



## RIVER MINING: ALTERNATIVE SOURCES OF AGGREGATES



BRITISH GEOLOGICAL SURVEY

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# Alternative sources of aggregates

DJ Harrison, EJ Steadman

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Discharging marine sand and gravel cargo from dredging vessel, UK.

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### *Parent Body*

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☎ 01793-411500 Fax 01793-411501  
[www.nerc.ac.uk](http://www.nerc.ac.uk)

# Preface

Throughout the developing world river sand and gravel is widely exploited as aggregate for construction. Aggregate is often mined directly from the river channel as well as from floodplain and adjacent river terrace deposits. Depending on the geological setting, in-stream mining can create serious environmental impacts, particularly if the river being mined is erosional. The impacts of such mining on farmland, river stability, flood risk, road and bridge structures and ecology are typically severe. The environmental degradation may make it difficult to provide for the basic needs (water, food, fuelwood, communications) of communities naturally located in the river valleys.

Despite the importance of this extractive industry in most developing countries, the details of its economic and environmental geology are not fully understood and therefore do not adequately inform existing regulatory strategies. The main problem is therefore a need to strengthen the general approach to planning and managing these resources. Compounding the problem is the upsurge of illegal extractions along many river systems. There is therefore a need to foster public awareness and community stewardship of the resource.

The project 'Effective Development of River Mining' aims to provide effective mechanisms for the control of sand and gravel mining operations in order to protect local communities, to reduce environmental degradation and to facilitate long-term rational and sustainable use of the natural resource base. This project (Project R7814) has been funded by the UK's Department for International Development (DFID) as part of their Knowledge and Research (KAR) programme. This programme constitutes a key element in the UK's provision of aid and assistance to less developed nations. The project started in October 2000 and terminates late in 2004.

Specific objectives of the project include:

- Resource exploration and resource mapping at the project's field study sites (Rio Minho and Yallahs rivers in Jamaica)
- Analysis of technical and economic issues in aggregate mining, particularly river mining
- Determination and evaluation of the environmental impacts of river mining
- Evaluation of social/community issues in the context of river mining
- Investigation of alternative land and marine aggregate resources
- Review of the regulatory and management framework dealing with river mining; establishment of guidelines for managing these resources and development of a code of practice for sustainable sand and gravel mining.

The 'Effective Development of River Mining' project is multidisciplinary, involving a team of UK specialists. It has been led by a team at the British Geological Survey comprising David Harrison, Andrew Bloodworth, Ellie Steadman, Steven Mathers and Andrew Farrant. The other UK-based collaborators were Professor Peter Scott and John Eyre from the Camborne School of Mines (University of Exeter), Dr Magnus Macfarlane and Dr Paul Mitchell from the Corporate Citizenship Unit at the University of Warwick, Steven Fidgett from Alliance Environment and Planning Ltd and Dr Jason Weeks from WRC-NSF Ltd. The research project is generic and applicable to developing countries worldwide, but field studies of selected river systems have been carried out in Jamaica and review studies have been undertaken in Costa Rica. Key participants in these countries have included Carlton Baxter, Coy Roache and Larry Henry (Mines and Geology Division, Ministry of Land and Environment, Jamaica) and Fernando Alvarado (Instituto Costarricense de Electricidad, Costa Rica).

The authors would like to thank the many organisations in Jamaica and Costa Rica who have contributed to the project. In addition to the collection of data, many individuals have freely given their time and advice and provided the local knowledge so important to the field investigations.

