RESTORATION of AGGREGATE QUARRY LAGOONS for BIODIVERSITY
Restoration Of Aggregate Quarry Lagoons For Biodiversity

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Disclaimer

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1. INTRODUCTION

1.1 General

This report is the main output from a Defra funded research project managed by Natural England through the Aggregates Levy Sustainability Fund (ALSF). The research was carried out in 2009/2010 by David Jarvis Associates Ltd (DJA) and Professor Geoffrey Walton and Associates LLP (PGWA).

This research is confined to a specific area of some aggregate extraction in England, namely the silt lagoons, their design and restoration to biodiversity objectives.

It follows on from two previous pieces of research undertaken as part of the Minerals Industry Sustainability Technology Programme (MIST) funded from the ALSF.

Research into the design, management and restoration of quarry silt lagoons for environmental and landscape benefits, Christina Allen, Geoplan Limited, 2004, had three main objectives:

- To undertake a desktop study to ascertain the range of afteruses proposed for sand and gravel silt lagoons within a pilot study area.
- To assess designs, operational management and restoration techniques that have influenced or are likely to influence, the afteruse of silt lagoons.
- To discuss the principle elements involved in the design, management and restoration of silt lagoons to maximise their beneficial use.

The study covered 42 Planning Applications and found that in 56%, nature conservation was the planned afteruse for the silt lagoons. It concluded that natural regeneration is best achieved when the silt bed can drain freely. The research concluded that the most critical factor in determining the range of habitats present in a lagoon is the relationship between the restored silt level and the final water table. It concluded finally that it is the relationship between design and management which realises the potential of silt lagoons.

Water-based quarry restoration: opportunities for sustainable rural regeneration and nature conservation, Hafren Water, 2008 had the objective of reviewing floating wetlands in a global context and to identify some of the principal features characterising these distinctive habitats.

One of the recommendations from this 2008 research suggested that “Techniques used for river bank restoration could be trialled on the quarry lake margins. This would involve the use of pre-planted coir pallets or coir rolls along the shore or immediately off-shore on artificial floating rafts.”
This current research project builds on these two previous pieces of research. It aims to describe current and traditional designs of silt lagoons, how these may be adjusted both to improve their core function and to speed up/provide a wider range of habitats on restoration and to undertake trials of coir matting/floating islands.

For the purposes of this research, the term ‘silt lagoon’ has been used to represent the various types of water body created to collect and settle out fine material produced by or during the extraction of minerals and the processing of aggregate in quarries in England. It is equally applicable to some silt traps and attenuation ponds used to control surface water flow and run-off associated with quarry workings.

Paramount in any consideration of silt lagoons is the question of safety. During operation and restoration and until drying out is complete, silt lagoons represent a potentially fatal hazard from drowning or as a consequence of the quicksand characteristics of meta-stable silt.

1.2 Methodology

Desktop research followed by a series of visits to aggregate quarries in England established the typical configuration, construction and restoration techniques currently used. The resultant information was analysed to see whether modifications in design, operation or restoration might lead to a greater operational efficiency, lower costs, enhanced safety, accelerated restoration and a wider range of habitats to increase biodiversity. Various stakeholders, including operators and ecologists were consulted.

Recommendations on design, operation and restoration are made together with areas of potential future applied research.

A small additional grant from Natural England allowed the installation of a floating island and peripheral coir matting at one site; the results of these trials will be written up by March 2011 and this report updated.
2. **SILT LAGOONS – THE BACKGROUND**

2.1 **Context**

Most aggregate operations in England (and indeed many other mineral operations) produce fine waste. Such waste is principally smaller than 75-100 microns (1 micron is $1,000^{\text{th}}$ of a millimetre) and comprises:-

- clay – smaller than 2 microns;
- silt - 2 to 60 microns;
- fine sand – larger than 60 microns.

These fines arise from crushing, screening and other mineral processing activities; the fine materials from these operations are commonly collected in water and pumped or conveyed in suspension for subsequent storage in lagoons. The silty materials eventually settle out of the suspension in which they were transferred into the lagoon, but commonly remain in a semi-liquid state for many years or even decades after deposition.

For this reason lagoons are treated as geotechnical structures and require careful design in accordance with the requirements of the Quarries Regulations 1999 to ensure that they do not collapse and cause problems within or outside the quarry. The long-term restoration of these structures can be a complex matter as access on to the surface of old lagoons can be exceedingly dangerous and is subject to the usual processes of risk assessment, method statements and working rules.

It should be noted that a variety of names are used across the aggregate sector for lagoon type structures. These include settling pond, silt pond, slimes pond, attenuation pond (although these strictly are for the management of surface water flows that may contain suspended solids), tailings pond etc. The word dam is commonly used loosely, and sometimes inappropriately, as an alternative to lagoon or pond. Some of these terms are applied to structures that act to settle suspended solids in water courses within or leaving a quarry and contain no discards from mineral processing.

Lagoons are constructed in a variety of ways that often influence the nature of the final structure and its eventual restoration. These structures comprise two basic types:-

- Excavated lagoons, typically voids remaining from previous mineral workings.
- Embankment lagoons which are impounded on one or more sides by a built retaining structure.

Excavated lagoons are commonly found in sand and gravel operations where the fines are removed by screening, washing plants and cyclones from the naturally occurring excavated minerals to produce a marketable product.

The fine materials from such operations can comprise 5-20% of the total mineral worked and lagoons in these workings often comprise a similar proportion of the eventual final surface area. As such excavated lagoons can be quite extensive and
occupy up to 2-3ha of final surface where sand and gravel has been worked in a number of separate, but contiguous, excavations. If however a lagoon occupies only part of the excavation it is likely to have an embankment retaining structure. In other locations, where the water table is such that the mineral excavation will eventually contain groundwater, it is not unusual for silt to be discarded into such flooded workings without any containing embankment, but to occupy only a limited proportion of the pond.

Figure 1 shows diagrammatically four different types of lagoons, one excavated and three different embankment lagoons viz valley fill, partial embankment and total embankment. The valley fill arrangement is also akin to that of an embankment within an excavation.

Lagoons have several basic functions as follows, but not all may be used in any one installation:

i To separate water from fine silts and clays produced during the processing of aggregates and to ensure that suspended solids have been sufficiently removed for discharge off-site.

ii To store settled silt prior to subsequent drainage/drying and excavation for re-depositing in permanent spoil heaps; alternatively to provide permanent storage for the silt.

iii To provide partially clarified water for further mineral processing.

iv To provide a storage capacity for run-off from the quarry operations during periods of heavy rainfall.

