more layers of stone, concrete or other material used to protect the sloping surface of an embankment, natural coast or shoreline against erosion.
Rip-rap	Widely graded rock armour.
Rubble-mound structure	A mound of randomly shaped and randomly placed stone.
Salmonid waters	Waters in which game fish (such as salmon, trout, grayling and whitefish) are found.
Scalpins	Small stones used for drainage in excavations, and as hardcore.
Scour	Erosion of bed or beach material close to a structure due to wave or river action.
Secondary aggregates	See Aggregates above.
Site of Special Scientific Interest (SSSI)	An area of land or water notified under the Wildlife and Countryside Act 1981 (as amended) as being of geological or nature conservation importance, in the opinion of the Countryside Council for Wales, English Nature or Scottish Natural Heritage.
Special Area of Conservation (SAC)	Established under the EC Habitats Directive (92/43/EEC), implemented in the UK by The Conservation (Natural Habitats etc) Regulations 1994 and The Conservation (Natural Habitats etc) (Northern Ireland) Regulations 1995. The sites are significant in habitat type and species, and are considered in greatest need of conservation at a European level. All UK SACs are based on SSSIs, but may cover several separate but related sites.
Special Protection Area (SPA)	The Directive on Conservation of Wild Birds (79/409/EEC) allows for the designation of areas specifically for bird species to prevent deliberative capture, killing and disturbance of certain endangered species as well as the destruction or damage to eggs and nests. (Designated sites are also subject to the provisions of the Conservation (Natural Habitats etc) Regulations 1994.)
Spoil	Soil or rock or other material arising from excavation, dredging or other ground engineering work.
Toe	The lowest part of a coastal or river defence structure or riverbank.
Under-layer	Granular layer beneath armour or cover layer which may serve as a filter and/or as a separating layer. May be replaced or augmented by a geotextile.
Waste	Waste is something that “the producer or holder discards or intends to or is required to discard” (Waste Management Licensing Regulations 1994). For a substance or object to be waste it must: fall into one of the categories set out in Part II of Schedule 4 to the Regulations; and <ul style="list-style-type: none"> ● be discarded or disposed of by the holder; or ● be intended to be discarded or disposed of by the holder; or ● be required to be discarded or disposed of by the holder (from DoE Circular 11/94).

Abbreviations

ASLQ	Area of Special Landscape Quality
ASR	alkali-silica reaction
BFS	blast-furnace slag
BOF	basic oxygen furnace (slag)
BOS	basic oxygen steelmaking
BPOE	best practicable environmental option
BRE	Building Research Establishment
BS	British Standard
C&D	construction and demolition
CBM	concrete-bound material
CCW	Countryside Council for Wales
CDEW	construction and demolition excavation waste
CEN	European Standards Committee
CEFAS	Centre for Environment, Fisheries & Aquaculture Science
CFMP	catchment flood management plan
Defra	Department for Environment, Food and Rural Affairs
DoE	Department of the Environment
DTI	Department of Trade and Industry
D50	particle size for which 50 per cent of the material is finer
EA	Environment Agency
EAF	electric arc furnace (slag)
EC	European Commission
EMP	estuary management plan
EN	English Nature
EPA	Environmental Protection Act
EU	European Union
FAS	flood alleviation scheme
FBA	furnace bottom ash
FEPA	Food and Environmental Protection Act
GGBS	ground granulated blast-furnace slag
HBM	hydraulically bound material
IBA	municipal solid waste incinerator bottom ash
IDB	internal drainage board
kt	thousand tonnes
MSW	municipal solid waste
mt	million tonnes
mt/a	million tonnes per annum
ODPM	Office of the Deputy Prime Minister
PFA	pulverised fuel ash
pH	acidity/alkalinity
PR	public relations
RCC	roller-compacted concrete
RTB	railway track ballast
SAC	Special Area of Conservation
SEPA	Scottish Environmental Protection Agency
SHW	Specification for Highway Works
SNH	Scottish Natural Heritage
SMP	shoreline management plan
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
TRL	Transport Research Laboratory
WFD	Water Framework Directive
WML	waste management licence
WRAP	Waste and Resources Action Programme

1

Background and use of the book

1.1

BACKGROUND TO THE STUDY

Construction is the largest consumer of natural resources in the UK. More than 90 per cent of the non-energy minerals that are extracted in the UK supply the construction industry. This represents, on average, nearly 300 million tonnes a year (mt/a) of primary materials (Smith, Kersey and Griffiths, 2002), the majority of which (some 214 mt/a) is in the form of aggregates. If, as expected, the UK's demand for aggregates increases by 1 per cent per cent per annum, then by 2012 an extra 20 mt of aggregates will be needed annually (see < <http://www.aggregain.org.uk>>). Concern is growing about the environmental consequences and the long-term sustainability of providing this large amount of construction material.