This report forms one of a series of technical Project Output Reports listed below:

- *Geology and sand and gravel resources of the lower Rio Minho valley and Yallahs fan-delta, Jamaica, 2003.* AR Farrant, SJ Mathers DJ Harrison, British Geological Survey.
- *Aggregate production and supply in developing countries with particular reference to Jamaica, 2003.* PW Scott, JM Eyre (Camborne School of Mines) and DJ Harrison, British Geological Survey.
- *Assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica, 2003.* J Weeks, WRc-NSF Ltd.
- *Scoping and assessment of the environmental and social impacts of river mining in Jamaica, 2003.* M Macfarlane and P Mitchell, Warwick Business School, University of Warwick.
- *Alternative sources of aggregates, 2003.* DJ Harrison and EJ Steadman, British Geological Survey.
- *Alluvial mining of aggregates in Costa Rica, 2003.* Fernando Alvarado Villalon (Costa Rican Institute of Electricity) and DJ Harrison, British Geological Survey.
- *Planning guidelines for management of river mining, 2003.* S Fidgett, Alliance Environment and Planning Ltd.

Details of how to obtain these reports and more information about the ‘Effective Development of River Mining’ project can be obtained from contacting the Project Manager, David Harrison at the British Geological Survey, Keyworth, Nottingham, UK, email: [djha@bgs.ac.uk](mailto:djha@bgs.ac.uk)

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# Summary

In most countries aggregates for construction are produced from the crushing and processing of hard rocks (mainly limestones, igneous rocks and sandstones) or from the extraction and screening of unconsolidated deposits of sand and gravel. The availability of aggregate sources varies from place to place within a country, depending on the geology. There are two main sources of aggregates in Jamaica; sand and gravel from alluvial deposits, especially from the active river channels, and limestone. The latter dominates in the north and west of Jamaica and the major producers of sand and gravel are in the south and east of the island. River sand is often in short supply and is generally the only available source of natural fine aggregate, an essential component of concrete and other building products.

There is considerable pressure in many countries to use secondary and recycled aggregates in construction because of the environmental problems associated with the production of primary aggregates. There is particular concern about the environmental effects of instream sand and gravel mining and thus there is a need to know to what extent alternative materials can augment or replace sand and gravel from this source. In Jamaica, the alternative sources include, marine sand and gravel, manufactured sand, river terrace deposits and recycled aggregates.

There has not been any production of marine aggregates in Jamaica but the environmental concerns of onshore extraction and land-use pressures require marine sources to be seriously investigated. Offshore sources are thought to exist off the mouth of the Yallahs river in Saint Thomas, Jamaica, but have not been investigated in detail. The Yallahs has formed a fan-delta onshore and this feature extends for a further two kilometres offshore. The onshore deposits consist of interbedded, poorly sorted, coarse gravels and sands which are over 30 m thick and which are extensively quarried, with extraction concentrated in the main river channel. The sediments offshore are thought to be similar in lithology and thickness to the land-based deposits and there is current interest in dredging marine aggregates from the mouth of the Yallahs river. However, a range of resource assessment, environmental impact, production and investment issues need to be addressed prior to any development.

Fine aggregate can be manufactured by crushing and processing hard rocks such as limestone and sandstone to produce fine grained (sand-sized) material. The degree to which such crushed rock sand can replace natural sand varies with rock type, the degree of quarry processing used and end-use. Nevertheless, in many parts of the world such material is a major source of fine aggregate. In Jamaica, 'stone dust' is produced as a by-product of limestone quarrying and is used, principally, in concrete block making and in asphalt products. The quality of the 'stone dust' is, however, variable and may perform poorly as fine aggregate. A few quarries wash the sand to remove fines and this significantly improves its quality. Sand is also produced from crushing river gravels at several sites, but this is coarse-grained and at the limits of specifications. Jamaica has large resources of rocks that can be crushed to produce manufactured sand, but improvement in quarry crushing and processing plant is required to consistently produce manufactured sand of acceptable quality.

In Jamaica, substantial resources of sand and gravel occur within the floodplain and terrace deposits and beneath the agricultural lands of the major river valleys. These deposits are not currently worked for sand and gravel aggregates; extraction is largely restricted to the river

channel deposits. It is common practice in many parts of the world for sand and gravel to be dug from such alluvial deposits. Indeed, in many countries they are the preferred source of fluvial sand and gravel as in-stream mining is restricted by environmental constraints. Development of the floodplain and terrace deposits in Jamaica will ease the pressure on mining of river channel deposits, reducing the impacts of river extraction. Nevertheless, there are environmental and other impacts associated with the working of river terrace deposits. If these resources are to be developed in future, a range of studies will be required, including exploration surveys, hydrogeological investigations and environmental and social impact assessments.