Although silt lagoons are widely in use they can take up a large area of land, silt is difficult to handle and dangerous. However, the cost and energy usage is usually less than employing alternative methods.
Figure 2.1 Diagrammatic lagoon arrangements
CHAPTER 2 – SILT LAGOONS – THE BACKGROUND

2.2 Characteristics of lagoons

In order to understand the form of lagoons at the end of their operating life, when restoration becomes an issue, it is necessary to review the ways in which lagoons are constructed and operated.

Excavated lagoon construction

Discharge into lagoons is generally a continuous operation during mineral processing. Depending on particle size, the ease of handling and the size of lagoon structures, some of the settled discards may be excavated and placed in spoil heaps elsewhere, especially the coarser materials that are normally deposited near the discharge point into the lagoon.

At the end of their operating life excavated lagoons may be:

- Filled to capacity and left.
- Left with a standing body of water at the distal end away from the discharge point.
- Capped with dry quarry discards and covered with top and sub-soil.

The first two of these potential states at the end of quarry operations are relevant to the present study although lagoon capping is considered below, because of the significant safety issues associated with it and the different type of restoration that can be applied to such areas.

Excavated lagoons are constructed wholly, or largely, below ground level and generally rely in part upon evaporation and seepage into the underlying ground for the fine discards to drain. Embankment lagoons generally rely upon the removal of water from the lagoon and its return for mineral processing. Where this water removal has taken place by pumping, this will cease at the end of mineral processing, but there will still be some water overflow due to rainfall.

Figure 2A shows an idealised situation where accumulated silt lies at the base of an embankment lagoon with coarse sediment collecting near the inflow point and finer silt and clay collecting at the distal section away from the inflow point (see Figures 2B and 2C respectively). In practice the discharge of discards is more complex where, although the coarser fine sand and coarse silt accumulates near the discharge points, this material is often eroded in a complex system of channels and beaches that may meander across the surface of the lagoon. In many lagoons an inclined beach with slopes up to 5-10° is formed near the discharge point and the surface of the deposited settled material slopes more gently away towards the further end of the lagoon. During operation drainage of the supernatant water may be obtained by pumping from floating pumps or by drainage channels where the ground surface is sloping away from one side of the lagoon (see below).
Figure 2.2 Silt accumulation across a lagoon
With un-capped lagoons the inflow discharge point may be elevated up to 4 metres above the distal end, depending on the size of the lagoon. Although elevated areas above supernatant water may dry out, much of the silt above the standing water may not dry sufficiently to support access by plant or individuals. The restoration of such areas is a key issue of this study.

As noted previously, the majority of excavated lagoons are associated with sand and gravel operations.

**Embarkment lagoon construction**

These are constructed above ground level on one or more sides and the surface drainage of these structures is often closely controlled and drainage of accumulated discards is easier to manage provided the embankments have been appropriately constructed to support excavating equipment with sufficient reach to form radial drainage channels extending to the embankment or water collection pond. Almost all embankment lagoons are treated as significant hazards in the Quarries Regulations 1999 and are subject to detailed geotechnical design and monitoring. Many embankment lagoons are long-term structures and the embankments are progressively raised to accommodate additional silt. An essential element in embankment lagoons is the internal drainage – typically a drainage blanket such as that shown diagrammatically in Figure 2C.

The majority of embarkment lagoons are eventually capped although some are excavated in whole or part and subsequently placed within the quarry confines.

This type of lagoon is more commonly associated with hard rock aggregate quarries although many of these are contained within the curtilage of larger quarries.

**Layout of lagoons**

It is important to understand and recognise the variety of in-flow and out-flow arrangements and the general layout of lagoons that can occur in any aggregate quarry.

Discards from quarry processing are usually delivered in suspension by pipe or through a system of ditches. There may be a single inlet point or multiple inlet points (often called spigots) where slurries are delivered by pipe or by a discharge over a weir, a process employed where the reduction of disturbance to sediment settlement processes is seen to be important.

The corresponding removal of supernatant water from a lagoon may be by (i) a single pipe through an embankment or beneath an embankment where a decant tower or floating weirs have been employed, (ii) by a weir to ditches or pipe-work, or (iii) by a fixed weir or by a floating pump or siphon. Some of these facilities may remain in place

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1 See “Health and Safety at Quarries”, HSE Books 1999. This includes the Quarries Regulations 1999 and the Approved Code of Practice. Lagoons are covered in Regulations 30 to 37.
after the active use of the lagoon and influence the drainage arrangements to some degree in the long term; they may also impact on access for restoration. Figure 3 shows some of the in-flow arrangements. Figure 4 shows out-flow and drainage arrangements at lagoons.

Figure 2.3 Inflow arrangements for lagoons
CHAPTER 2 – SILT LAGOONS – THE BACKGROUND

Figure 2.4 Outflow and drainage arrangements for lagoons
Lagoons are seldom single separate structures. Frequently they are arranged in series or in parallel to assist in removing suspended solids especially when the water is discharged off-site. Figure 5 shows the diagrammatic layout of lagoons in series and parallel that permit sediment to be excavated from one or more lagoons whilst the system remains in operation.

**Figure 2.5  Diagrammatic layout of silt lagoons**

*Note* that with ditch connections it is necessary to consider access arrangements when installing matting and artificial islands.
Figure 2.6 Attenuation and settlement lagoon arrangements
Figure 6 shows the situation which commonly occurs where the containment of storm water is an issue such that a large attenuation pond is required to accommodate exceptional storm flows. Out-flow from attenuation ponds is regulated so that settlement of suspended solids can be ensured within the settlement lagoon although some preliminary settlement will also occur within the attenuation pond.

The size of lagoons is sometimes prescribed by the requirement to excavate settled discards for disposal elsewhere within the quarry tips. This is a means of accommodating further use of the structure as a silt settlement facility. These lagoons are therefore defined by the reach of excavating equipment such that the lagoon width seldom exceeds 20m i.e. a 10m reach by an excavator standing on either side of the embankment of the lagoon. The lagoon length is typically 2 to 3 times that of the width.

More generally, especially where former excavations are used as a lagoon, the width and length of the structure is considerably greater and little can be done to allow for the removal of settled silt. In this situation restoration consists of either leaving the lagoon to re-vegetate naturally where there is no standing water or capping the whole or part of the lagoon. Lagoon capping is a significant safety issue and is covered in the following chapter.

