Quarrying and the associated processing operations inevitably lead to the production of quarry fines and waste. The amount and type produced depends upon the geology and rock type quarried, the efficiency of the extraction and processing operation and the local market for quarried products. New markets for these sub-economic quarry materials may help to reduce the amount currently being held in stockpiles across the UK.

This section is an output of the MIST Quarry Fines Minimisation' and Waterless Fines Removal' projects. These were co-ordinated by the British Geological Survey (BGS); the project team included Green Horizons Environmental Consultants and Camborne School of Mines. The project steering panel included Aggregate Industries, Bradley Pulverizer, Metso Minerals, QPA and Tarmac. Many of these project partners have also contributed material in the form of comments, images and case studies.

Introduction

What are quarry wastes?

Quarry wastes are a largely unavoidable by-product of the extraction and processing of aggregates (Photo 1).They are defined as wastes because no market currently exists for them, but unlike many other wastes they are generally inert and non-hazardous.

Materials that may be classified as quarry wastes include overburden (although this is frequently used in restoration) and interburden (material of limited value that occurs above or between layers of economic aggregate material) and processing wastes (non-marketable, mostly fine-grained material from screening, crushing and other processing activities).

Photo 1. Quarry plant and waste stockpile

The type and amount of waste depends on the nature of the operation. Most sand and gravel workings do not produce much, if any, permanent waste. Some produce significant volumes of clay and silt, which could be dug from settling ponds and used during restoration; although most is left in situ and is typically removed to free up space for more plant washings. Hard rock quarries produce variable amounts of quarry waste. Some produce small amounts of overburden while others may have large amounts of overburden and interburden that is not of sufficient quality for the desired product. Any waste that cannot be used immediately is stored in bunds or tips within the boundaries of the aggregates operation. The term tip is used to describe any accumulation of quarry wastes, including waste and soil heaps, stockpiled materials, backfill, screening embankments, and lagoons and settling ponds. All are strictly regulated under the Quarries Regulations 1999[422] and the accompanying code of practice (available from the HSE at www.hse.gov.uk). Tips may be permanent or temporary. For example, permanent screening embankments comprise waste or other materials not required for restoration works or other uses. They are generally designed so that they can be incorporated into the final long-term landscape on closure and restoration of the operation. Temporary amenity banks are often formed from stockpiled soil to the height of a few metres and are designed so that they can be re-excavated and used as a cover material during site restoration.

What are quarry fines?

Quarry fines, defined by BS EN standards, are the inherent fraction of an aggregate passing 0.063 mm (63 microns) (Photos 2 & 3). Many quarries also refer to their (sub-economic) fine aggregate (finer than 4 mm) as quarry fines (or quarry dust). The term is used here to denote both fine aggregate and quarry fines (material <63 microns).

Quarry fines can be considered a mixture of coarse, medium and fine sand material, and silt /

clay (silt and clay is known collectively as filler). In general terms, the higher the proportion of fine sand, silt and clay, the greater the environmental and social impacts and costs of production, storage and disposal, as the material is difficult to handle and is more prone to mobilisation under the action of gravity, wind and water. The filler content has a major impact on technical properties and on potential end use. The filler content of quarry fines may be reduced by washing with water or by other methods of separation to produce a clean, saleable sand product. The silt and clay residue is usually a waste product.

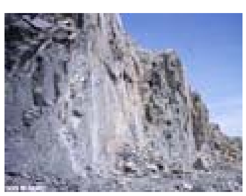
 Photo 2. Quarry fines stockpile

 Photo 3. Limestone quarry fines close-up

The taxes on waste disposal and on production of primary aggregate materials have encouraged the use of secondary materials as aggregate but have depressed the market for quarry fines. Many quarries in the UK have large stockpiles of material they cannot sell. Also, large demand for high-specification fine aggregate, and aggregate with specific shape characteristics, has resulted in an increase in fines production. The fines must be managed at most sites to prevent or minimise impacts, and certain mitigation methods may be necessary, irrespective of the source. The following sections outline the different sources of fines, which are related to blasting, processing, handling and transport.

Geological-related

Particle shape as well as grading and fines content are a function not only of the crushing process but also of the mineral composition and texture of the rock material. As a rule of thumb, a coarse-grained rock will generate fewer fines than a fine-grained rock this is because it takes less energy to separate individual mineral particles / crystals than it does to crush / break them apart. Likewise, a rock with a high content of flaky or elongated minerals will tend to produce a more flaky-shaped material (Photo 4). Also, the content of minerals with a low abrasion resistance will strongly influence the amount of fines produced during all stages of processing and handling i.e. softer materials will breakdown more easily than harder materials and hence produce more fines.

 Photo 4. Working face in sandstone quarry

Blasting-related

The production of fines is a natural consequence of blasting (Photo 5). Adapting the blasting process to produce larger broken rock fragments can reduce the generation of blasting-related fines, but the following factors also need to be considered:

- The trade-off between the costs of blasting and crushing a reduction in blasting costs may be offset by increased crushing-related costs, and vice versa.
- Oversize pieces of rock slow the loading process and may exceed the maximum size set for the primary crusher, leading to reduced efficiency.

Larger fragments are likely to increase maintenance costs for loading and crushing equipment.


Photo 5. Quarry fines arising from blasting

The size distribution of material produced by blasting has a significant impact on down-stream processes such as crushing. According to McLoughlin[421] increased explosive energy, with production of finer materials, increases productivity and reduces the costs of crushing and grinding. However, if fragmentation is too great an excess of fines could result; optimisation should consider all factors including predicted quantities and prices of products generated. Blasting tends to be optimised according to handling and crusher efficiency criteria rather than fines minimisation. However, a recent project, "Less Fines Production in Aggregate and Industrial Minerals Industry" [358] aimed to reduce the amount of fines resulting from blasting in quarries via the use of new blasting methodologies, and therefore the potential does exist for reductions in fines coming into the processing plant.

Processing-related

Most quarry fines are produced during the crushing, milling and size classification of quarried rock to produce single-size aggregate (ranging from 20 mm to 6 mm) and other products. Further details are available on Production and Process Technology (Photo 6). Crushing of quarried rock is carried out in stages, with the primary crushing stage typically carried out using jaw crushers or gyratory crushers and subsequent (secondary and tertiary) stages by cone or impact crushers [359]. In general, the greater the number of crushing stages the higher the amount of fines produced as a proportion of total plant throughput. The type of crusher used also directly controls the amounts of fines produced. A recent study on quarry fines by Manning [360] looked at possible relationships between quarry plant operation and the generation of quarry fines. The conclusions drawn have been critically reviewed in the following sections.


Photo 6. Hard rock aggregate plant

Relationship between the number of crushing stages and fines production

Fines production is directly proportional to the number of crushing stages; it increases with an increase in production stages (Photo 7). Multiple (three or four) stages are often used, as it is more energy efficient to keep the reduction ratio at each stage relatively low. Low reduction ratios also results in lower fines generation at each stage, especially where the mineral is fragile [356]; however the cumulative fines production may be higher than a process using fewer stages with higher reduction ratios.


Photo 7. Primary Gyratory Crusher

Scalping of feed to a crusher reduces fines generation

Removal of finer particles that do not require crushing can lead to less packing in the crusher chamber and reduced rock-on-rock interaction (Photos 8 & 9). This means that once particles have been broken they have an easier path to the crusher discharge, minimizing over-crushing and improving energy efficiency. Screen efficiency is also important. If screens operating in closed circuit with a crusher are inefficient, then undersize will be returned to the crusher. Some of this material, despite being below the closed side setting (CSS), will be crushed turning valuable sized products into fines.


Photo 8. Stockpile of sandstone scalpings


Photo 9. Stockpile of limestone scalpings

Impact crushers and fines production

There is compelling evidence that impact crushing (Photo 10) produces more fines than compressive crushing; impact crushers tend to produce 25 - 30% more fines than compressive crushers, such as jaw crushers and cone crushers. For example at the Duntroon quarry in Canada the replacement of a primary impact crusher with a jaw crusher resulted in a reduction of 5mm fines from 38% to 28% [361]. Dufferin Aggregates predicted [362] an increase in single-size aggregate from 40 - 50%, and an equivalent reduction in fines production, in a plant modification that replaced an old Vertical Shaft Impact (VSI) crusher with a modern cone crusher.

The type of impact applied in a VSI crusher can also influence the production of fines. Rock-on-rock interaction generates increased fines; although this crusher has lower wear rates and produces improved particle shape. Rock-on-metal interaction produces fewer fines while maintaining a cubical product [363]. The main disadvantages of rock-on-metal interaction are high wear of crusher components, and the loss in crushing efficiency with increased fines production as the anvils wear out.


