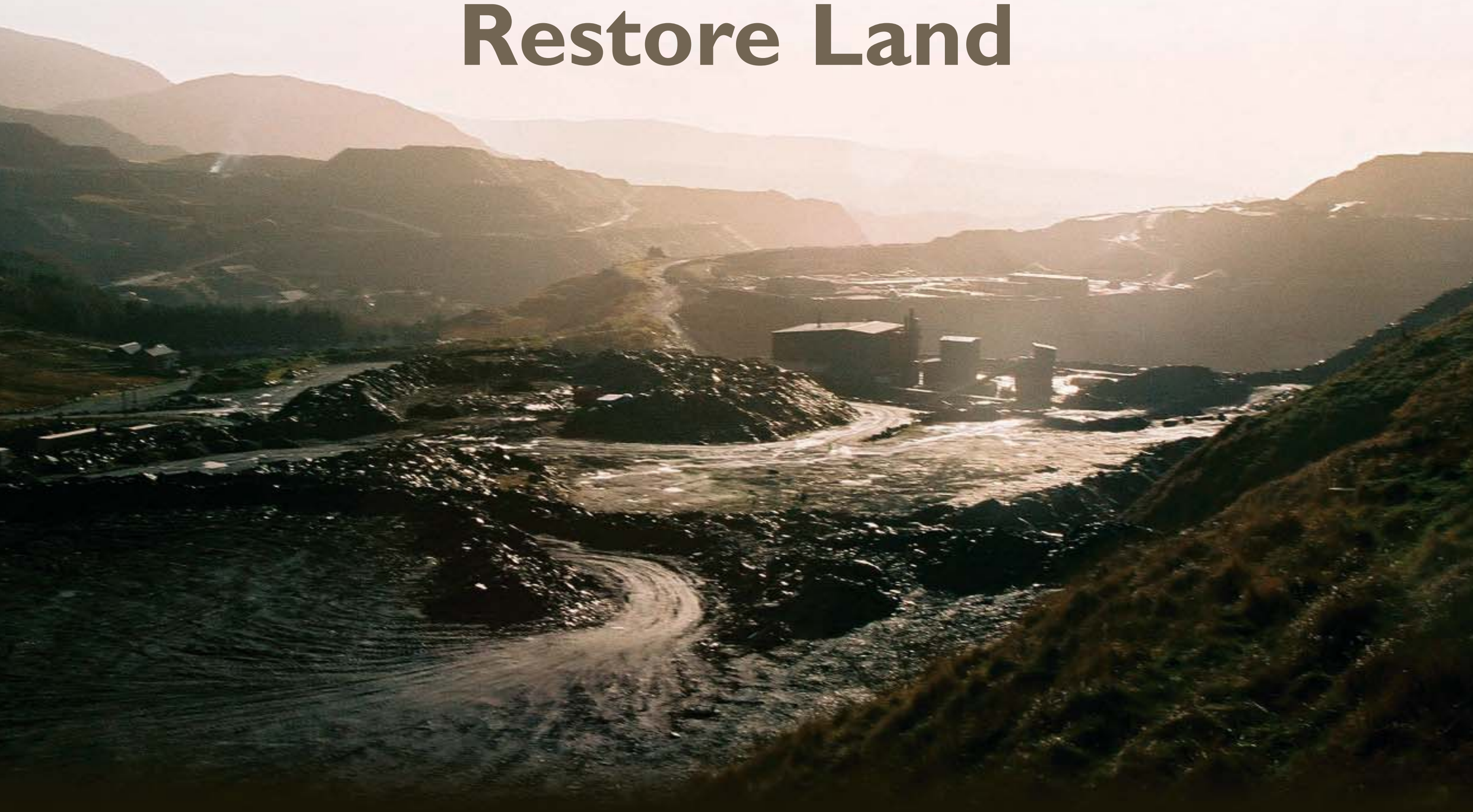
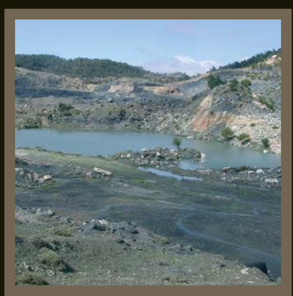
Using Organic Wastes and Composts to Remediate and Restore Land