2.3 Safety issues associated with lagoons

Before any restoration or re-vegetation work is undertaken on lagoons a check should be made of the latest Geotechnical Assessment of the structure. Geotechnical Assessments are required for all lagoons that are elevated more than 4m above surrounding ground (which may be inside or outside the quarry excavation) within 50m of the structure, or contain more than 10,000 cubic metres of liquid in suspension and/or sediment. This check should, if necessary, be supported by an overview of the report by a geotechnical engineer to ensure that the long-term security of the structure is not in doubt.

Lagoons form a potential hazard long after a site has become disused. One solution is to drain and over-tip, a process known as capping. The first step is to form a series of radial drains around the perimeter of the lagoon using a dragline or long-reach backhoe and to form a boundary collection ditch from which water is pumped. This assists in the

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2 Tips include lagoons and are subject to regular appraisals. If they are found to constitute a significant hazard, these structures are subject to Geotechnical Assessment by a competent person. Details of significant hazards with respect to the design and/or construction of lagoons are given in Regulation 32 and ACOP Para. 300 (b) and (c).

3 Issues surrounding closed lagoons that are no longer part of an active quarry are covered under Regulation 5 and Guidance Note 31. The owner of a disused lagoon at an abandoned or former quarry is responsible for its safety under the Mines and Quarries Tips Act and Regulations (1969 & 1971). Under Regulation 6 of the Quarries Regulations 1999 the operator, who may not be the owner, at a quarry closure “shall ensure that the quarry (and any lagoons) are left, so far as is reasonably practicable, in a safe condition”. This includes the need for appropriate fencing.
drying of the perimeter sediments. The drying process can take many months or years and the contents at depth can still remain liquid even after decades. Over-tipping comprises spreading dry material using low ground pressure plant in thin uniform layers of spoil. This minimises the risk of plant being lost following the collapse of the surface crust. The recommended means of covering a lagoon is shown diagrammatically in Figure 2.7. Gradually the thickness of cover can be increased until regular profiles can be formed and top and sub-soil replacement and other restoration activities can commence. Uneven point loading from trucks tipping onto a partly capped lagoon can have fatal consequences for those concerned.

Lagoons that are not capped remain significant hazards and many drowning incidents have been reported since lagoons that have a partially consolidated crust, that forms on the surface of dried sediments, is easily broken due to disturbance and vibrations - a process known as liquefaction. The materials disturbed act in a similar fashion to quicksand. It is therefore essential that uncapped lagoons, especially where standing water is present or may have been present, in part of the former lagoon area, are securely fenced with warning signs. This is particularly important where the lagoon lies in otherwise restored ground e.g. farmland etc., where there may be formal or informal access or the potential for trespass. Just because a lagoon is covered in dense vegetation does not imply that the lagoon is safe for access by plant or people. Such areas can become wildlife havens – but with attendant potential risks to those who visit or trespass.

It follows that the installation of any restoration, re-vegetation, island construction or the use of any matting or other materials placed over a former lagoon must be undertaken in a safe, fully risk assessed manner. Typically this implies the use of long-reach equipment the siting of which, on the bank of the lagoon, must be rigorously checked. There must be no likelihood of the plant sliding or collapsing into the lagoon sediments; it must also be out of the reach of any overhead cables. Similar considerations will relate to hydro-seeding type techniques that may be employed. As in other parts of a quarry where there is access by vehicles or persons edge protection is essential as required under Regulation 13 of the Quarries Regulations 1999.

A full risk assessment is also required for the handling of materials from punts or similar low draught vessels. It should include the risk of grounding and capsizing and subsequent escape.

Access onto lagoons should never be attempted without a detailed Risk Assessment and remote reach trials (e.g. using a backhoe boom to test the rigidity of the surface) and

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This is of importance where engineering and restoration works such as those considered in this report are in progress outside an active quarry. The removal of fences and barriers to undertake the works must not provide an opportunity for unrestricted access since the HSE are likely to prosecute if accidents arise from the failure to provide secondary fencing. (See Tarmac – v – HSE 2009). Fencing around active quarries is covered in Regulation 16 and should be based on an appropriate Risk Assessment.
access should always be restricted to those locations that have been adequately investigated.

2.4 Alternatives to silt lagoons

The main alternative to silt lagoons is dewatering. This can be done by natural, chemical or mechanical techniques and processes. However even these processes may not remove all the water from a sludge, they may just reduce it to a damp solid state.

There are three main dewatering techniques used in the aggregate sector. These are:

1. Dry Process Screening.
2. Thickeners.
3. Plate/Belt Filter Press.

Other technologies such as hydrocyclone classifiers and classifying tanks are used to separate sand from sludge, silt or clay.

1. Dry Processing

Drying reduces the moisture content of a material by the application of heat to evaporate water from the discard (whether in part or whole).

There are many types of driers with many variations. For example driers apply heat via convection, conduction, radiation or electromagnetic methods. Variations include whether the material in the drier is stationary or moving, or whether the motion between the dryer and the drying medium is co-current or counter current.

Generally in the quarrying industry, convective, direct heat, continuous dryers are the type most commonly used\(^5\).

Examples of these dryers are:

a) Rotary dryers (i.e. cascade driers) – These consist of a long cylindrical drum which rotates on rings set on rollers. On the inner side of the drum there are spiral flights/lifters. The drum is inclined to promote the movement of material from the feed point to the discharge point under gravity. As feed enters the tube the flights/lifters shift the material and it cascades within the drum. As the material is being lifted and falls, hot gas is streamed through the drum drying the material by evaporation. The silt leaves the drum with reduced moisture content (see Figure 8 - 1a).

b) Fluidised bed dryers – Material is fed into the fluidised bed dryer and forms a layer of fine grained solids. Hot air is then supplied beneath the bed through a perforated distributor plate and fluidises the material (i.e. takes on fluid like properties) and appears to boil. This close contact between the particles and hot air/gas enhances heat transfer through convection and conduction. The hot air

\(^5\) www.goodquarry.com
can be supplied at a flow rate which supports the weight of the particles in a fluidised state (see Figure 8 - 1b).

2. **Thickeners**

Thickeners are typically mechanically aided settling systems that rely, in part, on the use of flocculants to promote agglomeration of fine particles. The most common type of system comprises a large circular tank with slowly rotating rakes which aid in settling of suspended solids and assist in transporting material downward to a central discharge point. Flocculants are added to the feed pipe. The discharge is essentially a thickened slurry occupying less space in its final storage containment cell; it may comprise a step towards further drying such as with filter presses (see Figure 8 - 2).