Reflecting this, in April 2002 the UK Government introduced an Aggregates Levy as an environmental tax on the commercial exploitation of aggregates in the UK. Presently set at £1.60 per tonne, the main objectives of this levy are to reduce the demand for primary aggregates and encourage the use of alternative materials (see < <http://www.hmce.gov.uk/business/othertaxes/agg-levy.htm>>).

This latter objective is particularly relevant to the present project. The UK is already a leading user of these materials in Europe and has established large and successful markets for alternatives to primary aggregates. In England alone, some 50 mt/a are derived from recycled or secondary sources, as identified in previous research (see < <http://www.aggregain.org.uk>>). Increasing the use of alternative (eg recycled) construction materials is a potentially more sustainable way to meet future demands.

Several definitions of aggregate are used in this book. The following standard terms from the European Standards for Aggregates should now be regarded as the correct definitions for construction aggregates in the UK and EU:

- **aggregate** – granular material used in construction; it may be natural, manufactured or recycled
- **recycled aggregate** – aggregate resulting from the processing of inorganic material previously used in construction
- **manufactured aggregate** – aggregate of mineral origin resulting from an industrial process involving thermal or other modification.

To these standard terms it is useful to add two further definitions:

- **primary aggregate** – construction aggregates produced from crushed rock and sand and gravel (land- and marine-won). These aggregates are subject to the Aggregates Levy
- **secondary aggregates** – construction aggregates produced from by-products of industrial processes (manufactured aggregates) such as metallurgical slags, pulverised fuel ash (PFA,) and incinerator bottom ash (IBA), plus aggregates produced as by-products from other mineral extraction processes such that they do not incur the Aggregates Levy, such as china clay sand and slate aggregates.

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 each year (Smith, Kersey & Griffiths, 2002). This, coupled with limited available landfill space and the implementation of the EU Landfill Directive, influenced the UK Government's introduction of the Landfill Tax (see < <http://www.hmce.gov.uk/business/othertaxes/landfill-tax.htm>>) and waste strategy (see < <http://www.defra.gov.uk/environment/waste/strategy/cm4693>>) in an attempt to secure changes to behaviour and to meet new waste targets. 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.

In the specific case of coastal and river engineering activities, the UK uses each year about 1 million tonnes of armour-stone and about 2 million tonnes of largely sea-won aggregates, at a value well in excess of £100 million. At present, this usage consists almost entirely of primary materials, such as marine-dredged sand and gravel for beach recharge schemes and high-quality rock, predominantly from coastal quarries. Because of recent severe river flooding, and the predicted acceleration of sea level rise, it is expected that the increase in the demand for materials will be proportionately greater in this sector of civil engineering than for general construction.

It is therefore important that coastal and river engineers address their resource usage and reduce consumption wherever possible. The Environment Agency has introduced targets to encourage the use of alternatives to primary aggregates to this end. In addition to reducing the basic resource demands, there may be a further potential advantage to the natural environment in reducing the impacts (CO₂ emissions, embodied energy etc) associated with the extraction, processing and transport of primary materials to construction sites.

Furthermore, the water sector of civil engineering can provide a crucial pathfinder role in promoting new applications of alternatives to primary materials. There are three reasons for this:

- the sensitivity of the water environment, limiting the levels of allowable contaminants
- the harsh conditions, especially on coasts, requiring use of strong and durable materials
- the need to keep scheme costs low, given the limited funding available from the Exchequer.

Successful applications in this sector would help promote further applications across the entire construction industry. This will contribute to a general reduction in the demand for primary resources in construction and in the disposal of materials from construction and demolition to landfill. It will also lead to a specific improvement in the sustainability of river and coastal engineering, reducing their demands for primary aggregates.

1.2

OBJECTIVES AND SCOPE OF STUDY

The strategic, long-term objective of this study is to reduce the impact of river and coastal construction on natural resources by promoting the use of alternative materials in place of primary aggregate and other materials.

The project's aims are to:

- raise awareness of the potential use of secondary aggregate and recycled/reused materials as aggregates
- reassure designers and constructors of the appropriateness of using alternatives to primary aggregates
- help address the barriers to the use of alternatives to primary aggregates in a strategic and co-ordinated way, and hence
- enable the construction industry to provide more sustainable and cost-effective solutions for river and coastal engineering;

To assist in achieving the above aims, this study had the following subsidiary targets:

- to identify river and coastal engineering works that could use alternative materials
- to review the availability and suitability of recycled and secondary materials available that could replace primary aggregates
- to identify any barriers to the use of these materials, and how they might be overcome
- to present guidelines for the possible use of alternative materials, with case histories describing where they have been used
- to identify where further development or research could extend the use of such materials.

This project is principally a scoping exercise, reviewing the potential for the use of secondary and recycled aggregates, including inert C&D waste, in coastal and river engineering schemes. The target audience for this publication is the construction industry, demolition contractors, coastal and river engineers, and environmental and minerals regulators.