Many mineral wastes fulfil the technical requirements to substitute for primary aggregates and many governments are now encouraging greater use of mineral wastes as aggregates. Concrete, bricks and asphalt, for example, may be crushed and screened to produce secondary aggregates that can be used in construction. Recycling concrete rubble not only reduces environmental impacts of new aggregate production, but also avoids impacts associated with disposal. In Jamaica, the degree of recycling of mineral waste materials into secondary aggregates is very small, although some construction and demolition waste is used as fill.

In conclusion, there are several potential sources of alternative aggregate materials in Jamaica. There are, however, large resources of natural primary aggregate materials, although their extraction creates considerable environmental problems. The planning and management of aggregate resources must be based on the consideration of all possible sources. Therefore, the viability of alternative materials needs to be considered when formulating aggregate resource management plans.

# 1 Introduction

In Jamaica, sand and gravel is extracted from the active stream channels of several rivers and is used, with minimal processing, as aggregate for construction. This is a common situation in many developing countries where rivers form easily accessible sources of aggregates which are assumed to be naturally replenished during the wet season or during flood events. River sand, in particular, is often in short supply and is considered a premium product, because it is generally the only readily available source of natural fine aggregate, an essential component of concrete and other building products. There is a need to maintain, or indeed increase, sand production in Jamaica.

In recent years there has been an increasing use of, and interest in, alternative materials for natural aggregates. The onset of shortages in some construction materials in certain areas has made it important that these issues be examined in more detail during the formulation and implementation of resource management strategies. Mineral planners need to know to what extent substitute materials can augment or replace natural aggregates. This knowledge will influence decisions on management involving natural resources.

Aggregates suitable for most purposes can be obtained from sources other than river channel deposits, although in most cases more processing will be required. In Jamaica, these alternative sources include, crushed limestone, crushed igneous rock, marine sand and gravel, river terrace deposits and recycled aggregates. This report is intended to help the management of aggregate resources in Jamaica by documenting the potential of local resources of alternative materials as aggregates for the construction industry.

## 2 Alternative Sources

### 2.1 Marine Sand and Gravel

In many countries marine dredged sand and gravel make important contributions to aggregates supply. In northwestern Europe, extraction of sand and gravel from marine sources has taken place for over 70 years, but has grown considerably over the last 30 years (Figure 1). Dredging for marine aggregates occurs in several countries, chiefly the Netherlands, Great Britain, Denmark, Germany, Belgium and France. Marine aggregates are also traded commodities within Europe. The principal use is as aggregate for concrete, but supplies of marine materials are also critical for beach recharge schemes and for coastal reclamation projects.

There has not been any production of marine aggregates in Jamaica (or indeed in the Caribbean) but environmental concerns of onshore extraction and pressures of land-based development require marine sources to be seriously investigated.

In Jamaica, offshore deposits of sand and gravel have not been investigated in detail although such deposits are thought to exist off the mouth of the Yallahs river, where it emerges into the shallow Caribbean Sea after draining the southern slopes of the Blue Mountains. The Yallahs has formed a fan-delta onshore, with an area of over 10 km<sup>2</sup> and this feature extends for a further 2 km offshore (Figure 2).



**Figure 1 Trailer suction hopper dredger used to dredge offshore deposits of sand and gravel in Europe.**

**Figure 2 Yallahs beach, St Thomas, Jamaica. The fan-delta sand and gravel deposits extend offshore from the beach and form a resource of marine sand and gravel.**



The onshore deposits are an interbedded succession (over 30 m thick) of coarse or very coarse, poorly sorted sandy gravels and sands. The gravel size ranges from small pebbles and cobbles to large boulders 2 m or more in diameter. The gravels grade laterally and vertically into coarse, poorly sorted sands with scattered pebbles. Clast composition is predominantly volcanic and metamorphic lithologies, plus some limestones. Both gravel and sand fractions are sub-angular to sub-rounded in shape. Finer grained lithologies (fine sands and silts) occur locally, but are volumetrically insignificant.