3. **Belt/Plate Filter Press**

   a) **Belt Filter Press** – sludge previously treated with a flocculant enters a gravity dehydration tank where the flocculants are agitated to promote solid, liquid separation. Any free water drains off and is collected. The sludge then continues through stages of low, medium and high pressure, along a filter belt, which is constructed of a woven material. The belt passes through rollers which squeeze the water out of the sludge. The water passes through the woven material and is collected for recycling or discharge. The sludge cake exits the machine and the clean filter belt is recharged with fresh sludge (see Figure 8 – 3a).

   b) **Plate Filter Press** – this consists of a series of chambers contained by plates supported by a frame. Sludge enters the press and is pumped up into the chambers between the filter plates. The plates have filter media between them. Once the chamber is filled, the continuous stream of sludge to be dewatered results in an increase in pressure which pushes liquid (filtrate) through the filter plates and up to an outlet port from which it is discharged. The filter press then opens and as each plate disengages the cake falls under its own weight. This cake is collected and stored/disposed (see Figure 8 – 3b).

In general the above systems of handling liquid processing wastes produce very weak engineering soils that may only be stored in appropriately engineered structures such as embankments within tips and require carefully managed placement procedures.

However some sludge cake from these processes may have a limited commercial value, usually as an additive to substrate for soil development/land improvement, if suitable for use as a soil ameliorant or in aqua culture these materials may be useful for wildlife habitats, wetlands restoration and fisheries improvement.
In general the above processes are the exception rather than the rule given the high energy costs involved. They are most likely to be used where space is at a premium and water management problems exist.
Figure 2.8 Alternative methods of handling silt to avoid lagoons
3. SILT LAGOONS – THE ISSUES AND OPPORTUNITIES

3.1 Safety

General

It has already been noted that silt lagoons are very dangerous places and that safety is paramount. Such safety concerns begin during construction, continue during operation and remain beyond the end of active quarry operations. Even apparently dried out lagoons can be highly dangerous – there have been fatal accidents resulting from vehicle movements on such sites.

One positive consequence of the dangerous and long term nature of silt lagoons is that they often tend to be located to one side of the main quarrying activities and are seldom frequently visited or disturbed. On restoration of the whole site, silt lagoons should be securely fenced as vegetation invades. Such isolation may be a benefit to biodiversity and deter human disturbance.

It is therefore essential, and a legal requirement, that lagoon design is undertaken by competent persons identified as geotechnical specialists as defined in the Quarries Regulations (Reg. 2). The restoration and biodiversity objectives for lagoons need to be incorporated within this framework and not attempted otherwise.

During construction and operation

The safety issue most relevant to this research is centred on the adequacy of machine and other access as noted in Section 3.2. It is often the case that silt lagoons are constructed in dry or temporarily pumped locations which provide almost unlimited access for machinery. Once operational (and in combination with further silt lagoons built in a complex) machinery access may be severely limited, not least by connecting drains and pipework, or the absence of appropriate edge protection. Opportunities to introduce temporary or permanent elements for the purposes of encouraging biodiversity may therefore be similarly restricted unless appropriate arrangements have been made in the initial design.

On decommissioning

Access constraints on plant, that may control where silt can be excavated during operation, also commonly applies on decommissioning. If excavation is feasible and appropriate locations for the disposal and positive use of excavated dry or drying silt need to be identified as part of a holistic operational and restoration plan. The resulting void from silt excavation also needs to be considered in any restoration scheme.

Limiting public access remains a key safety issue on decommissioning and any new design or management solutions which may encourage biodiversity must also not increase the danger to the public and other stakeholders.
Bird Strike Issues

It is recognised that annually tens of millions of pounds worth of damage is caused to civil and military aircraft by bird strike, especially near airports and runways. It is therefore necessary to ensure that any schemes for enhancing biodiversity, including bird life, accommodate the appropriate controls to reduce the risk in flight zones.

3.2 Efficiency of operation

General

There are four main issues which present opportunities for increasing biodiversity and/or minimising the environmental impacts while increasing the efficiency of the silt settling process.

Minimising the footprint

Many current silt lagoons and silt lagoon complexes do not appear to be designed and/or operated to maximise efficiency. This lack of efficiency may lead to larger bunding, increased areas of water, and more lagoons in the sequence. Inadequate removal of silt/re-use and wasted space between silt lagoons/other uses may also increase the footprint. Individually or in combination these factors can unnecessarily increase the footprint; this in turn can have negative final land use as well as adverse ecological and landscape impacts.

Re-excavation

With good access and beneficial locations for disposal, planned and phased excavation of silt lagoons through the operational life of the quarry, may minimise the necessary lagoon area and maximise positive use of the silt. Excavation, however, may cause disturbance to emerging or potential ecological interest and silt does not cease to be a problem just because it has been excavated.

Re-circulation

Some aggregate sites are high volume users of water. The removal of suspended solids prior to final discharge into the downstream drainage network is an added financial cost to the quarry operator. Where appropriate re-circulation of water minimises the total volumes discharged off site and subject to EA controls and thresholds. Hence, at most quarries, lagoons for the settlement of processing discards do not directly discharge ‘cleaned’ water off site and separate lagoons are used for site run-off.

Flow rate decrease

The simplest and most effective way to encourage the settlement of suspended silt from the water is by slowing down the rate of flow (and removing turbulence). The settlement of silt depends on the time during which silt is in suspension in a lagoon (the residence time). Lagoon design should always accommodates this issue.
The proper planning, design and management of a silt lagoon network provides the opportunity to increase efficiency, increase and accelerate ecological opportunities and to save money through the avoidance of double handling and the re-visiting of mature landforms and landscapes. It is an activity for geotechnical specialists, landscape architects and ecologists co-operating within the limits of the law.

### 3.3 Increase biodiversity during operation

Silt lagoons, more often than not are rectilinear, relatively steep sided and strictly functional. Essentially many lagoons are utilitarian quarry life structures that will eventually be capped. However, some short-term opportunities may exist for temporary refuge type facilities to be incorporated. Where lagoons are scheduled to remain as long-term features at the end of quarry operations opportunities exist to design them for a more diverse range of habitats than are usually found. This is not to detract from some of the specific aquatic, littoral and ruderal environments which occur in many silt lagoons.

### 3.4 Increase biodiversity post operation

Opportunity exists to increase the range of habitats encompassed within a silt lagoon restoration scheme. Again, this is not to detract from or, indeed, to remove the slowly emerging habitats typical of drying silt beds; such bare areas are noted for their gradual invasion by pioneering species and their floristic, herpetological and insectivorous value in particular.