Photo 10. HSI Crusher

Handling and transport-related

The handling, transfer and transport of aggregates (e.g. by truck and conveyor) do not typically create large amounts of fines. However, the activities may liberate fines that are already present. Conveyors and uncovered trucks can be significant sources of dust. To a more limited extent, haul trucks may generate fines by the crushing action of tyres on coarser rock fragments and particles, and handling and transfer of materials may also generate and liberate fines.

Why are they treated separately?

Quarry wastes and quarry fines have been treated separately in this review; this has been done primarily to highlight the economic distinction between the two materials. Quarry wastes per se have limited economic value apart from value on the quarry site as material for uses such as void fill, embankments and roadway base. Quarry fines on the other hand, are a quarry product that can be used as a low-value construction material; mainly as filler in asphalt and concrete blocks. Given the regional market variations for low-value construction raw materials, quarry fines may be considered a quarry waste in certain locations around the UK.

The mineral planning process places conditions upon all quarries to control the environmental impact of their operations; these include conditions that dictate the location and size of quarry waste tips. Currently, wastes from quarries are not controlled waste, which is regulated by the Environment Agency. However, future legislation may change this.

Annual production

The quantity of quarry waste and quarry fines produced in the UK is unclear with little information in published literature and limited access to known data due to commercial sensitivity. Quarry waste and quarry fines originate in all rock types including sedimentary (sand and gravel, sandstone, limestone and dolomite), igneous (diorite, dolerite, granite and lava) and metamorphic (marble and slate). Estimated values for the production of aggregate, quarry waste and quarry fines are shown in Table 1. The total annual production of quarry waste in the UK is estimated at 22.8 million tonnes (based on a waste to saleable product ratio of 1:9). The total annual production of quarry fines is estimated at 53.9 million tonnes; this is based on estimates of fines production of 20% for limestone, igneous and metamorphic rock, and sand and gravel, and 25% for sandstone.

Quarry fines and waste — Table 1

Estimated production of aggregate, quarry waste and quarry fines in the UK.

Rock type	Annual production (million tonnes, 2005)		
	Saleable aggregate[1]	Quarry waste[4]	Quarry fines
Sandstone	10.0	1.1	3.3
Limestone[2]	67.3	7.5	18.8
Igneous and Metamorphic Rock	44.6	5.0	11.2
Sand and Gravel [3]	82.4	9.2	20.6
Total	204.3	22.8	53.9

[1] Estimated aggregate production from the Annual Minerals Raised Inquiry (2004)

[2] Limestone including dolomite and chalk

[3] Land- & marine-won sand and gravel

[4] Estimated quarry waste based from Defra mineral waste statistics, available here

The distribution of quarry fines stockpiles is not uniform across the country. The markets for bulk materials are usually local to urban centres and quarries in remote areas may have problems finding markets for fines. This is further complicated if there are local sources of alternative materials (free of the Aggregates Levy); such as slate waste in North Wales and china clay sand in south-west England. Fines are a particular problem in quarries producing high Polished Stone Value (PSV) (>55) aggregates from sandstones or certain igneous rocks. The requirements for smaller sized chippings (10 and 14 mm) for road surfacing materials has led to a higher production of quarry fines. Also, changing asphalt technology has resulted in reduced usage of quarry fines in road surfacing and sub-base materials.

Some areas (such as limestone quarries in the Mendips or igneous rock quarries in Leicestershire) produce a large volume of quarry fines due to the massive scale of the operations and there may be a substantial excess of fines. In other locations, however, there may be a local shortage of fines for a specific market (such as limestone fines for a block plant) and local quarries may optimise (increase) fines production by use of impact crushers. Alternatively, fines may be imported from other quarries or regions (where commercially viable) or a quarry fines substitute may be used to meet a local demand. Fines may accumulate if the material is of poor quality, particularly if it has a high silt/clay content or is highly absorptive. Examples may include certain Jurassic limestones and certain hardstone (sandstone and igneous rock) fines.

Environmental and Socio-economic Issues

Summary of impacts

Although they are generally inert and non-hazardous, the generation, treatment and/or disposal of quarry waste and quarry fines can be a source of friction between aggregates companies, local communities and other stakeholders. This is particularly true if a site is producing more than originally planned or that can be properly accommodated within the site boundary. Therefore, ensuring that the site design is correct at the planning stage is essential.

The nature and extent of the environmental and social impacts will vary from site to site according to their characteristics and specific local context. The impacts experienced by the local community are likely to be significantly influenced by the nature and proximity of housing, amenity areas and local businesses. Different stakeholders will have quite different opinions regarding the impacts that they consider most important. Many of the potential impacts can be prevented or mitigated by the use of good practice. The acceptability of impacts that remain after good practice measures have been put in place should be considered in the context of the economic and other benefits that accrue from aggregates production.

Due to the environmental, social and economic costs associated with storing and managing wastes, aggregates companies try to first minimise the generation of waste and then find beneficial uses for any waste that is produced. However, at some sites there is a net excess of waste after beneficial uses have been considered, and this must be managed to avoid environmental and social impact. In general terms, the potential impacts of quarry waste can be summarised as:

- Visual intrusion: Quarry waste tips and quarry fines stockpiles can be a significant visual intrusion, mainly when waste is dumped off-site or above the skyline (especially when it is not landscaped or vegetated). Although it is often used as a visual or noise screen, it can be considered an eyesore (Photo 11).

- Water: Run-off from quarry waste tips or quarry fines stockpiles can cause erosion and contaminate local watercourses. Suspended solids (and acid drainage) may harm freshwater ecosystems and impact on other water users. Waste may also create problems if dumped on flood plains where it may exacerbate flooding. Settled silt and clay can also be washed out and displaced from settling ponds and lagoons during storm events. Suspended solids are covered in the Water section of this website.

- Dust: Large quarry waste tips or quarry fines stockpiles can be a source of airborne dust, which can be exacerbated if they are elevated above the original ground level. Dust may also originate from air filtration units/ stacks, haulage trucks, conveyors and transfer points (Photos 12 & 13).


Photo 11. Stockpile of quarry fines and scalpings


Photo 12. Sand and gravel conveyor


Photo 13. Crushed rock conveyor

Impacts

The effects of dust, suspended solids and disposal have been used to define potential impacts on air, water quality, land quality, fauna and flora, human health and local communities / other stakeholders. Water consumption is addressed as a separate impact.

Air quality

Dust:
Dust can have a substantial impact on air quality (Photos 14 & 15). Generally the impacts diminish as distance from the source increases and the most acute impacts are likely to occur in enclosed spaces (for example the processing plant) or in close proximity to major sources. Impacts resulting from air quality degradation can include those related to health (although these are typically linked to occupational rather than environmental exposure), visual intrusion and, most commonly, nuisance for surround communities and businesses.

Suspended solids :
As suspended solids are by definition those particulates present in water, they have no direct impact on air quality. However, indirect impacts on air quality may arise via the disposal of fine material recovered from water.

Disposal :
Disposal areas are a major potential source of dust during operational activities. The impact may extend beyond the closure of operations if steps are not taken to address long-term dust creation and can be exacerbated by the fact that disposal areas are elevated above the original ground level. Dried silt ponds may also be a source of dust, unless they are capped with soil.


Photo 14. Dust from quarry traffic

 Photo 15. Lorry after wheel washing

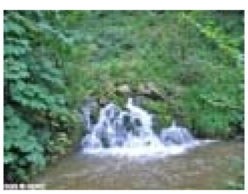
Water quality

Dust :
Transfer of dust from the air to surface waters can result in contamination. Impacts generally relate to the presence of suspended solids (in addition to those arising from water erosion). In rare cases, physical impacts may be aggravated by the presence of chemically active minerals in the dust (e.g. limestone contains alkaline calcium carbonate and sulphides) that can alter water chemistry and suitability for the fauna and flora that it supports.

Suspended solids :
Suspended solids are generally inert, although there may be exceptions (the most common being minerals that alter the water pH). Even inert solids can have a significant impact on water, and on the fauna and flora that it supports (see below). The presence of suspended solids can affect water quality far beyond the site boundary (Photos 16 & 17); this can seriously impair the use and increase the cost of water for other users and uses (e.g. drinking water, industrial uses, irrigation, and fisheries, as a coolant and for recreational purposes).