Deposits onshore are extensively quarried, with extraction concentrated in the centre of the Yallahs river channel. About 80% of material extracted is of gravel size and the gravels are crushed to manufacture sand and to satisfy the demand of 50:50 gravel:sand. To date, total aggregate production from the Yallahs fan-delta is estimated at approximately 5 million tonnes (Farrant and Mathers, 2003). Jamaica Pre-mix Ltd (as one of the two companies working the deposit) currently produces about 450,000 tonnes of aggregates per year from quarries in the river channel. Extraction has however, significantly changed the river channel morphology. Whereas previously the river displayed a braided morphology, the channel is now incised up to 6 m below the level of the fan-delta surface. During flood events, rapid headward erosion of the fluvial deposits occurs, and has resulted in the undermining of the coastal road causeway which was washed away in recent floods (October, 2002).

The sediments offshore are likely to be similar in lithology and thickness to the land-based deposits currently extracted at Yallahs, although this is not proven. Offshore sands and gravels, may offer a realistic alternative to the onshore deposits at Yallahs, and there is current interest in investigating the possibility of dredging marine aggregates from the mouth of the Yallahs river.

A range of investigations need to be undertaken and considered prior to development;

- Resource assessment (based on seismic and sampling data)
- Environmental impact studies (involving bathymetric surveys, studies of sediment movement and coastal processes, ecological and fisheries studies etc.)
- Production issues (studies of extraction methods and strategies, processing requirements etc.)
- Transportation issues ( wharf and plant development etc.)

If adequate aggregate resources are present of the required quality, and if sufficient financial investment is available and all development issues are addressed responsibly, then it is likely that development of marine aggregate resources at Yallahs will be viable.

## **2.2 Crushed Rock Sand**

Sand can be manufactured by the crushing and processing of consolidated rocks, to produce fine-grained material variously known as ‘crusher fines’, ‘crusher dust’, ‘stone dust’, manufactured sand’ or ‘crushed rock sand’. Such materials are a major source of fine aggregates in many parts of the world. Certain hard rocks in Jamaica, specifically some limestones and bodies of igneous rock, are potential sources of crushed rock sand. ‘Stone dust’ is currently produced at several limestone quarries on the island (Figures 3 and 4) and is used primarily in concrete block making and in asphalt production, but in some cases it is also used in ready mixed concrete.

The degree to which crushed rock sand can replace natural sand will vary with rock type, the type of quarry processing employed and end use. The grading of a fine aggregate (‘sand’) has a major effect on the properties of both fresh and hardened concrete. Well-graded and well-shaped fine aggregate (most natural sands) produces concrete that can be readily pumped and worked, and which attains a fine finish. Many crushed rock sands have undesirable particle sizes and grain shapes which directly affect concrete quality and workability. They are typically ‘gap-graded’ with large proportions of coarse sand and very fine-grained material, but only small proportions of fine to medium sand sizes. This may limit their usage. Many crushed rock sands

**Figure 3 Mobile processing plant at Brazilleto Quarry, Clarendon, Jamaica. The quarry produces high purity stone for lime production, limestone aggregate and manufactured sand.**



**Figure 4 Crushed rock (limestone) sand at Brazilleto Quarry, Clarendon, Jamaica. The sand is not washed and is used in asphalt and concrete blocks.**



also contain angular particles which are rough and irregularly shaped and which therefore require a larger volume of cement owing to their high surface area-to-volume ratio. Generally, many crushed rock sands are also too fine grained. The high fines content (material finer than 150 microns) may limit their use. This results in a high surface area which affects the water requirements of the concrete; concrete made with such material has a high water demand, influencing the workability of the concrete. In addition, the high water demand results in increased cement usage, significantly increasing construction costs.