Best Practice Manual

Using Organic Wastes and Composts to Remediate and Restore Land

Best Practice Manual

Mark Nason

Julie Williamson

Susan Tandy

Matina Christou

Davey Jones

John Healey

SLATE ALFRED McALPINE

NAGREF SOIL SCIENCE INSTITUTE OF ATHENS

Life

PRIFYSGOL BANGOR UNIVERSITY 1884

TITAN

UPM

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

Citation:
Nason, M., Williamson, J., Tandy, S., Christou, M., Jones, D. and Healey, J. (2007). Using organic wastes and composts to remediate and restore land: best practice manual. School of the Environment and Natural Resources, Bangor University.

ISBN: 978-1-84220-101-5

Further copies:
School of the Environment and Natural Resources,
Bangor University,
Bangor,
Gwynedd,
LL57 2UW. WALES.

+44 (0)1248 382281
senr@bangor.ac.uk

Free download:
www.bangor.ac.uk/ies/TWIRLS/TWIRLS_home.htm

Acknowledgments:
This manual is the final output of a three-year research and demonstration project (Treating Waste for Restoring Land Sustainability: TWIRLS) based at the School of the Environment and Natural Resources at Bangor University and funded by the European Commission Directorate General for the Environment under the LIFE-Environment III Programme (LIFE04 ENV/GB/000820). The project director was Prof. John Farrar, Bangor University. The authors acknowledge support from the Commission as well as our partners: Alfred McAlpine Slate Plc, UPM-Kymmene (UK) Ltd, NAGREF - Soil Science Institute of Athens (SSIA), Welsh Assembly Government; and our collaborators Titan Cement Co SA, Association of Communities and Municipalities of the Attica Region (ACMAR) and Envar.

Environment Agency Wales; Conwy, Gwynedd and Flintshire Councils; United Utilities and Dŵr Cymru; Countryside Council for Wales; Roy Thomas Planthire Flintshire; Terry Rendell and Tony Heaney of The Ecology Company; Emorsgate Wild Seeds; David Wynne of Organic Resource Management; David Jenkins of Amlwch Industrial Heritage Trust; Dave Royle of Envar; Mike Walker of RSPB Lake Vyrnwy; Simon Dennis of Smith Grant LLP provided materials and helped during field trials.

We gratefully acknowledge technical contributions from Rhidian Jones, Jon Holmberg, Karoliina Rikka, Llinos Hughes, Julian Bridges, Matthew Ling, Mark Farrell, Saskia Pagella, Nabila Devros, Marcella Brannagan, Nina Menichino, Jenni Younger and James Walmsley of Bangor University; Mike Prosser and Hilary Wallace of Ecological Surveys; Elizabeth Avramides and Antonis Papadopoulos (NAGREF-SSIA).

Additional contributors to this manual:
Jeremy Jacobs (The Composting Association), David Evans (The Land Restoration Trust), Claudia Watts (Buglife), Paul Mathers and David Tompkins (WRAP); George Arvanitis (ACMAR); Symeonidis Kostas and Menidiatis Christos (Titan); Elizabeth Avramides and Antonis Papadopoulos (NAGREF-SSIA).

Foreword

Over a period of several millennia man has been a powerful force, influencing the development of soils and driving the factors which cause soil degradation. In the United Kingdom Neolithic man first burned vegetation to create areas of grazing and subsequently Bronze Age and Iron Age farmers converted forests and grasslands for agricultural production. Man's interference with soils intensified during the industrial revolution involving the replacement of natural soils with spoil from mining or industrial wastes, some of which were toxic to plants or animals. Today soil degradation is widespread in post-industrial conurbations on previously developed brownfield land and also in those rural areas where wastes from mining extraction dominate the landscape.