### 3.5 Acceleration of processes

For safety, access, amenity, aesthetic and financial reasons, speeding up the drying process and returning silt lagoons to viable dry land is desirable. Similarly, if possible and within the safety controls noted above, it would be valuable to speed up the creation of a wider range of habitats more quickly notwithstanding the value of some very slow regenerating areas.
4. POSSIBLE DESIGN AND OPERATIONAL TECHNIQUES

4.1 General

The overall objective of silt lagoon design is the production of operationally safe and efficient schemes which settle silt, produce water suitable for re-use in mineral processing and, where feasible, maximise and accelerate the restoration objectives, particularly those relating to biodiversity.

Essentially, design techniques should aim to control water flow and reduce turbulence to increase the rate of silt settlement. Frequently this implies optimising the length of travel of the silt-laden water. Workforce/machine access should be thoroughly assessed at the outset to facilitate maintenance, silt extraction and for the application and management of restoration techniques. Enhancing the means to deliver biodiversity objectives is an essential part of the design objective.

4.2 The number of lagoons

Generally, one very large silt lagoon is sometimes preferred as the management required is limited; the opportunity for this type of lagoon is somewhat restricted. However, lagoons in series or in parallel are the more usual case and the area of water is reduced, but the aggregate length of the sides of the lagoons is increased. Provided the rate of inflow of silt is regulated the risk of turbidity and wave erosion at the lagoon edges is reduced. In one large silt lagoon, silt deposition occurs across the water body from the outfall pipe; the coarser particles settle first and a full range of silt sizes eventually settles out. In a network of lagoons, there may be a clearer definition of the gradation of deposition between the individual lagoons i.e. the coarse deposition through fine deposition to clear water depending on the size of the individual lagoon – finer silt requires a longer residence time and/or a reduced rate of in-flow.

Hence a larger number of lagoons has advantage in terms of biodiversity. The length of lagoon edge is increased compared with a single very large lagoon. Equally, birdlife (particularly wild fowl and waders) may fly from one lagoon to another if disturbed whereas this opportunity is not open to them if there is only one water body. Where separate lagoons are awaiting de-silting, as frequently occurs with lagoons in series or parallel, there may be periods where individual lagoons have exposed silt and silt immediately beneath the water surface.

Generally, therefore, a network of lagoons may be preferred from a biodiversity perspective during the operational period. At the end of the operational phase the removal of some parts of dividing bunds may be feasible to leave in-situ island refuges. This is only feasible if machine access has been incorporated in the initial lagoon design.

4.3 Projecting spurs

Especially in a large single silt lagoon (but applicable to all sizes), scope exists at the construction phase to incorporate projecting spurs into the initial design (see Figure 4.1
While again having cost and material balance implications, these spurs or peninsulas have the advantage of reducing turbidity, increasing flow length, increasing the edge to water surface ratio. The retrospective construction of spurs is not recommended without significant attention to construction details. When a lagoon is in operation the construction of spurs is a complex geotechnical matter that is not simply addressed by tipping waste rock or soil into the lagoon however large it is since collapses can occur on already deposited silt. If spurs are to be used ab initio then the lagoon area needs to be enlarged to maintain the equivalent silt storage capacity and settlement area.

Peninsulas provide potential for some enhanced definition of wet, dry and intermediate areas as well as some shelter and refuge from disturbance for birds. At the completion of the operational phase, sections of these peninsulas may be removed to create in-situ islands as in Figure 4.2iii.

**Figure 4.1 Simple lagoon**

(i. A silt lagoon with a direct flow route from input to exit point)

(ii. On restoration a large body of open water offers little opportunity for enhancement)
From an operational perspective, most silt lagoons are rectilinear (see Figures 4.1 and 4.2) since experience shows that a length to width ratio of 2:1 to 3:1 performs better than with other configurations or shapes for the available area. This rectangular form is also preferred since it avoids wasted space between lagoons, the need to accommodate field boundaries, roads etc and the ease of construction and maintenance by machinery.

If space permits, from an ecological perspective, there may be a preference at any particular location to have other shapes which may aid local biodiversity objectives. Theoretically, silt lagoons could range from circular shapes which would maximise the water surface area to edge ratio and the distance from edge to centre of the water body to long, thin or ‘starfish’ shapes which would create the opposite effects (particularly maximising the percentage of ‘edge’ habitat). Many of these would not be efficient in terms of silt settlement. A horseshoe shaped lagoon, with sub-parallel sides, may offer an optimal balance between ‘edge’ and ‘length’ while providing good dry silt storage during operation and opportunities for restoration to a complete island on restoration (see Figure 4.3).
There is clearly a balance to be achieved between safe and efficient operational requirements and the local biodiversity objectives; these will vary from site to site. The overall dimensions and shape of any silt lagoon should not, therefore, automatically be the default rectilinear solution provided it meets the requirements of the Quarries Regulations and achieves settlement objectives.

4.5 Lagoon shallows

Edges to silt lagoons tend to be relatively steep, straight slopes into the water. Dividing bunds are typically variations on a trapezium in section. Such forms are utilised to simplify design and control construction/maintenance costs. The form also minimises land take and reduces the volume of construction materials needed.
From an ecological perspective such short, steep slopes may not offer the maximum potential for habitats and interest.

If possible, the incorporation of ‘shallows’ at some of the water edges may not only provide a range of interesting habitats but, appropriately designed and managed, may aid the removal of the suspended silt and provide an intermediate safety ‘platform’ before the deep water or deep silt.

In lagoons where de-silting is not required such shallows may incorporate a range of vegetation including reed species which may enhance the deposition of silt, offer valuable habitat and improve the visual impact of the operational silt lagoon. These shallows and reed beds could provide ecological value during the operational phases as well as on de-commissioning.

4.6 **Access management**

Safety can be, in part, achieved by discouraging access to the silt lagoon area. However, proper and extensive access, with appropriate edge protection wherever necessary, to all corners of the lagoon network, may provide greater safety coupled with easier management and operation of the silt settling process. It also allows for the installation, monitoring and management of ecologically important habitats.
5. POSSIBLE RESTORATION TECHNIQUES

5.1 General

Techniques, some of which are un-tried or conceptual, rather than proven, are outlined below. Two of the techniques were explored in a small trial at Shellingford Quarry, with the assistance of Multi Ag (Earthline) Limited.

5.2 Curtains

This is a technique which performs a similar function to projecting spurs and dividing bunds described in Chapter 4. It takes up less site footprint and materials and overcomes the problems and risks associated with the installation of spurs after a lagoon has commenced operation. Water bodies may be divided up using “curtains” which are held in position by guys and/or anchored floats and booms. In this way, the flow path is lengthened with potential for separation of heavily silt laden water from the cleaner areas and ecological opportunities increased during the operational phase.