Crushed rock sands are successfully used as fine aggregate in many countries, although they are generally blended with natural sands to produce the desired grading and workability. Crushed rock sand products, particularly if they are to be used in concrete mixes, must be consistent in quality and of acceptable grading. Preferably, they should be manufactured in a purpose designed crushing and screening plant, in contrast to 'crusher dusts' from hard rock quarrying, which are made as residues of coarse aggregate production. A 'Barmac' type of crusher (which utilises high velocity rock-on-rock impact crushing and results in favourable particle shape and consistent grading) has proved to produce high quality crushed rock sand from a range of rock types. It is the preferred crusher for high quality manufactured sand.

In Jamaica, crushed rock sand or 'stone dust' as it is known, is made by crushing limestone as a co-product of coarse aggregate production at the many limestone quarries on the island. Currently there are 17 active licensed limestone quarries with crushing plants in Jamaica (Scott and others, 2003). In most quarries the crushing plants are old and are generally not focused on optimising the quality of the products. Hence the quality of the 'stone dust' is variable and may perform poorly as fine aggregate in concrete and concrete products. Fines are removed from sand by washing at a few quarries (eg. Hodges Minerals, Black River). This significantly improves its quality.

Sand could also be manufactured in Jamaica by crushing some of the Cretaceous volcanic rocks or granodiorites. There is no extraction of these rocks at present. They are mostly deeply weathered, covered with a thick surface zone of weak, low quality rock and they also generally occur in relatively remote locations with poor road access. A few areas of relatively fresh volcanic rocks have been identified (eg. Bito and Ramble, St. Thomas) which are potential resources of skid-resistant coarse aggregates (Scott and others, 2003). If quarries are developed in the future for such high specification materials, then the fines from production could be suitable for use as crushed rock sand. Such fines would be particularly valuable in asphalt due to their polish resistant properties. The quality of crushed rock sands from igneous rock operations may, however, be variable as the very fine grained material (generally <75 microns) may contain significant proportions of clay minerals which may result in high drying shrinkage values or problems caused by swelling clays. It may therefore be necessary to determine the mineralogy of the fines and to investigate its likely effect on the drying shrinkage of concrete products.

Sand is also produced from crushing the excessive amounts of natural river gravel at several of the larger river sand and gravel fixed processing plants (eg. Jamaica Pre-mix, Yallahs and Sha-Gore, Lionel Town, Rio Minho). The resulting sand is generally coarse-grained and at the limit of specifications (Figure 5). Blending of medium-grained sand (natural river sand) is needed to improve sand quality. A 'Barmac' crusher has recently been installed at the Sha-Gore plant, resulting in improved sand quality (Figure 6).

Aggregates must be fit for the purpose to which they are used and need to be made to acceptable quality standards. Much of the crushed rock sand currently produced in Jamaica is of low and variable quality. Little attention appears to be paid to aggregate quality or aggregate standards. Jamaica has large resources of rocks which can be crushed to produce manufactured sand for the construction industry. However, if good quality buildings, roads and other constructions are to be produced then aggregates are required which meet specifications. This will require investment in quarry plant, education within the industry, regular materials testing, and commitment and adherence to quality standards (see also Scott and others, 2003).

**Figure 5 Manufactured sand from crushed river gravels, used for concreting aggregate, Penas Blancas, Costa Rica.**



**Figure 6 Sha Gore processing plant, Rio Minho, Clarendon, Jamaica, producing good quality natural aggregates and manufactured sand from alluvial deposits.**



### 2.3 River Terrace and Floodplain Deposits

Although river channel deposits of sand and gravel form significant resources that may be continually or seasonally replenished, their extraction may cause scouring and erosion of the channel and other environmental problems. In Jamaica many river channels have been traditionally quarried for aggregates, but the impacts of river mining (Macfarlane and Mitchell, 2003) may in future limit these operations.