Disposal :
Disposal areas are a major potential source of suspended solids in run-off that may ultimately report to surface waters. Disposal areas may affect the surface water regime (e.g. by changing surface water flow paths). Quarry waste or quarry fines disposal may also create problems if dumped in or near areas prone to flooding.

 Photo 16. Clean water discharge

 Photo 17. Landscaped clean water discharge

Land quality

Dust :
Dust impacts are relatively limited in most cases. Rarely the presence of chemically active mineral phases in the dust (e.g. sulphides occasionally present at hard rock quarries) may alter soil chemistry and suitability for the fauna and flora that the soil supports.

Suspended solids :
In most circumstances direct impacts from suspended solids are unlikely.

Disposal :
Temporary or permanent land sterilisation may result from the use of space within or outside the working area, some of which could otherwise be put to beneficial use. Temporary or permanent loss of the associated fauna and flora are also likely, although this can be mitigated by appropriate restoration of the disposal areas (Photo 18).

 Photo 18. Restored meadow on quarry site

Fauna and flora

Dust :
Coating of vegetation and contamination of soils could possibly reduce the yield and value of agricultural products (MPG 11[155]). Although generally inert, the chemical nature of the dust will sometimes influence the severity of the impacts upon soils and vegetation. Dust may have physical effects on plants such as abrasion of plants, shading, and cumulative effects e.g. drought stress. The chemical effects of dust are likely to be more important than any physical effects. Dust deposited on the ground may produce changes in soil chemistry, which may in the longer-term result in changes in plant chemistry, species competition and community structure. For further details on air pollution click here.

Agricultural lime (crushed limestone) has traditionally been used to increase crop productivity; limestone dust deposition is likely to be well below the level of agricultural applications and effects on crops are likely to be minimal. Areas of high ecological value or agricultural resources, such as designated nature conservation areas containing sensitive species, intensive horticultural areas, and fruit growing areas, may be more sensitive to dusts than other areas.

Suspended solids :
Silt can detrimentally affect fish spawning grounds, cause damage to fish gills and impact the invertebrate species resident in watercourse sediments. Suspended solids also reduce penetration by sunlight. Blanketing of benthic flora and changes in bottom morphology and characteristics may occur, particularly in areas where suspended solids tend to settle out, with associated impacts on flora and fauna. Exposure to suspended solids may result in the death of fish, biodiversity impacts and food chain disruption.

Disposal :
Inhibition of vegetative regeneration and impacts on biodiversity may all result from disposal activities.

Human health

Dust :
Potential health impacts are almost exclusively linked to the presence of airborne dusts, in particular respirable particles. Respirable particles, i.e. those that are less than 10 µm in diameter (known as PM_{10}), have the potential to cause effects on human health, including effects on the respiratory and cardiovascular systems. Atmospheric levels of PM_{10} are composed of three main types. Primary particulate matter (from combustion sources, particularly road traffic); secondary particulate matter (mainly sulphate and nitrate formed by chemical reactions in the atmosphere); and coarse particulate matter (consisting of suspended soils and dusts, sea-salt, biological particles and particles from construction and quarrying, MPG 11). Although there is evidence that opencast coal mining can give rise to increased concentrations of PM_{10}, there are no substantiated claims that health has been affected around working quarries. For further details on air pollution click here.

The term 'pneumoconiosis' refers to a group of lung diseases caused by the inhalation of dusts. Most cases occur in retired workers, the majority from the coal mining industry; other industries affected being quarrying, foundries and potteries, where silica is the predominant cause. Repeated and prolonged (10 - 15+ years) occupational exposure over many years to relatively high concentrations of crystalline silica in the respirable size range can cause the lung disease silicosis and can also be associated with lung cancer.

Suspended solids
Waterborne fines do not pose a significant risk to human health.

Disposal
No direct impact on human health.

Local communities and other stakeholders

Dust-related :
Local communities can potentially be affected by dust up to 1 km from the source, although concerns about dust are most likely within 100 metres (see Social and community section). Deposited dust gives rise to the greatest number of complaints to quarries from local communities, particularly for contrasting colours that are more noticeable on deposition. Settled particles may show up particularly on clean or polished surfaces such as cars, windows and window ledges, or surfaces that are usually expected to remain free from dust.

There may be many sources of dust that are unrelated to aggregates production, which may not always be readily distinguishable from site dust and so may give rise to unwarranted complaints. In these cases an operator may need to demonstrate that the dust does not originate at their site (Photo 19). There may be a local perception of elevated risks to human health from inhalation of dusts originating at quarry sites despite evidence to the contrary. Visual and nuisance impacts, for example plumes, reduced visibility, coating and soiling of surfaces leading to annoyance, loss of amenity and a need to clean surfaces and materials.

Physical and / or chemical contamination and corrosion of artefacts leading to increased cleaning and maintenance requirements, and impacts on specific industrial activities (e.g. degradation of paint or polish finishes, and the contamination of laboratory, quality control and medical facilities (MPG 11155.)). Impacts may be aggravated in some cases by the presence of chemically active mineral phases in the dust (e.g. limestone, and sulphides sometimes present at some hard rock quarries).


Photo 19. Community visit to quarry site

Suspended solids :
The presence of fines can cause turbidity in water; which may limit its use for public supply, irrigation, and industrial applications. It also has an aesthetic impact.

Disposal :
Waste dumps can be a visual intrusion; particularly when waste is dumped at or near site boundaries, or piled-up above the skyline, especially when it is not landscaped or vegetated. Although often used as a visual or noise screen, it can be considered an eyesore. Concerns about tip stability, including long-term erosion and major short-term failures.

Water use and consumption

Excessive water abstraction from surface waters may impair essential aquatic ecosystem functions, leading to ecosystem degradation or loss, with impacts on associated fauna and flora. Abstraction from groundwater may locally depress the water table, causing direct and indirect environmental impacts over an extended area.

In both cases, the availability of water to other users may be significantly reduced (note, however, that changes in the regulation of abstraction are more likely to result in reduced availability for quarrying operations in the future). Impacts may be aggravated by factors such as rate and timing of abstraction.

Efforts to reduce water consumption by recovery and reuse may have significant economic, environmental and social implications. For example, the use of settling ponds and lagoons may sterilise otherwise useful land and bury or require the relocation of existing fauna and flora, while local communities may have negative perceptions of settling ponds and lagoons for environmental and aesthetic reasons. Impacts may also extend into local surface waters during storm events if solids are washed out' of the pond or lagoon.

Although water may be consumed on site in order to suppress dust, the most significant use of water is in washing plants, which are designed to remove fine-grained particles and recover a clean aggregate product from crushed rock or sand and gravel. Washing plants are covered in the Production and Process Technology section . Water consumption and contamination are important factors behind the consideration of waterless or water efficient fines recovery methods. The use of water efficient technology, water recycling (for example, through the use of settling ponds or lagoons or thickener/ filter press methods (Photos 20 & 21) to remove contained solids) can all substaintially reduce the overal consumption of water at a site. A detailed section on Production and Process Technology is available here.


Photo 20. Belt filter press discharge


Photo 21. Water recovered from belt press

Minimisation

Why minimise quarry waste and quarry fines?

Recently, the market for aggregates in the UK has changed; the Landfill Tax and Aggregates Levy have encouraged the use of secondary material, but also depressed the use of quarry wastes in lower value construction applications. However, quarry wastes and quarry fines continue to be produced and stockpiles of these sub-economic materials are increasing at some locations. Consequently, there is a developing business case for minimising quarry wastes and quarry fines generation. Business-related drivers include the need to comply with the planning process (www.bgs.ac.uk/Planning4Minerals) and regulation, the need to maximise revenue in the form of saleable products and the need to avoid resource sterilisation within the quarry boundary through fines disposal.

Equally, the need to minimise fines is driven in part by the environmental and social consequences of their production and the costs of dealing with increasing volumes . While difficult to quantify in financial terms, such consequences may represent a substantial business risk for companies, not least through damage to corporate reputation when impacts occur. Regulatory compliance is another major driver and is likely to remain so water and air quality are highly regulated, for example:

- Regulation of the water environment (Water Resources Act 1991 and Water Act 2003)
- The Salmon and Freshwater Fisheries Act 1975.
- The Land Drainage Acts 1991 & 1994.
- Discharge consents, abstraction & transfer licences - as issued by Environment Agency.
- Enforcement notices - as part of the Water Resources Act 1991

(UK legislation is available online from Office of Public Sector Information: www.opsi.gov.uk)

Different stakeholders will have quite different opinions regarding the aspect of quarry wastes and quarry fines that they consider most important. Their interest in promoting a change from waste management to waste minimisation will vary accordingly.