In response to concerns about the degradation of soils throughout the EU, in September 2006 the member states adopted the Thematic Strategy of Soil Protection. Crucially for brownfield land this strategy includes measures to preserve soil functions, arrest decline in organic matter and restore degraded and contaminated soils. It is in this context that the Treating Waste for Restoring Land Sustainability (TWIRLS) EU Life-Environment Partnership Project, undertaken and inspired by Bangor University, is so timely and relevant to brownfield restoration activities. In order to restore key soil functions to degraded brownfield land an input of organic matter is usually essential to provide the necessary carbon sources for fungal and microbial communities and the mineral elements necessary to sustain all forms of soil biota and higher plants growing in the soil. Good quality composted bulk organic materials such as source segregated green waste, sewage biosolids and paper mill waste are the best sources of organic matter for composting which are readily available in large quantities.

This Manual of Best Practice provides a comprehensive framework and detailed description of the ways in which composts created from bulk organic materials may be used alone or mixed with mineral wastes for the restoration of a wide range of derelict land sites to create green landscapes which encompass newly created habitats of conservation value. The manual carefully explains every step in the process, starting with the legal and regulatory framework, via the various methods of producing compost, establishing a compost site and using the product for creation of habitats for conservation and biodiversity and the remediation of contaminated sites. Not only are restoration practices at the TWIRLS project sites described and assessed but the manual also showcases several case studies of best practice in the use of compost for the creation of habitats and biodiversity on brownfield sites.

This Best Practice Manual will be a most valuable reference document for a wide range of planners, environmental professionals and landscape architects and also will provide excellent guidance for brownfield land developers. The TWIRLS project team are to be congratulated on a valuable manual which combines good quality science with the practical knowledge required for the restoration of green landscapes on derelict brownfield land.

Dr Philip Putwain
Honorary Senior Research Fellow,
School of Biological Sciences,
University of Liverpool
Principal: Ecological Restoration Consultants

Contents

Section 3...25

Using organic wastes and composts to restore land

Executive Summary

Purpose and scope

The purpose of the Best Practice Manual (Using Organic Wastes and Composts to Remediate and Restore Land) is to provide practical guidance on reusing organic wastes, particularly through the process of composting, to produce soil-forming materials suitable for the restoration of degraded land. 'Restoration' is used here in its broadest sense, i.e. to repair degraded land to some sustained functional use, whether it is for conservation, amenity or productivity, but not necessarily reverting to its former (undegraded) use.

The manual draws on the experience of demonstration sites implemented under the European Commission LIFE-Environment funded project TWIRLS (Treating Wastes for Restoring Land Sustainability) as well as other key organisations leading the way in using organic wastes and compost to restore brownfield land. It is written for land managers, quarry managers, government and local agencies, non-government organisations, national park authorities, environmental consultants and higher education researchers.

The three main sections of the manual cover:

- the legal and regulatory frameworks governing use of organic wastes and products with particular reference to the UK's Waste Management Licensing Regulations (1994, as amended; WMLR), planning permission, the Composting Industry Code of Practice, and the Quality Protocol;
- procuring, making and using compost for creating habitats of conservation value, including definitions, advantages and challenges (including those associated with growing bioenergy crops on remediated land), and managing fertility; and
- using organic products for remediating contaminated land.

Key findings and recommendations

1 Using composts and untreated wastes for large-scale land restoration and bioremediation has the potential to mitigate low and declining levels of Soil Organic Matter (SOM), offset anthropogenic emissions of CO_2 and increase biodiversity.

2 Composting and land-spreading of wastes is controlled under the Waste Management Licensing Regulations (WMLR) and regulated within the UK by environmental agencies from whom formal permission (a written 'exemption' to WMLR) is almost always required to produce compost and spread it on land. 'Quality Protocol' compost is released from regulatory control for land-spreading but non-QP compost requires formal permission.