During periods of flooding in the river valleys, sand, gravel and fines may be spread extensively over the floodplains, resulting in wide spreads of potentially useful aggregate beneath a cover of silty alluvium. Such deposits, occurring as floodplain or raised terrace deposits are likely to occur in most of the wide alluvial plains in Jamaica. Geological mapping of alluvial deposits in the lower Rio Minho (Farrant and Mathers, 2003) has revealed thick sequences of sand and gravel in two river terrace deposits. The First (or Floodplain) Terrace comprises a fining upwards sequence of 2-3 m of silt and clay, overlying 6-8 m of sand and gravel, overlying 1-2 m of coarse gravel. The mapping has shown that extensive areas of the lower Rio Minho, from Longville to Alley, are underlain by this deposit. A higher level river terrace deposit (the Second Terrace) also occurs, but is capped by a thick (15 m) sequence of silt and clay and hence it is unlikely to be prospective for sand and gravel. Some extraction takes place from the Floodplain Terrace deposits in the Rio Minho (Figure 7), but in general there is little extraction from such sources in Jamaica, despite the probable occurrence of widespread, thick, good quality resources.

It is common practice in many parts of the world for sand and gravel to be dug from floodplain and terrace deposits. Indeed, in many developed countries they are the preferred source of fluvial sand and gravel as extractions from river channels are restricted by environmental constraints. The sand and gravel aggregates from the terrace deposits (Figure 8) are generally of similar quality to that available in the river channel deposits, although there is always considerable variation within alluvial deposits.

The extraction of river terrace deposits will result in some environmental impacts, which are distinct from the effects of river channel mining. By removing sediment from the floodplain and adjacent terraces, sand and gravel extraction may result in loss of agricultural land or ecological habitat, although, if the pit lies above the water table (dry pits), it is possible to reclaim the pit to agriculture on completion of mining. Sand and gravel extraction from such deposits can be looked at as a temporary use of land. However, if the extraction intersects the water table (wet pits) this results in land-use conversion from farmland to open-water ponds. This then holds the potential for creating wetland habitats, depending on the climatic and hydraulic regime. Extreme seasonal variability in water levels, for example, may constrain opportunities for habitat creation in reclaimed pits. A further potential impact of floodplain extraction arises if the sand and gravel pits are captured by the active river channel during flood events. Pit capture, may result in trapping the rivers bedload, substantially altering the rivers dynamic regime and leading to changes in channel position. Levees constructed around the pit may, however, prevent flooding and pit capture.

In Jamaica, it is likely that substantial resources of sand and gravel exist within the alluvial deposits, and beneath the agricultural lands, of the major river valleys. Such deposits are not currently worked for sand and gravel aggregates. If these resources are to be developed in future, to replace or augment river channel supplies, then regional geological/resource mapping and site exploration surveys (involving boreholes, test pits, geophysical surveys, sampling and laboratory studies) will be required. Additional studies needed, will include hydrogeological investigations and environmental and sociological impact assessments. Development of the floodplain and terrace deposits will provide good quality sand and gravel aggregates, which are readily accessible to local markets and which will ease the pressure on mining of river channel deposits, leading to a reduction in the impacts of river extraction.

**Figure 7 Chin's quarry, Lionel Town, Clarendon, Jamaica. Extraction of sand from river terrace deposits flanking the Rio Minho.**



**Figure 8 River terrace sand and gravel deposits, Cambridgeshire, UK. Such deposits are a major source of high quality aggregates in Britain and many other countries.**



## 2.4 Secondary Aggregates

The construction industry, worldwide, uses large amounts of raw materials each year and this demand is not likely to decrease in the near future. In many developed countries, the source of the raw materials is changing. There is increasing political and environmental opposition to the quarrying of hard rock and the production of sand and gravel from pits or by marine and river dredging. A second related environmental issue is the concern regarding the disposal of large quantities of mineral wastes. There is, therefore, a pressure to find less environmentally damaging sources of supply and there is a need to solve a waste disposal problem. Many mineral wastes fulfil the technical requirements to substitute for primary aggregates and many governments are now encouraging greater use of mineral wastes as aggregates.