Government/regulatory authorities

- development of policies to protect, enhance and preserve air, water and land resources
- enforcement of compliance with relevant regulations and laws
- sustainable use of resources
- protection of sensitive species

Company

- increased operating efficiency and reduced production costs
- improved health and safety for workers
- reduced risk of breaching consents and prosecution

- reduced long-term liabilities
- reduced waste storage space, handling, transport and disposal costs
- reduced monitoring costs
- reduced administration with regard to waste disposal
- improved company image in the eyes of the shareholders, employees and community

Local communities

- protection and preservation of the local environment
- access to, and use of, high quality local water- and land-based amenities
- uncertainty and concern regarding exposure to contaminants

Non governmental organisations / pressure groups

- monitoring compliance
- focus on site-specific issues

Minimising quarry wastes and maximising their usage

The amount of waste produced should be minimised by good quarry design and operation. Material that is dug and not used is obviously wasting time and money and so designers and operators will always try to reduce this.

Research projects were carried out at Leicester University as part of the MIST programme into various ways of reducing waste production. The first project focused on minimising the errors involved in resource evaluation by evaluating drilling techniques and statistical analysis [257] The second project aimed to develop systems able to identify the parts of a deposit best suited for individual products and thus generate the least waste, leading to optimisation of extraction [258]. In some parts of the industry, using a different method of working can reduce waste. For example, slate waste can be reduced and production of slate improved, by the use of diamond wire cutters rather than blasting.

In some cases, it may also be possible to find new uses for quarry wastes. The AggRegain website gives a comprehensive account of the range of construction materials where recycled and secondary aggregates can be used; many of these uses can also apply to quarry waste. For example, an increasing amount of the waste sand produced in china clay workings is being used as secondary aggregate in the construction industry, particularly since the introduction of the Aggregate Levy. An example [QFcs8] is given on the AggRegain website. However the cost and mode of transport means that the material is currently not economic much beyond the south-west of the UK.

In some cases it may be possible to process quarry wastes to generate products for the construction industry. Through reprocessing, Penmaenmawr Quarry in North Wales (Photo 22) was able to utilise previously dumped material as part of a road and tunnel scheme [QFcs7]. AggRegain also has an example [QFcs9] of waste slate being used as slate aggregate in road construction. Washing of clay-rich scalpings is carried out by an increasing number of quarries to recover saleable aggregate; for example, Dowlow Quarry near Buxton [365]. However, not all operations will have the necessary plant or a suitable local or regional market for the upgraded material.

 Photo 22. Hard rock quarry

Methods for minimising quarry fines

Minimisation at source

The production of quarry fines is a direct consequence of the extraction and processing operations carried out in a quarry. The amount of fines produced depends to a large extent on the nature of the rock, the degree of fragmentation achieved by blasting and the type of crushing used to produce aggregate. The good practice guidance in the *Production and Process Technology* section covers optimisation of crusher performance, which can be used to reduce fines production. Click here for further details on Production and Process Technology.

Those responsible for aggregate production do not aim to produce excess quarry fines. Generally, the amount of fines produced is manageable with most quarries finding an outlet or subsequent end-use, even if this is for onsite landscaping or void filling. Some quarries, however, have an excess of quarry fines.

Production and quarry managers focus on aggregate production and may not have the opportunity to take a critical look at the performance of their operation. In most cases, this is carried out by regional performance managers, consultants or experts working for equipment suppliers. A performance review requires a thorough audit of the production process; as part of this, a process flowsheet is devised which summarises the throughput tonnage figures, crusher and screen settings, and product gradings. Flowsheet analysis is aided by the use of proprietary computer software such as AggFlow 2006 (aggflow.com) and JKSimMet (www.jktech.com.au) or software, developed in house by equipment suppliers (such as Bruno as used by Metso Minerals). These software tools enable the planning and simulation of the crushing process, with the ability to use different machine combinations and settings. The software models the behaviour of crushers with different rock types based on laboratory and process plant data. The simulation can be fed with theoretical or real information on the feed material; the accuracy of the simulation can be increased by the use of real feed variables. Adjustments made to the settings or by changing the type of equipment may optimise the process to give the maximum aggregate production and minimise fines production.

Several case studies are given below (using the process optimisation software Bruno) to illustrate the importance of process optimisation. These illustrate three sandstone quarries, one limestone quarry and one sand and gravel quarry. The case studies present "before" and "after" process flowsheets; which in all (but one) case represents real process changes made to increase the production of saleable aggregate and reduce the production of quarry fines. The following summarises the key points of each case study, with a link to each detailed case study document.

Case Study 1: Sandstone quarry, mid Wales QFcs1

This is a sandstone quarry in mid Wales that produces high PSV roadstone and crushed rock aggregate . The original process plant included a three-stage crushing circuit with a primary jaw crusher, secondary Horizontal Shaft Impact crusher (HSI) crusher and two tertiary cone crushers. The main product is a 0/20 aggregate that contained 38% quarry fines (material <4mm). The aim of the process change was to reduce the quarry fines content of the crusher product. The process change involved replacing the HSI crusher with a secondary cone crusher. This not only enabled an increase in production from 250 to 300 tph, it also reduced the quarry fines content of the aggregate to 30%. Overall, this process change represented a 20% increase in production of the 0/20 aggregate product; it also represented a 21% reduction in the quarry fines production. Click here for Case Study 1.

Case Study 2: Sandstone quarry, mid Wales QFcs2

This is a sandstone quarry in mid Wales that produces high PSV roadstone and crushed rock aggregate. The original process plant included a three stage crushing circuit with a primary jaw crusher, two secondary Horizontal Shaft Impact (HSI) crushers and a tertiary cone crusher. The product of the crushing circuit is a 22 mm material that is sent onto the screening plant to produce graded aggregate. The crushed material contains 36% quarry fines. The aim of the process change was to reduce the quarry fines content of the 22 mm crusher product. The process change involved replacing the HSI crushers with a single secondary cone crusher. This reduced the quarry fines content of the 22 mm material to 33%. Overall, this process change represents an 8% reduction in quarry fines content of the crushed material. Click here for Case Study 2.

Case Study 3: Sandstone quarry, south-west England QFcs3

This is a sandstone quarry in south-west England that produces high PSV roadstone and horticultural sand. This case study represents a simulated process change. The current process plant has a four stage crushing circuit with a primary jaw crusher and cone crushers in the secondary, tertiary and quaternary stages. Production of quarry fines is 55 tph. The aim of the simulated process change was to increase the production of saleable aggregate and reduce quarry fines production. The simulated process change involved replacing the tertiary and quaternary cone crushers with a single tertiary VSI crusher. This would reduce quarry fines production to 39 tph. Overall, this process change would enable a 18% increase in the production of saleable aggregate; it would also represent a 29% decrease in fines production Click here for Case Study 3.

Case Study 4: Limestone quarry, East Midlands QFcs4

This is a limestone quarry in the East Midlands that produces roadstone, crushed rock aggregate and agricultural lime. The original process plant included a two-stage crushing circuit with a primary jaw crusher and a secondary HSI crusher. The product of the HSI crusher had a quarry fines content of 37%; overall, the plant produced 67 tph of quarry fines. The aim of the process change was to increase the production of concrete aggregate (5/20) and reduce quarry fines production. The change involved replacing the HSI crusher with a secondary cone crusher. This reduced the quarry fines content of the crushed material to 29% and overall quarry fines production was reduced to 44 tph. Overall, this process change enabled a 50% increase in concrete aggregate production; it also represented a 34% reduction in quarry fines production. Click here for Case Study 4.

Case Study 5: Sand and gravel quarry, East Midlands QFcs5

This is a sand and gravel quarry in the East Midlands that produces ready mixed concrete, graded sand and gravel, and bagged aggregate. The original process plant included a screen to remove oversize (>50 mm), a washing plant and a single crushing stage. A VSI crusher was used to crush material coarser than 20 mm; the crushed product was fed back into the plant. The crusher product still contained a significant proportion of material coarser than 20 mm and 6% of material finer than 0.075 mm. The aim of the process change was to reduce the amount of material coarser than 20 mm in the crusher product and also to reduce its filler fines content.

The process changes involved increasing the size of the screen used to remove oversize (>100 mm) and replacing the VSI crusher with a cone crusher. This increased the feed to the crushing stage from 75 to 131 tph. The proportion of material coarser than 20mm in the crushed product was reduced by 80%; the fines content was reduced by 50%. Overall, the production of saleable aggregate increased from 265 to 300 tph. Click here for Case Study 5.