5.3 Floating islands

Where it is not possible to create peninsulas and cut-off islands it is possible to provide floating man-made islands. The value of floating wetlands and islands has been described in a report on water-based quarry restoration¹. Floating islands have the advantage that they do not require a pyramid of material underwater even if a mechanism for placing an island in an active lagoon was feasible. In addition the volume of water for the silt-settlement is not reduced.

As part of this study, a floating island has been installed at Shellingford Quarry in Oxfordshire; the installation process is described in Chapter 6.

It is hoped that the island will provide a valuable, safe habitat particularly for roosting, loafing and nesting wildfowl during the operational phase of the silt-settling process.

5.4 Coir matting

As part of the same on-site investigation at Shellingford, coir matting has been trialled on the margins of a partially dry area of silt; this is described in detail in Chapter 6.

It is intended that these coir mats, which also contain growing plants of selected species before installation, will speed up the drying process on the lagoon edges particularly through evapotranspiration. The roots from these plants are intended to anchor themselves into the drying silt and aid de-watering.

¹ Water-based quarry restoration: opportunities for sustainable rural regeneration and nature conservation, Hammond et al 2008
These coir matting fringes could offer a valuable technique for providing some ecological diversity during the operational phase while establishing a valuable habitat in the long term (after operations). It is ideally suited to settings where some variation in water level occurs during daily operations – such variations arise due to fluctuations or delays in processing, but also from storm rainfall.

Safety needs to be considered in the evaluation of the use of the mats; they may give the appearance of a secure stable surface when, in fact, this is not the case.

5.5 Blowers and hydroseeding

This is a method that is suitable when access ‘onto’ the drying silt is restricted even for the placement of coir matting. It can provide early and diverse habitat creation.

Hydroseeding techniques are well-established in other situations such as motorway embankments and quarry faces (see Figure 5.1). The same technique could be used to encourage plant growth on the drying areas of silt lagoons. Access to the edge of these areas for machinery has already been highlighted and is critical. Any vegetation established through the hydroseeding process should speed up the drying process.

As with the coir matting, the issue of perceived safety from vegetation growing on soft dangerous silt needs careful consideration.

5.6 Booms and sausages

There are other ways to deliver seeds and growing medium out onto the drying silt. Techniques exist to pump materials into biodegradable ‘sausages’ from the drying lagoon edge. The sausages are sealed off and allowed to degrade on the silt surface establishing vegetation. The number, length and diversity of the sausages can be varied depending on the desired speed of establishment. Long-reach backhoes can assist with placement and anchoring of the sausages thereby reducing safety risks.

5.7 Reed beds

Reed beds have been mentioned with regard to the establishment of shallows. However, reed beds are now extensively used in sustainable urban drainage, sewage treatment and water filtration schemes.

There appears to be no reason why extensive reed beds should not speed up silt settlement, particularly in the lagoons furthest from the initial discharge point. The tolerance level of reed beds to inundation by silt has not been studied adequately but it should be possible to establish a network of lagoons which maximises silt deposition without killing the reeds.

The biodiversity advantage of having extensive reed beds during and after the operational stages is very high. A Biodiversity Action Plan target includes for the creation of 1200ha of new Phragmites reed bed by 2010; silt lagoons provide an
excellent opportunity to achieve this provided reed establishment techniques can be safely employed.

There is a similar target of 3,375ha of wet woodland by 2015; silt lagoons may also provide opportunities to achieve part of this.

Figure 5.1 Hydroseeding on an inaccessible slope; similar techniques could be used on exposed lagoon sediments
6. TRIALS OF COIR MATTING AND FLOATING ISLANDS

6.1 General

This report has identified 4 geometric variations of lagoons and 6 restoration techniques which may be applied to improve silt lagoon ecology and/or speed up the achievement of biodiversity objectives.

With some small additional funding, it has been possible to extend this research and install trials of two of the techniques at an operational site in Oxfordshire. These will be monitored from March 2010 – March 2011 and this report will be updated.

The trial is located in a closed lagoon (floating island) and an active lagoon (coir matting) at Shellingford Quarry, near Faringdon in Oxfordshire. The quarry is operated by Multi Agg (Earthline) Limited. Full details of the establishment and installation are contained in Appendix 1.

6.2 Coir matting

Coir, in the form of matting, has been used extensively in restoration and reclamation projects. Examples include:

1. **River Sow Flood Alleviation scheme**
   As part of a flood alleviation scheme willow plants were used to create a 1m high living retaining wall. Under the same scheme well established, pre-vegetated coir pallets were used to form a 300m long marginal corridor to provide a link between two existing water vole habitats.

2. **Cricketers Pond, Hertfordshire**
   Coir rolls and pallets were used to filter pollutants entering a village pond. Coir rolls were used to slow down the flow of run-off entering the pond allowing it to seep into the soil instead. Pre-planted coir pallets provided a margin to the pond and the plants aid in filtering out pollutants as well as improving the ecology of the pond.

Coir matting offers the following proven features since it:

- is lightweight;
- is biodegradable;
- is linkable;
- holds plants/seedlings in place;
- may be palletised;
- retains fertilisers and nutrients;
- is relatively inexpensive;
- is available from a number of sources;
- may be sustainably sourced;
- provides immediate protection to soil surface;
- drapes easily to irregular profiles;
is speedy to install.

In addition, coir matting in the context of silt lagoons may:

- speed up the drying out of peripheral areas;
- extend restoration to areas which could otherwise be dangerous;
- speed up natural soil-forming processes;
- speed up evapotranspiration.

### 6.3 Floating islands

Artificial islands (particularly floating islands) have also been used extensively in other situations including preparations for the London Olympics in 2012. Examples include:

1. **Tottenham, Hale**
   Improvement of fish habitat and introduction of attractive breaks in sight lines. Floating islands were moored along the Lee Valley and provided an attractive environment for birds, amphibians and insects. Fish protection grilles were attached beneath the island to provide a safe environment for fish among the roots.

2. **Otter Enclosure, Montana Zoo**
   Floating island provided vegetation to otherwise concrete enclosure also to be aesthetically pleasing, enhance the water quality and provide habitat for otters. They were shown to be durable and to withstand sharp claws and teeth.

Floating islands offer the following proven advantages since they:

- are mobile/manageable;
- do not require a large underwater pyramid of supporting material as in a natural island;
- can have immediate effects;
- may perform a variety of biodiverse functions (feeding, loafing, nesting etc);
- provide security and separation;
- accommodate some fluctuation in water level;
- may reduce wave action and turbulence;
- are readily available from various sources.