There are many types of mineral wastes and recycled materials which could potentially be used in construction. They include mining and quarrying wastes (coal, slate, china clay, and others), demolition and construction wastes, road planings, waste glass, metallurgical slags, power station ashes, and other mineral wastes.

Materials with potential for re-use in construction can be subdivided into natural secondary aggregates (slate waste etc), manufactured/by-product secondary aggregates (slags etc) and concrete and demolition materials.

A variety of waste materials occur in the course of construction and demolition activities. They may include materials such as concrete, natural stone masonry, metals, bricks, timber and glass, plastics and plaster/gypsum products. Analysis of demolition waste materials in the UK showed it to be composed on average of 50% concrete, 35% masonry, 8% asphalt and 7% wood, plastic, glass, gypsum, metals and other debris. Most of these waste materials have the potential to be recycled into secondary aggregates.

Concrete, bricks and asphalt may be crushed, screened and graded to produce secondary aggregates, which can be used in construction (Figure 9). Recycling concrete rubble not only reduces environmental impacts of new aggregate production, but also avoids impacts associated with disposal. Asphalt road planings are bituminous roadstone materials removed from the surface of roads prior to resurfacing or maintenance. In Britain, most road planings find their way into some form of secondary aggregate use, such as fill and low-grade roadstone.

Mineral wastes usually have an uneven geographical spread and may occur in relatively remote locations (eg many mine wastes). There are often high monetary and environmental costs in transporting them to prospective markets. Although all aggregates are sensitive to transport costs, there is often less incentive for mineral waste producers to seek sales of their materials as secondary aggregates, because of the generally lower quality and lower prices they command. Cost, customer acceptance and materials specification (Figure 10) are often seen as the main barriers to increased use of waste and recycled materials. Two problems commonly occur:

- In most cases specifications for construction aggregates were originally based on use of natural materials. Opportunities for the use of mineral waste is not necessarily clear.
- There is a lack of information on how to provide an adequate assurance of quality for the use of waste and recycled materials in construction.

Specifications are needed to promote rather than discriminate against the use of waste materials. Information is also required on the variability of waste materials and its control, both to assist in the preparation of realistic specification requirements, and to enable the setting up of quality systems.

**Figure 9 Recycled asphalt to be used as secondary aggregate, Suffolk, UK. The secondary aggregate processing plant is sited in a working alluvial sand and gravel pit, utilising on-site storage, processing and distribution facilities.**



**Figure 10 Washing marine aggregate to remove salt, Amsterdam, Netherlands. Alternative aggregates may require significant processing to meet the required specifications.**



Most developed countries (such as Denmark, Germany, UK, Netherlands, United States of America, and Japan) are pursuing policies encouraging waste minimisation and recycling in construction. Such policies may not be immediately relevant to developing economies but it is certain that pressure will continue to promote, wherever possible, the use of secondary aggregates and reduce the production of primary aggregates from quarrying operations.

In Jamaica, the degree of recycling of mineral waste materials into secondary aggregates is very small, although some construction and demolition waste is used as fill. There are huge resources of limestone and large resources of fluvial sand and gravel, which are easily accessible to produce relatively cheap, general-purpose aggregates. Therefore, at the moment, there is little demand to substitute recycled materials for primary aggregates. In future, the issue of the environmental degradation associated with present practices of river mining and limestone quarrying, may encourage both the regulatory bodies and the construction industry in Jamaica to consider contributions to aggregates supply from alternative sources, such as secondary and recycled materials.