Industrial experience of quarry fines

Reported cases of quarry fines minimisation are relatively rare in published trade and research journals. Anecdotal evidence provides more information but is often of limited usefulness due to commercial confidentiality. The following is a summary of quarry fines production information gathered during interviews with producers in recent years.

Igneous and Metamorphic rock quarries

Hard rock quarries work a range of rock types including granite, hornblende tonalite, diorite, olivine dolerite and hornfels. Production was mainly crushed rock aggregate and roadstone (coated and uncoated), as well as railway ballast, armourstone, ready mixed concrete, gabion basket and drainage stone, and Type 1 sub-base. The process plants had three to five stage crushing circuits with primary gyratory crushers or Jaw crushers, secondary cone crushers or jaw crushers, tertiary cone crushers, quaternary cone or VSI crushers, and one operation had a quintinary VSI crusher. They produce 25 to 35% quarry fines; this high level is largely attributable to the current demand for 10 mm aggregate. The quarry fines are typically used in concrete products or washed for use as building or concrete sand.

At some sites, the demand for quarry fines exceeds supply; typically, this is addressed by recrushing single-size aggregate to produce more quarry fines. In some cases, recrushing is carried out on the 10 and 14 mm aggregate, which requires minimal additional crushing or aggregate in the size range 28 - 40 mm, which is often surplus to requirements. Another means of increasing quarry fines production is reducing the closed side setting (CCS) on jaw and cone crushers; this has the effect of increasing the reduction ratio of the crusher and increases the production of fines.

Another means of increasing quarry fines production is to increase the feed rate to the VSI crusher. The VSI crusher produces significant quantities of fines; typically VSI crusher product has 40% quarry fines compared to 4 to 20% fines in cone crusher product. The main use of a VSI crusher is to control the particle shape of the aggregate, especially where the rock has a tendency to produce flaky-shaped particles. At one site, the plant operated without the VSI crusher in an attempt to reduce quarry fines production. However, this resulted in a gradual build up of flaky material in the process circuit which eventually started to blind the screens (affecting production throughput) and it also reduced product quality.

Limestone quarries

The limestone quarries reviewed covered those mainly producing crushed rock aggregate and roadstone (coated and uncoated), as well as agricultural lime, armourstone, concrete blocks, ready mixed concrete, lime and mineral filler. The process plants have two to four stage crushing circuits with primary jaw, gyratory or HSI crushers; followed by HSI crushers, cone crushers, or hammer mills in the secondary and tertiary stages. One operation had a quaternary HSI crusher.

Limestone quarries typically produce 14 to 20% quarry fines; this is mainly used in concrete block manufacture and asphalt, or incorporated into Type 1 sub-base. Quarry fines production is approximately 30% using hammer mills and 23% using cone crushers. One site did not produce enough quarry fines to meet demand; fines production had been increased by tightening the CSS settings on the cone crushers, screening out fine material from the 6mm aggregate and adding fines from the dust collectors.

Sandstone quarries

The sandstone quarries reviewed covered those mainly producing crushed rock aggregate and roadstone (coated and uncoated, including high PSV roadstone), as well as building stone. The process plants have three or four stage crushing circuits with primary jaw crushers, secondary cone crushers (one secondary jaw crusher), tertiary cone, VSI or HSI crushers, and one operation had a quaternary cone crusher.

Production of quarry fines ranges from 25 to 40% of plant throughput, typically 30 - 35%. This level of fines production is attributed to the current demand for 10mm aggregate (Photo 23). Approximately half of the sites did not have a problem with fines as production was matched by demand; some sites did not produce enough and have actively sought to increase fines production by tightening up crusher settings. Others sites have no sales of quarry dust, stockpiles are increasing and in some cases are nearly at a critical level where they threaten to sterilise resources.

Quarry fines are mostly used in asphalt, concrete blocks, in Bentonite Enhanced Soil and as inert fill material. Dry dust is preferred by customers, especially bone dry material as it has better flowability and does not contain lumps. Many sites have covered quarry fines stockpiles, although this may only represent a small fraction of that held on stock; one site had 1000 tonnes under cover out of 90,000 tonnes on stock. Quarry fines stockpiled outside may contain 9 - 13% moisture; when wet some quarry fines become hard and virtually unusable. If stockpiles of quarry fines are too wet they tend to become self-levelling.

Photo 23. Sandstone aggregate stockpile

Alternative uses for quarry fines

Minimisation is also possible by identifying additional uses for quarry fines. These include:

Construction uses

- site remediation or landfill capping layer and basal liner
- unbound or loose fill uses in earthworks, trenches, underground caverns, road base and bedding
- other unbound applications insulation, drainage filters, pond lining, garden landscaping, pathway surfacing, sandbag fill and recreation
- bound applications such as asphalt, bitumen, and other surfacing materials
- fines used as aggregate in concrete
- fines used to make synthetic aggregate and lightweight aggregate
- fines used as aggregate in brick and block making
- tiles and artificial stone.

Non-construction uses

- soil remineralisation - fines as a fertiliser material or agricultural lime
- artificial soils
- culture media for bio-filtration
- mineral filler (typically only fine dust from limestone quarries)
- treating oil waste.

Given these potential uses, quarry fines were not, until recently, considered a waste material but rather a product waiting for a market. However, usage was variable depending partly on fines character and quality, partly on local market opportunities and partly on the nature and structure of individual quarrying businesses. In addition, there is anecdotal evidence suggesting that the Aggregates Levy has had a major effect on the utilisation of quarry fines in some areas. In the period since the introduction of the Levy, quarry fines have, in certain areas, become more difficult to market economically due to competition from cheaper alternative materials that are not subject to the Levy. Anecdotal evidence suggests that stockpiles of quarry fines are increasing, although this situation does have marked geographical variations. In addition, the lack of construction of new roads in recent years has resulted in fines accumulating in quarries.

The recent study *Exploitation and Use of Quarry Fines* [360] summarised the current state of knowledge concerning the exploitation of hard-rock quarry fines. New research, mainly in the United States, is demonstrating the value of fine aggregates in improving the characteristics of concrete and asphalt. For these uses, adequate specifications for the aggregate do not appear to exist currently, and are being developed, for example, by the International Center for Aggregate Research (www.icar.utexas.edu) . Most importantly, grading, and concrete workability are key factors. Recent research on new uses for quarry fines includes the following:

- Research at the University of Wisconsin indicates that limestone quarry fines and fly ash can be used to produce an effective low-cost, self-compacting concrete. [366]
- Synthetic aggregate can be created from a mixture of quarry fines with paper sludge, clay or dredged harbour sediment. This is fired in a kiln to form an aggregate that compares favourably with natural and commercially available synthetic aggregate. [367]

Currently, the ability of quarries to sell fines into the construction market is hampered by the lack of product specifications. The lack of clear guidance and considerable variability of fines as they exist in current stockpiles are obstacles to identifying new and relatively high value or high volume outlets within concrete and asphalt-bound products. For some applications, including use in bound and unbound layers, capping and infiltration layers, and as general fill, improved knowledge of the characteristics of fines will help to maximise their potential for use in higher specification applications. Although fines are in competition with secondary aggregates for many uses, which do not attract the Aggregates Levy, they do have a competitive advantage due to their consistent composition, superior physical properties and wide availability. Quarry fines may require additional processing, typically to remove material finer than 63 microns, to be suitable for use in construction products. The standard approach is the use of a washing plant (Photo 24)


Photo 24. Mobile washing plant

The widespread use (in some countries) of crushed rock in soil remineralisation provides an outlet for quarry fines that may become increasingly important in view of its ability to meet new objectives relating to soil protection (Photos 25 & 26). There is a specialist niche market for some quarry fines amongst farmers and horticulturists; quarry fines are gaining popularity with growers seeking alternatives to standard fertilisers. This appears to be well developed in North America and Australia, and is present in the UK. A well-known advocate of rock dust for soil remineralisation is the SEER (Sustainable Ecological Earth Regeneration) centre: www.seercentre.org.uk. This advocates the use of a mix of municipal compost and quarry fines to improve soil fertility; the quarry fines come from an andesite roadstone operation (Collace Quarry) in Perth and Kinross, Scotland. Although higher prices can be achieved than for low-grade construction uses, packaging and transport costs are high, and volumes are trivial compared to construction. In addition, standards and specifications may be unfamiliar (and seem idiosyncratic) to the quarrying industry.