The initial phase of the study concentrated on reviewing the types of river and coastal engineering schemes that are carried out in the UK and the quantities, availability and characteristics of secondary and recycled aggregates.

In both of these areas, attention was first focused on the large-volume ends of the spectrum, for example materials arising from demolition, and beach recharge projects. Beach recharge projects over the whole of the UK involve the use of 1–3 mt of material each year. Overcoming prejudices and barriers to replacing primary aggregates in such high-profile schemes would have a major effect on the wider use of alternative materials. However, it also became clear that local, small-scale uses of recycled or secondary aggregates were already under way, providing valuable examples for wider dissemination. This project therefore considers a wide range of possible applications where alternatives to primary aggregates could be considered.

The project has involved widespread consultation and discussions with experienced practitioners in both river and coastal engineering and in waste recycling. Examples of the deliberate and considered use of alternatives to primary aggregates in coastal and river engineering have been sought, within the UK and worldwide. Where possible, past schemes have been collated and presented as case histories, to demonstrate that potential does exist for further and perhaps more ambitious applications.

However, this review together with a workshop held as part of the project, also revealed some barriers to the widespread use of secondary and recycled materials in this form of civil engineering.

These included concerns about:

- potential risks to water quality and to the wider natural environment (eg by pollution)
- the quality and consistency of alternative materials, and hence their durability
- the possible effects on amenity and aesthetic value of rivers and coasts
- the availability and costs of alternative materials, and the continuity of their supply.

This project sought to separate perceptions from the reality of these issues, and the publication indicates ways in which the remaining obstacles to using alternative materials may be overcome.

During the project, particularly during the consideration of barriers, the need for additional research work has been identified that cannot be satisfied within the scope or duration of this project. This is particularly the case with regard to:

- assisting with the development of policy that will help to take this application forward
- evaluating and revising specifications
- implementing and monitoring pilot projects.

The book therefore makes recommendations on the further work that is needed to overcome prejudices and demonstrate the successful uses of alternatives to the use of primary aggregates in coastal and river engineering projects.

1.3

LAYOUT OF THE BOOK

Section 1.4 of this book briefly explains the project methodology. Thereafter, it has been laid out to match the five short-term targets described in Section 1.2.

Chapter 2 reviews the types of river and coastal engineering schemes around the UK and includes some provisional indications of the types and quantities of materials that are used in their execution.

Chapter 3 provides a description and analysis of the secondary aggregates and recycled inert C&D waste that are available in the UK. This is largely based on information supplied by WRAP's AggRegain initiative (see <<http://www.aggregain.org.uk>>), supplemented by an initial view on the likely usefulness of each type of material identified for this particular project.

Chapter 4 deals with the barriers to the use of secondary aggregates and of recycled inert C&D materials in river and coastal works. It discusses the environmental and also the practical engineering issues that arise in these situations.

Chapter 5 summarises guidelines for the uses of alternatives to primary aggregates, based on the information gathered during this study. Where possible, this guidance is supported by case histories.

The final chapter (6) sets out recommendations for the future research and development that is likely to be needed to increase the usage of secondary and recycled aggregates, including inert C&D waste. Particular emphasis is placed on practical measures such as trial schemes, rather than on further desk studies or reviews, and on the dissemination of information on such schemes to help convince other engineers that reducing primary aggregates is not only possible but beneficial. These

recommendations are based on the findings of consultation with the project steering group and key stakeholders, discussion at the project workshop and through a peer review of this book.

1.4

PROJECT METHODOLOGY

The study began with a review of information both on alternative materials and on past examples of river and coastal engineering schemes that have made use of them. This was carried out through literature and Internet searches and by consultations with the project steering group members and with a wide range of organisations in the UK and overseas.

The review was subdivided into three main topic areas:

- potential alternative construction materials (restricted to England, Wales and Scotland)
- examples of the use of these materials in coastal and river environments (accidental or as engineering works)
- potential barriers to the usage of such materials (concern about pollution or aesthetics, for example).

The last of these three topics was the subject of a project workshop. This was organised because of the importance attached to identifying, and where possible overcoming, any barriers to using these alternative materials.

As a result of the work carried out by WRAP under the AggRegain initiative, much was already known about the types, quantities and availability of secondary aggregates, but there was rather less detail on the types of inert C&D waste that might be usable. When investigating these materials, the project ranged further than seeking recycled granular materials, and considered the larger elements of demolition rubble such as kerbstones, concrete railway sleepers and the like. This project also considered some secondary aggregates, such as china clay sand, slate aggregate, dredged material and scrap tyres.

The second part of the project collated, analysed and reported on the information gathered, drew up preliminary guidelines for the various groups of organisations with an interest in processing, selling, licensing and using alternative materials in coastal and river engineering.

Finally, the main conclusions from the project were summarised, and recommendations drawn up for further work aimed at reducing the use of primary aggregates in coastal and river engineering.