Specifically with reference to silt lagoons, they may:

- send down root systems which speed up the settling out of suspended material;
- speed up the dewatering process through evapotranspiration;
- provide a central source of seed material which naturally assists the re-vegetation process.
7. CONCLUSIONS AND RECOMMENDATIONS

Lagoons are a very important low cost, low energy method of separating and segregating fine discards arising from the processing of aggregates. Although some alternative techniques are available (Chapter 3.3) they are usually expensive and require significant input of energy, often in locations where there is little waste heat available.

However lagoons present problems for restoration, especially if restoration is not seriously considered and covered in the initial engineering design required by the Quarries Regulations.

The basic configuration and requirements of lagoons have been simply outlined and a number of methods of enhancing restoration and biodiversity considered for those lagoons that cannot be removed or safely capped. These methods include four basic geometric layout methods (variations in the number of lagoons, the provision of projecting spurs, varying lagoon shape and providing shallows). Six post-construction techniques have also been proposed (curtains, floating islands, coir matting, blowers and hydroseeding, booms and sausages and reed beds).

Pilot trials have been held of a floating island and coir matting on closed and active lagoons respectively. Initial indications are promising; further reporting is proposed within the next 12 months.

Given that lagoon restoration is a significant issue with many lagoons due to close on currently active quarries and many closed lagoons without good final restoration it is considered that further work is required. This work could include the following small scale investigations:

- Trials of inflatable booms and sausages.
- Trials of the use of curtains to increase flow path length.
- Trials of risk assessed reed planting and the use of comparative hydroseeding techniques.

It is considered that larger scale trials, to assess the potential for comprehensive lagoon bank pre and post-planting and larger floating islands, should be undertaken. It would also be useful to assess and set out the approaches than can be used to incorporate ecological design into the statutory design of a forthcoming proposed lagoon. There are currently no guidelines to cover this gap in restoration planning.

If there is one overriding conclusion, it is that geotechnical engineers and landscape ecologists need to be jointly involved in the design of lagoons that seek to meet biodiversity objectives. Geotechnical engineers are not usually acquainted with landscape ecology and landscape architects and ecologists are not qualified by law to design lagoons. Together improvements can be more readily achievable and extend beyond the “add-on” items listed in Chapter 5.
APPENDIX 1

A description of the procurement, design, delivery, installation and monitoring of floating island and coir matting trials at Shellingford Quarry, Oxfordshire

1. Introduction

Coir pallets and floating islands (as discussed in Chapter 6 of the main report) are currently being used as an effective method of introducing marginal habitats and vegetation to lakes, rivers and canals. A trial of their use in silt lagoons has begun at Shellingford Quarry – see Figures A1 and A2.

Shellingford quarry is situated near Faringdon in South Oxfordshire (NG SW 469 279) it is an active sand and gravel quarry that also extracts high quality limestone. The aggregates produced comprise Quaternary limestone gravels and crushed rock from the Jurassic Highworth Limestone. The quarry covers approximately 29 hectares, lies south of the A417 with agricultural fields to the east and the west and a business park to the south east. The nearest main settlement is the village of Stanford in the Vale approximately 1.5km to the east.

The quarry has been working since the 1970s and is now managed by Earthline Ltd, the current owners of Multi Agg Ltd who provided assistance and support in kind for this study.

Figure 1.1 Site Location Plan (NTS)
2. Procurement

After conducting desk top research of water management and bioengineering solutions, and discussions with specialist companies, it was decided that trials of coir pallets and floating islands could be undertaken at the silt lagoons. The materials used were readily available in the UK and available as pre-vegetated components. As noted above, the materials were selected as they were straightforward to install and relatively inexpensive.

Information and prices were obtained from a number of UK-based supplying companies. SALIX expressed considerable interest in the project, as well providing competitive rates. They gave a presentation to the project team and provided further advice on the coir pallets and floating islands, in particular the sizes available, how much components weighed, the vegetation types and method and ease of installation. A site meeting was arranged with representatives from SALIX, and the Quarry Management, resulting in agreement being reached on the location and design of the trials, and on access and health and safety arrangements. SALIX then supplied a method statement and risk assessment for the work, and an order was placed for the required quantities and sizes of appropriate products. SALIX also provided a member of their staff to assist with the installation.

3. Design

The design was primarily influenced by location and accessibility of the trial areas and the need to manhandle the components for the work near the lagoon. The locations are indicated in Figure A2)

Floating Islands

The floating island is intended to act as a floating refuge for birds and other fauna and can provide instant cover if it is constructed using pre-vegetated coir pallets. Once vegetation has established, it is hoped that the floating island would provide a source from which vegetation can spread and colonise.

As the floating island would need to be constructed on land and then manoeuvred manually onto the lake, it was decided to construct a rectangular island comprising 10No. 2m x 1m sections. This would form a 4m x 5m rectangle (20m²). Depending on its location, the size of the island might limit erosive wave action on the side of the lagoon.

Components used included:

- 20No. 1m x 1m pre-vegetated coir pallets (mixed species);
- 4No. 5m x 1m unvegetated coir pallets (to act as growing medium for the vegetated pallets placed above);
10 No. 2m x 1m plastic island structures, linked together to create the supporting/floating structure for the coir pallets.

The island was to be located on a closed lagoon with no inflow or outflow.

**Coir Pallets**

Used on their own, the coir pallets are intended for establishing marginal vegetation. It was therefore decided that they would be used on the edge of a working silt lagoon with the intention that once the vegetation has established it would spread and colonise the margins of the lagoon. Uptake of water by the plants would then dry out the lagoon more rapidly than would otherwise be the case, and the vegetation would aid in the filtration and promotion of settlement of suspended solids. The water level in the lagoon varies by up to 0.5m.

To minimise the risks of working around the perimeter of the lagoon, the coir pallets would be positioned in a linear arrangement along the margin of the lagoon.

Components used:

12 No. 2m x 1m pre-vegetated coir pallets, consisting of:

- 2 No. Carex and Caltha
- 2 No. Phragmites
- 2 No. Phalaris
- 2 No. Lythrum
- 2 No. Lycopus
- 2 No. Caltha

This gave a total trial area of 24m$^2$.

The fluctuating water levels in the lagoon would necessitate weighing down the mats or pallets with steel bars threaded through the coir fabric. This aimed to maintain their position on the margins of the lagoon.
4. **Preparation**

The majority of preparation was taken up organising supply, logistics and risk assessments. This consisted of:

1. On-site meetings and communications with the quarry owner, environmental officer and operations manager regarding the trials and their importance.