 Photo 25. Growing trial in quarry fines

 Photo 26. Growing trials in quarry fines

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Mitigation

Mitigating the potential impacts of quarry wastes

An operator will normally use a mixture of approaches to deal with quarry wastes; the mix being determined by what is technically and economically feasible, taking into account the concerns of local communities and other stakeholders and planning obligations.

Plan for quarry waste disposal

All approaches to dealing with quarry wastes are underpinned by the careful planning for disposal. It is essential that the operator has accurately calculated the total waste volume (bearing in mind any capacity to avoid waste generation or find beneficial uses) and can properly accommodate this within the site design. If the design is not right, site development problems are likely to arise from waste disposal issues. Waste tips should be located to minimise potential effects on the landscape and surface water flow and quality and take into consideration potential land-use conflicts with local communities and stakeholders.

Find beneficial uses for wastes

As noted above, quarry wastes can often be put to beneficial use around the site and have long been used to ameliorate the impact of workings on the landscape through use in screening banks, backfilling, replication or simulation of natural landforms and to prepare ground for revegetation and restoration. Soil materials should be stored in a manner that protects their physical, chemical and biological characteristics until they are required for restoration. Good practice should be implemented to prevent environmental and social impacts from wastes for which no beneficial uses exist.

- Quarry waste tips must be designed, constructed, operated and maintained to avoid instability or movement that might give rise to health and safety risks. [368] Incidents involving tip instability are now rare.
- Ideally all waste should be kept out of sight within the workings to reduce visual impacts and the risk of dust dispersion. Where tips cannot be hidden their height and shape should be managed to reduce their visual impact and exposure to wind erosion. Amenity banks are an exception.
- Waste tips should be revegetated as soon as possible to prevent wind and water erosion (and subsequent dust generation and contamination of surface waters with suspended solids). Non-vegetated waste tips are liable to erosion and collapse.
- Bare tips should be kept wet during hot dry weather to control dust generation.
- Surface run-off from waste tips should be captured and treated to remove suspended solids prior to discharge.
- On closure, tips should be regraded where necessary to create a stable final landform and to prepare them for revegetation and integration with the surrounding landscape.

Mitigating the potential impacts of quarry fines

Options for mitigating the potential impact of quarry fines vary according to the type of impact, and which environmental compartment is being considered (i.e. air, water or land). However, management and protection of one environmental compartment will often have knock-on effects for the others. For example, removal of dust from air will generate dry or wet solids that require disposal, and the treatment of suspended solids in water may lead to temporary or permanent land sterilisation if settling ponds and lagoons are used.

The following sections assess the options for managing quarry fines and their impacts on the quality of air, water and land. Health issues and protection of fauna and flora are typically addressed through the management and protection of air quality, and are not therefore dealt with as separate issues. The majority of local community and other stakeholder concerns are a result of perceived, actual or potential impacts on air, water and land quality and dealing with these can often effectively address any local community and stakeholder concerns (although other more general concerns regarding quarrying activity per se will typically remain).

Siting and design of operations

Through decisions on the siting and design of operations it should be possible to reduce the requirements for the remedial treatment of dust-contaminated air and suspended solids contaminated water. Such decisions must comply with relevant planning and regulatory constraints within a comprehensive planning system (www.bgs.ac.uk/Planning4Minerals) and should emphasise preventative measures (i.e. those that avoid transfer of contaminants to air and water). Examples include locating the processing plant away and down-wind from local communities or dust-sensitive businesses and ensuring that disposal dumps are located away from surface waters. The design of an operation may include buffer zones within which certain activities are limited to ensure the potential for impacts within surrounding areas is minimised.

The choice of site and design must take into account the nature and duration of aggregates extraction, location and topography, the characteristics of the various environmental effects likely to arise and the various management measures that can be applied to deal with the residual impacts not eliminated by siting and design (in general, the siting and design of operations can only limit or reduce the requirements for the remedial management of quarry fines with respect to protecting air and water quality).

The location of activities likely to cause environmental and social impacts can change during different phases of working, and therefore the relationship between activities and sensitive areas surrounding the quarry may change with time. Some air and/or water-related environmental and social impacts may be difficult to accurately define or anticipate in initial plans. The use of appropriate buffer zones to maintain distances between the operation and surrounding communities may go some way to limiting unanticipated effects.

Typically, appropriate siting and design should reduce community impacts and can contribute to a significant improvement in local perception of the operation.

Containment

The complete enclosure of the processing plant can be used to help prevent the transfer of particulates to the external environment (Photo 27). This will increase dust concentrations within the plant and therefore suitable mitigating activities (such as air filtration) are necessary to ensure working conditions are in compliance with relevant health and safety requirements.

Containment is not always possible for mobile crushing plant. As an alternative to wetting, the issue of airborne dust can be partially addressed using covers or wind shields over transfer points and the use of dust extraction, especially at fixed conveyors and feed to crushers and screens.

In all cases, containment buildings should be designed to blend with the surrounding environment and minimise visual intrusion. Unsympathetic containment building design can increase the perception of quarrying as a visually unappealing activity.


Photo 27. Plant containment buildings

Washing plant

As described elsewhere (Production Processing) washing plants are designed to remove fines (silt and clay) and generate a clean aggregate product from crushed rock or sand and gravel using wet processes (Photos 28 & 29). Fines are transferred to the water phase and removed to settling lagoons or thickener/ filter press systems. Water is typically recovered from these systems and recycled to the washing plant in order to minimise water consumption.

Wet processes reduce the likely release of dust into the atmosphere. However, water availability is likely to decline in many parts of the UK through reductions in supply and increasingly stringent restrictions on water use by industrial operations. In areas of high demand for water abstraction, available water resources will increasingly be limited and methods for conserving or reducing water consumption in quarries will be needed. In these cases, the use of washing plant may come under increased pressure.


Photo 28. Washer barrel


Photo 29. Wash jets over wet screen

Damping/wetting

Damping and wetting are commonly applied to dust arising from all sources on the quarry site. Fine sprays or fog suppression can be used in the processing plant and at locations such as quarry fines transfer points and disposal areas to control dust transfer to air. Water bowsers and rain guns can also be used at external locations.

However, the use of water to remove dust from the air is temporary; when the water evaporates, the dust is easily mobilised and lifted back into the air. Therefore, damping and wetting is an ongoing process. It must be monitored to minimise the risk of creating an unsafe environment within the plant or run-off contaminated with suspended solids in the external environment. Water consumption may be significant, as much is lost to the atmosphere by evaporation.

Surface cover

Cover materials can be used to control wind and water erosion of fines from waste tips, haul roads and other areas prone to erosion. A number of natural materials are generally available on site (e.g. overburden, soil, and coarser waste rock). Some of these may themselves be a source of dust (air) or suspended solids (water) under certain conditions and vegetative cover is often required to control erosion. Synthetic materials may also be used (e.g. geotextiles, asphalt) but are generally significantly more expensive than natural alternatives.

Maintenance of natural cover materials is likely to be lower in cases where vegetation has become established and is protecting the cover against wind and water erosion. Other erosion prevention techniques may be required if vegetation has not yet established. Specialist assistance may be required in the use of synthetic cover materials, and for the establishment of a self-sustaining vegetative cover.

With respect to waste tips, the permanent application of natural and synthetic covers may only be possible when the final dump configuration has been achieved or a specific dump area has been completed. In practice this means that significant areas of fines may be left uncovered for long periods, resulting in the generation of wind blown dusts. Temporary covers can be continuously applied, but will substantially increase the cost of handling and placement, even if suitable material is available on-site.

Screening and wind speed control

There may be opportunities to supplement site planning and waste tip design with physical screens and barriers to limit the exposure of quarry fines to wind erosion and reduce wind speed (decreasing the likelihood of fine particulates being picked up and increasing the likelihood of dust settling within the site boundaries). Screens and barriers can include buildings, windbreaks, solid fences and vegetated embankments and bunds (Photos 30 & 31). In many cases the most effective method may be the use of dense medium and high-level vegetation (e.g. local shrub and tree species), which may also bring the additional benefits of reducing visual intrusion for surrounding communities.

Maintenance issues for non-vegetation methods are likely to be significant any barriers or screens work by absorbing or channelling kinetic (wind) energy, which over time is likely to cause physical degradation. Vegetation may require maintenance activity in the short-term, but should be self-sustaining in the longer-term. Specialist assistance may be required on wind modelling and simulation in order to optimise the location of screens and barriers within the limits set by site topography and wind speed or direction.