### 3 Conclusions

All mineral extraction, production and consumption will have some environmental impact. Aggregate production, however, is fundamental to economic growth and most impacts associated with aggregate mining are relatively benign. There are, nevertheless, some situations in which aggregate production can lead to serious environmental impacts. The rush to build quickly and cheaply with whatever materials come to hand can result in severe environmental problems. The planning and management of aggregate resources must be based on sound technical information about the availability, costs and environmental impacts of all possible sources. The viability of alternative materials needs to be considered when formulating an aggregate resource management plan.

In Jamaica, there are several potential sources of alternative aggregate materials. In particular, there appears to be a substantial resource of marine aggregates lying immediately off the mouth of the Yallahs River. If dredging of these deposits is proven to be viable, then their extraction will make a significant contribution to the islands supply of sand and gravel aggregate, particularly in the Kingston area.

There are also likely to be large resources of sand and gravel contained in the fluvial terrace deposits of the major river valleys. Such terraces are largely used for agriculture and therefore have a high land value. Development of these lands for sand and gravel extraction could be a temporary use of the land with opportunities for positive restoration to agriculture, amenity or wildlife habitat use. In many countries of the world, where mineral extraction from dynamic geological environments such as active stream channels is discouraged, or is not allowed, then sand and gravel aggregates are mined in large volumes from pits on the current floodplain or adjacent river terraces. Development of such deposits will require systematic geological exploration as, unlike deposits in the active stream channels, the resources are not visible at surface. The terrace sands and gravels may also contain small, but variable proportions of fines (silt and clay) but in general they will be of equivalent composition to the river channel deposits, requiring a similar degree of processing.

River sand and gravel deposits are often the only source of sand for use as fine aggregate in construction. Most natural river sands are also of the required grading and particle shape for use in concrete and concrete products. Sand, however, can be manufactured by crushing various hard rocks and the quarry fines from production of coarse, crushed rock aggregates are often sold as fine aggregate ('sand') for the construction industry. In Jamaica, 'stone dust' is produced during limestone quarrying and is sold as 'sand' for use in concrete and asphalt. Manufactured sand is also produced by crushing gravel at several of the larger river mining processing plants. Such

crushed rock sands are largely at the limits, or fall outside the specifications of fine aggregate for concrete manufacture, and poor quality blocks and other products may result. The grading and particle shape of the sand can be greatly improved by investment in new processing plant, such as 'Barmac' impactor rock crushers and washing plants.

There is considerable scope to increase both the production and quality of crushed rock sand in Jamaica, although this will require considerable investment in new quarry plant and a commitment to produce higher quality construction materials. Increasing production of manufactured sand may lead to less dependence on supplies of natural river sand, reducing the environmental burden caused by its extraction.

When they are available, recycled materials may also have potential for substitution for primary aggregates and should be considered as alternative resources which can be developed. Recycled concrete and demolition materials and asphalt road planings can be readily processed into secondary aggregates which can be used in construction. Every attempt should be made to minimise waste and to recycle materials in construction as this avoids the need for waste disposal and leads to a reduction in the environmental impact caused by primary aggregates production.

The extent of environmental impact which is acceptable is, however, relative and in part depends on the wealth of the country. In less economically developed countries there may be less funding available and little political will to address the impacts. Some impacts may be relatively short term and restricted to the site; others may be long lasting, far reaching and have serious health and safety issues. There is, therefore, a need to study, understand and manage the environmental impacts of aggregate extraction. It can then be judged which types of operation are likely candidates for compromise and which impacts need prevention or close control.

Restriction of aggregate supply by environmental regulation may lead to severe effects on local supplies and economics of aggregates for the construction industry. Investigation of alternative materials is therefore an integral part of resource management plans.

## References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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For more information contact:

David Harrison,  
River Mining Project Manager

Economic Minerals and  
Geochemical Baseline Programme

British Geological Survey,  
Keyworth, Nottingham NG12 5GG  
United Kingdom

Tel: +44 (0)1159 363213

Fax: +44 (0)1159 363352

e-mail: [djha@bgs.ac.uk](mailto:djha@bgs.ac.uk)

[www.bgs.ac.uk](http://www.bgs.ac.uk)



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