2. Meetings, communication and site visits with the SALIX team to discuss the trials, their product range, and the methods of installation.

3. Ordering of equipment and products.

4. Receiving the risk assessment and method statement from SALIX, and confirming PPE requirements for working at the quarry.

5. Arranging dates of delivery and installation.
Good communication between all the parties involved and careful preparation in the run-up to the trials resulted in the installation running smoothly.

5. **Delivery**

SALIX organised the delivery (by curtain-sided lorry) of the necessary components for the day before installation. This was arranged with the operations manager. The components were unloaded by forklift truck and stored overnight in a location that did not disrupt the day-to-day operations of the quarry.

On the day of installation the components were moved from the storage location closer to the trial locations by wheeled loading shovel, the pallets having been placed in the bucket of the loading shovel by forklift. See Figure A5. A bulldozer was used to create a temporary access road to allow the loading shovel to get as close as possible to the edge of the lagoons.

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**Figure A3** Equipment arriving in a curtain-sided lorry

**Figure A4** Equipment stored over night

**Figure A5** Fork Lift Truck moving pre-vegetated mats

**Figure A6** Equipment placed into loading shovel.
The components were then manually carried or dragged the last few metres to the edge of the lagoons.

6. **Installation**

**Floating Islands**

A suitable location close to the edge of the closed lagoon was chosen for assembling the floating island. The equipment, in addition to that listed in Section A3 above, included:

- 20No. softwood posts;
- 2No. rolls of cord (100 lin m/roll);
- Pack of black plastic ties (approx. 45cm in length).
The floating island structure was assembled first. The floating raft base units were assembled by clipping the plastic units together to form a 4m x 5m rectangular block (see Figures A11 and A12).

1m x 5m unplanted coir pallets were placed on top of the structure, followed by 1m x 1m pre-planted coir pallets the whole structure (coir pallets and raft units) were secured together using black plastic ties. Once ties had been tightened the tails were removed.

Figure A11 Floating raft base units clipped together

Figure A12 Assembling the floating raft base units

Figure A13 & A14 Unplanted coir pallets placed on top of plastic floating island raft
Figure A15 & A16: Pre-planted coir pallets placed on top of unplanted coir pallets.

Figure A17: Pre-vegetated Pallet

Figures A18 & A19: Using zip ties to secure the components together
Heavy duty cord (doubled up for strength) was attached to the floating island in 6 places. The fully-constructed island was then manually manoeuvred closer to the lagoon edge and then into the water, this operation requiring 5 people (including one person managing the cords). It should be noted that the size, and in particular weight, of this size of raft was at the upper limits for manually moving into the lagoon, especially manoeuvring the raft over the uneven surface of the bank. The floating island was then pushed out onto the water, by lifting and sliding opposite sides of the raft in turn.

Once the floating island was in the water it was easier to move (as long as water depth was sufficient). The island was pulled along the lagoon from the bank and positioned in place across one corner of the lagoon. The position for the floating island was determined by:

1. Length of fixing cord.
2. Wind direction.
3. The need to position the island away from the northern side of the lagoon for quarry safety considerations.
The cords were then attached to timber stakes (approx. 1m x 50mm) driven into firm ground in the bank. The whole activity took approximately 3 hours (see Figures A21 to A24).

**Figure A21** Rope attached to floating island

**Figure A22** walking in the floating island

**Figure A23** Pulling the floating island along lagoon

**Figure A24** Floating island positioned in lagoon corner

**Coir Pallets**

A suitable location close to the edge of the lagoon was chosen and equipment for the coir pallets was manually moved to this location. The equipment included:

- 24 No. Steel bars (1m long, 50mm wide and 5mm thick)
- 24 sq m mixed and single species, pre-vegetated coir pallets (1m x 2m each)

The pre-vegetated coir pallets were flipped upside down and the steel bars were woven through the matting to give the pallets sufficient weight to accommodate subsequent movements arising from changes in water level and wave action. The pallets were then
turned the right way up, carried to the water’s edge and positioned half in and half out of the water (with the exception of Phragmites, which was largely in water).

The location of the pallets was determined by checking the stability of the substrate and by the gradient of the bank at the edge of the lagoon.

The linear design of the pallets was determined for ease of installation and monitoring. The mats differed in weight (the phragmites pallet was much heavier than the others and needed two people to carry it comfortably). The whole activity took around an hour to complete.
7. Monitoring

Monitoring will be undertaken in August 2010 and in February 2011.

8. Conclusions and principal findings

Health & Safety

A Method Statement and Risk Assessment must be in place before work commences.

The following equipment should be available:

- Throw Line
- Life Jacket
- Full PPE

Helpful/essential machines & tools:

- Fork Lift Truck
Loading Shovel

Bulldozer

360° Backhoe (crawler mounted)

Sledge Hammer

Lifting Bars

Clippers/pen knife

The main problems encountered and findings noted were:

- Machinery could only take equipment to a certain point and from there it had to be manually transported. The pallets did differ in weight. In particular the Phragmites pallet was heavier than the others and needed 2 people to carry it comfortably.

- The floating Island was verging on being too heavy to handle; the inability to access the edge of the lagoon with mobile plant was a significant problem.

- Installation and deployment of the floating Island into the lagoon would have been easier from a flatter and shallower more stable lagoon margin.

- When pulling the floating island to its final position along the edge of the lagoon it would have been easier and faster if some of the existing vegetation along the bank had been cut/removed.

- The final positioning of the floating island would have been simpler in a more acute corner of the lagoon where the water was deeper. Shallow corners require longer lines. Alternative anchoring systems need to be investigated.

Coir Pallets

Machinery & tools used included:

Fork Lift Truck

Loading Shovel

Bulldozer

Sledge Hammer

In addition three persons were involved in the installation in addition to the quarrying company. The main problems encountered on the day were:

- Limited access for machinery/mobile plant.
Some pallets required two persons to manoeuvre.

The pallets did not indicate which side the vegetation was on.

Installation was dirty and protective clothing was essential in addition to PPE.

More attention would be required to testing the stability of in situ silt if a more comprehensive planting scheme was to be attempted.

**General Conclusion**

Initial indications are that the installations are in place and accommodating wave movements and water level changes. The island is occasionally occupied by ducks. Both the island and the matting are showing signs of vegetation growth.

Future trials will require longer to check on signs of growth and use by wildlife. It should be recognised that the lead in time for installation of these techniques can be significant especially if access is limited and weather conditions are poor as was the situation at the quarry. Equally it should be recognised that most lagoons are not designed for easy access and the measures described in the Appendix and the main report are best used when incorporated in initial lagoon design.