Photo 30. Limestone quarry fines under cover


Photo 31. Sandstone quarry fines under cover

Solids handling and transport controls

On-site vehicle speeds should be restricted, as there is a direct relationship between speed and the amount of material thrown up in the air from wheel contact with the road, and the dust lost from bulk material being transported. Although normally restricted to traffic leaving the site, it may also be necessary to sheet vehicles being used for the on-site transfer of quarry fines. If dry, the surface of carried materials may also need to be sprayed with water in order to reduce dust losses. Ensuring that haulage vehicles are covered and surface material is wet can effectively reduce airborne dust and dust spillage while material is in transit. Dust is easily picked up in the wind when the material is falling through the air at points of transfer. Where conveyors are used for the transport of crushed or graded materials the transfer points should therefore be sheltered from the wind or the entire conveyor may be covered as dictated by local weather conditions. Drop heights at transfer points should be minimised and water sprays used to prevent dust release.

Fabric filters, cyclones, wet collectors and electrostatic systems

Crushing and sizing are the major sources of particulates within the processing plant (where the plant is partly or wholly contained within a constructed building). Very fine-grained material may be removed from the air in dry processing plants by bag filters, cyclones, wet collectors (scrubbers) or electrostatic precipitators at dry processing plants. The choice of equipment will be dictated in part by the size range of dust requiring removal. Fabric filters and electrostatic separation are most suitable for fine and ultra-fine particulates, while cyclones and wet collectors are more useful for coarser dust.

Regular checks and routine maintenance are essential if efficiency and performance of air filtration is to be maintained, particularly for fabric filters that may become torn or worn.

These methods are not suitable for external applications, and increases in the volume of air requiring treatment, or concentration of particulates may require expensive retrofits of additional capacity (i.e. higher throughputs with existing equipment is likely to negatively impact performance, maintenance and breakdowns)

Waterless and reduced water removal of fines

The use of waterless, and reduced water, technologies for removal of fines is reviewed elsewhere. Further details on dry processing are available here. This would not only minimise water use (thus reducing the environmental impact of mineral extraction) but also remove the need for settling ponds and lagoons and enable easier handling of fines (potentially encouraging their use in other applications). Eliminating the need for water is also desirable for the conservation of water resources and for improving the sustainability of quarrying operations.

However, the use of waterless methods for removing fines from quarry materials has yet to be taken up in the UK. An example of the use of an air classifier, outside of the UK, is at Hanson Aggregates Tyrone Quarry in Lawrenceburg, Kentucky, USA. This quarry produces manufactured sand for use in asphalt using a VSI crusher; the crusher product contains 16% of material finer than 75 microns. A portable air classifier is used to remove the fines and produce a sand product with 7% finer than 75 microns. The main motivation for using the air classifier was the lack of available water; these quarries are located in dry areas where water use is restricted or has to be transported by truck into the quarry sites. Another was the desire to avoid the environmental issues that accompany the use of settling ponds [369]. Another example is Sunrock Group's Butner Quarry in North Carolina, USA that adopted the same dry processing technology. This is a basalt quarry that produces manufactured sand for use in asphalt and concrete using impact crushers; the crusher product contains 15% of material finer than 75 microns. Air classifiers are used to remove the fines and produce sand products containing 5 to 6% finer than 75 microns. The main motivation for introducing dry fines recovery here was to reduce the amount of fines sent to the settling ponds by the washing plant; previously the settling ponds had to be emptied once a week which was proving to be expensive and required excessive handling of fines stockpiles [370]. The air classifier used in both cases is a dynamic centrifugal separator (www.fisherind.com/Air_Separator.htm).

Other examples of the use of air classifiers to remove fines from crushed quarry material include:

- *Bowling Green North Quarry* (Cemex), Kentucky, USA: a Sturtevant Whirlwind air classifier is used to remove material finer than 75 microns from crushed limestone to produce material for Superpave and aglime as a by-product. [371]
- *Pompton Lakes Quarry* (Tilcon New York), New Jersey, USA: a Buell gravitational inertial classifier is used to produce a manufactured sand from granite-gneiss quarry

fines. [372]

- *Thorold Quarry* (Walker Industries), Ontario, Canada: a Buell gravitational inertial classifier is use to remove material finer than 75 microns from crushed dolomitic limestone to produce manufactured sand. [373]
- *PGI Quarry* (Hanson), Johor, Malaysia: an air classifier is used to remove the material finer than 75 microns present in the quarry fines and produce a manufactured concrete sand. [374]
- *Plesovice Quarry* (Kamen a Pisek spol. Sro) South Bohemia, Czech Republic: a cascade air separator is used to remove material finer than 63 microns from granulite quarry fines to produce a manufactured sand (0/4 mm) product. [375]

Potential limitations may include the quality of the final product, and inability to completely eliminate the use of water (i.e. it would entail process water management and recycling and reductions rather than totally waterless approaches). Equally, the environmental and social issues associated with potential increases in dust generation within the plant, and subsequent releases to the external environment (unless mitigated) may offset the benefits arising from reduced water use and consumption.

Air classification trials (laboratory and pilot scale)

Testwork to determine the technical feasibility of using a dry process to remove fines from sand was carried out on material from four sand and gravel quarries in Britain. A tonne of sand was collected from each site, dried and processed using laboratory and pilot-scale air classifiers. In the laboratory, a Hosokawa Alpine Laboratory Zig-Zag classifier (Photo 32) was used (www.hosokawa.co.uk/zigzaglab.php) and for the pilot-scale trials, a Bradley Pulverizer Windsifter (Photo 33) (www.bradleypulverizer.co.uk/winsifter.html) was used. The results are given in Table 2 and the findings of the trials are summarised here:


Photo 32. Laboratory air classifier


Photo 33. Pilot-scale air classifier

Sand and gravel quarry 1, south-east England: a sand and gravel quarry using a standard washing plant to produce building and concrete sand. The sample was a 2 mm wet-screened sand, which contained 3% of material finer than 63 microns. The laboratory and pilot-scale processing trials reduced the fines content in the sand product by 44% and 72% respectively.

Sand and gravel quarry 2, north-east England : a sand and gravel quarry using a standard washing plant to produce concrete sand and dry sceening to produce building sand. The sample taken was a 4 mm dry-screened sand, which contained 6-7% of material finer than 63 microns. The laboratory and pilot-scale processing trials reduced the fines content in the sand product by 12% and 29% respectively.

Sand and gravel quarry 3, south-east England : a sand and gravel quarry using a standard washing plant to produce building and concrete sand. The sample taken was a 6 mm dry-screened sand, which contained 9-10% of material finer than 63 microns. The laboratory and pilot-scale processing trials reduced the fines content in the sand product by 20% and 12%

respectively.

Sand and gravel quarry 4, south-east England: a sand and gravel quarry using a standard washing plant to produce building and concrete sand. The sample taken was a 4 mm wet-screened sand, which contained 0.6 to 3% material finer than 63 microns. The laboratory and pilot-scale processing trials reduced the fines content in the sand product by 33% and 84% respectively.

Quarry Fines + Waste				Table 2
Fines content of feed and products, air classification trials				
Sand and gravel quarry	Laboratory trial		Pilot-scale trial	
	Feed material (% <63 microns)	Product (% <63 microns)	Feed material (% <63 microns)	Product % <63microns)
1	2.7	1.5	3.2	1.0
2	5.9	5.2	7.5	5.7
3	9.9	7.4	10.2	9.7
4	0.6	0.4	3.2	0.6

These results represent fines reductions ranging from as low as 12% to as high as 84%. The fines reduction, as reported in trade journals, achieved by quarrying operations using air classifiers to remove fines is in the range 50 to 65%. The results achieved in the pilot scale trials for sites 1 and 4 are comparable with this. The chief factor causing the lower recoveries in the other site trials is insufficient disaggregation of material finer than 63 microns; this highlights one of the chief advantages of using wet processing as material is fully dispersed before size separation.

These trials were carried out on a limited number of sand and gravel quarries. It is possible that air classification would be more successful at other sand and gravel sites; however this does not take into consideration the cost of drying which may make air classification economically unfeasible. The detailed findings of the process trials are given in a separate report.

The more likely application of air classification would be in crushed rock quarries, particularly in the processing of quarry fines to produce saleable manufactured sand products. It is possible that air classification would provide an efficient means of reducing current stocks of quarry fines, especially at many limestone quarries, producing a sand product and a saleable aglime by-product. Whereas, air classification may be useful at sandstone and other hard rock quarries for producing manufactured sand, the silica-rich, fine-grained by-product currently has no sales outlet and would likely remain a waste material.

Drainage management

Drainage management can be used to keep relatively clean water separate from water with a high- suspended solids content; for example, keeping rainfall run-off from site buildings separate from washing plant process water. This will reduce the volume of contaminated water requiring treatment and minimise the water erosion and suspension of fine particulates from quarry fines dump areas. Drainage management may include the construction and lining of ditches around the site boundary to reduce lateral movement of water from adjoining areas, the use of contour banks and drains to capture water that would otherwise cause erosion and diversion of clean run-off around dump areas.

Generally, drainage management will be required across a quarry site to control erosion and water contamination impacts. Drainage-related features require proactive maintenance to ensure performance and effectiveness do not reduce over time. Some features such as banks and ditches can be stabilised by the establishment of vegetation.

Mechanical removal

Examples of mechanical removal options include a combination of hydrocyclones (Photo 34), thickeners (Photo 35) and filter presses (Photo 36). Click here for further details on washing plants. Some thickeners can now produce a paste suitable for backfill and surface stacking or disposal in a single step, replacing older style thickeners that required an additional vacuum filtration step [376]. Removal of suspended solids from process plant waters (e.g. washing plant) is a target for mechanical removal options, but they may also be applied to other contaminated surface waters (e.g. arising from external sources, including run-off from fines disposal areas). Mechanical methods may not be able to remove ultra-fine particles without the additional use of chemical aids (flocculants).


Photo 34. Washing plant cyclones


Photo 35. Washing plant thickeners


Photo 36. Plate press filter cake

Gravity separation (settling ponds and lagoons)

Silt lagoons are a common method of removing suspended solids from water (Photo 37). They work by slowing the flow of surface waters to facilitate the settling and consolidation of suspended solids. Their use may be constrained by land availability and site topography. Typically, they comprise one or more joined voids, developed in areas of prior working or in areas that have specifically been excavated to hold them. Discharge quality may decrease significantly during storm events, when chemical aids may be required to speed settling and remove ultra-fine particles from suspension.


Photo 37. Discharge into silt lagoon

Lagoons receiving significant clay material in the overall suspended solids may fill more quickly, reducing the useful working life of the pond or lagoon. Therefore, to operate properly, other voids must become available for the disposal of waste removed from the ponds or lagoons. Usually, fresh ponds and lagoons are created and the full ponds and lagoons closed and restored. Alternatively, ponds and lagoons have to be cleared periodically as the site does not have sufficient space for the entire silt and clay output of the operation. With proper planning ponds and lagoons can be designed for restoration to a wide range of habitats, as part of landscape improvements and for other beneficial end-uses.

Chemical treatment (flocculants)

Synthetic flocculants are often used in conjunction with mechanical recovery methods and settlement lagoons or ponds to reduce settling times, reduce the volume and water content of settled solids, and enhance the removal of ultra-fine particles, which are generally the most difficult to remove from suspension. They are also used where insufficient area is available to install a pond or lagoon with suitable capacity to allow gravity settling for a given flow and suspended solids content. Required dose rates are typically low (of the order a few grams per cubic metre), and use is relatively simple and low-tech, although overdosing can impair performance and increase operating costs. The use of flocculants needs to be optimised depending on the mineralogy and size of suspended solid requiring treatment.

Care should be taken to ensure that flocculant chemicals are stored in an approved manner such as in drums or surface tanks with impervious bunds to contain spillage, and located away from operating areas, natural or engineered drainage pathways, waterways and areas prone to flooding. This is particularly important as there may be concerns regarding the presence and use of chemicals on-site and the potential risks associated with discharge into local surface waters.

Biological filtration (reedbeds and wetlands)

Where space is available, the presence of reeds or other aquatic vegetation in ponds or lagoons can enhance the removal of suspended solids by slowing the water and physical filtration by the plant roots. Wetlands can be described as areas flooded or saturated by surface water or groundwater often or long enough to support those types of vegetation and aquatic life that have specially adapted to saturated soil conditions. Constructed wetlands attempt to duplicate natural systems and can be designed using settling ponds and lagoons as their starting point.

Natural generation of reedbed (Photos 38 & 39) and wetlands can occur in suitable settling ponds and lagoons, leading to low maintenance, self-sustaining systems. Artificial or accelerated promotion of reedbed and wetland species may be labour intensive (and incur additional costs) until the systems are established, and may require specialist assistance in design and maintenance.

It is important to recognise that not all sites will be suitable for reedbeds or wetlands. In the quarrying sector many of the additional benefits presented by reedbeds and wetlands (e.g. removal of dissolved inorganic and organic contaminants) are largely irrelevant, reducing the financial case for specific construction. Reedbeds and wetlands will therefore rely on an existing need for settling ponds and lagoons in the majority of cases.

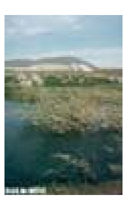
Photo 38. Natural reed bed in lagoon

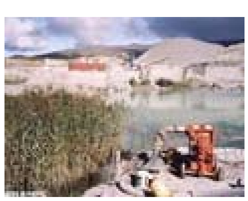
Photo 39. Natural reed bed in lagoon

Backfilling of quarry fines

Quarry fines may be immediately or ultimately replaced in the voids created by aggregate extraction (Photo 40). The timing of the movement of quarry fines is critical to avoid economic costs associated with double handling, and environmental/ social costs associated with multiple transfers of the waste (e.g. dust generation at transfer and holding points). Therefore, ideally, wastes should be immediately transferred to their final location to avoid double handling and the risk of generating additional dusts and contaminated run-off. However, in many cases immediate placement may be constrained by operational considerations, and where fines have limited beneficial on-site uses (e.g. landscaping and land restoration) they may need to be stored in temporary dumps.

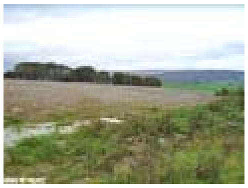
Photo 40. Quarry filled with waste and fines

Design, siting and closure of surface quarry fines disposal tips

Where infilling of worked-out areas is not possible, temporary or permanent surface tips should be located where topography offers maximum protection against erosion. Tips should be located where prevailing winds will blow dust away from local communities and dust-sensitive businesses and buildings and where the risk of direct discharge of contaminated run-off is minimised. Erosion control should be based around the establishment of a self-sustaining vegetative cover, with the use of interim measures such as drains and contour banks as necessary. Temporary or permanent cover materials may be required to control erosion and support the vegetative cover. Tip heights should be minimised to control exposure to wind, although this may increase the tip area.

Tips will often require substantial maintenance works to prevent or minimise wind and water erosion. This is particularly true before and during the establishment of vegetative cover. The choice of site and design of operations can only limit or reduce the potential generation of dusts and contaminated run-off. The permanent application of natural and synthetic covers and subsequent vegetative growth may only be possible when the tip configuration is finalised or a specific tip area has been completed. This means that significant areas of fines may be left uncovered for long periods, resulting in the generation of dust and contaminated run-off. Temporary covers can be continuously applied, but will substantially increase the cost of handling and placement, even if suitable materials are available on-site.

SUMMARY OF GOOD PRACTICE: QUARRY FINES AND QUARRY WASTES

Good practice for mineral planning authorities

Consider the need to agree or specify planning conditions relating to:

- the location of waste heaps both temporary and permanent;
- means of controlling of leachate and run-off;
- the height and shape of waste heaps;
- surface treatment, e.g. vegetation;
- progressive restoration, preferably within the workings; and
- the period within which temporary heaps must be removed.

Good practice for operators

- Minimise the production of waste.
- Try to find a use for waste, e.g. landscaping.
- Site waste heaps within workings wherever possible.
- Use waste as part of a programme of progressive restoration.
- Landscape and vegetate waste heaps as soon as possible.
- Site waste heaps having regard to potential effects upon:
  - the landscape;
  - groundwater;
  - surface watercourses; and
  - the flood regime.
- Ensure that waste with a physical or chemical contaminant is encased so that it cannot escape to the atmosphere or be leached to aquifers or surface watercourses.
- Store top soil and sub-soil and overburden, in a manner that is compatible with ultimate restoration.
- Fine waste, e.g. dust, can be treated by cementation to create non-eroding solid material. Silt can be mixed with other materials or used as part of landscaping and covered with more robust materials. It should be confined permanently and securely away from water supply catchment and recharge areas.
- Wastes should be used positively wherever appropriate, e.g. where they would be beneficial as part of progressive restoration, or amenity screen cs56. If they cannot be hidden then they should be landscaped and vegetated as soon as possible.