3 Contaminated soil may be co-composted with organic wastes, with formal permission, provided it is deemed non-hazardous according to Environment Agency definition under technical guidance WM2.

4 Legislation changes regularly, so always contact the local regulatory agency prior to undertaking composting and land-spreading of organic wastes and composts.

5 Composts and organic wastes supply essential plant nutrients (i.e. N and P) in organic forms, which will be released over a longer timescale than from mineral fertilisers. Since the production of mineral (particularly N) fertiliser is energy-expensive, organic wastes are a more sustainable option for providing the nutrients necessary to establish vegetation at bare sites. In addition, although still a risk to be managed, there is less potential for leaching of N and P from organic wastes leading to contamination of ground- or surface waters.

6 Tertiary-treated biosolids is a valuable resource and the TWIRLS project has shown it may be safely included as a compost feedstock material without increasing final human pathogen loading.

7 The fertility of composts and soil-forming materials constructed from organic wastes can be modified to more closely match the requirements of diverse target habitats. When mixed or applied together, high C, low nutrient wastes such as de-inking paper fibre reduce (through dilution and biological immobilisation) the availability of N and P from more fertile organic materials such as tertiary-treated sewage sludge.

8 The pH of soil-forming material can be adjusted by mixing with acidic materials, particularly sulphurous wastes or elemental sulphur (S^0). However, the availability of potentially toxic elements in composts or mixed organic wastes can be altered by adjusting pH and, importantly, the safe use of acidic wastes requires knowledge of the chemical composition (especially heavy metal content) of both the soil-forming materials and the acidic wastes. Preliminary trials, therefore, are recommended before adjusting pH of larger amounts of compost for creating acidic nutrient-poor soil-forming materials.

9 Composting as a biological treatment for remediation of contaminated land is gaining favour as a green technology.

10 Mixing contaminated soil with compost enhanced the biodegradation of polycyclic aromatic hydrocarbons (PAHs) once the mix was applied to land and vegetation was established.

11 Mixing metal contaminated soil with compost lead to a reduction in plant shoot uptake of copper, lead and arsenic.

12 Composting can reduce the concentration of endocrine disruptor compounds in feedstocks such as treated sewage.

13 The composting and land-spreading of organic wastes to remediate contaminated land appears to be a viable approach for PAHs and some metals. However, proof-of-concept trials should always be conducted before field-scale work commences.

14 Whilst reducing carbon (C) emissions from landfill, the process of composting organic wastes is not a C-neutral process. Atmospheric C 'fixed' by plants is released to the atmosphere when organic matter is composted. Industrial-scale composting incurs material and energy costs. We therefore recommend:

- Further research to calculate the net retention of waste-derived C in different waste management systems;

- Undoubtedly, composted waste materials represent an excellent resource for land restoration (and for use in agriculture). However, for the purposes of providing organic matter and nutrients either for plant establishment or for bioremediation, where levels of potentially toxic elements (PTEs) are not of concern, practitioners should consider using wastes that have not been treated, since *any* treatment system incurs additional C costs;

- In-vessel systems can incur greater C costs than open-air windrows. If compost is deemed to be the most effective soil-forming material for restoration, in-vessel systems should only be used where i) regulators stipulate their use, i.e. for composting animal by-products, or ii) it can be demonstrated that real environmental and human health benefits (i.e. reduced exposure to bioaerosols, treatment of exhaust gases) are offered by in-vessel systems.

Section 1

Introduction

Section 1

Introduction

1.1 Who should read this manual

As the 21st century produces more and more waste and the pressures on land usage for development, housing and recreation increase, the challenges we face in terms of recycling organic waste and products and their current or potential use in land restoration are major issues that concern society as a whole.

Arising from a unique opportunity which brings together industry, government agencies and academic researchers working as a team, this manual is based upon their cumulative experience, assimilating cutting-edge technologies used under field-scale conditions and within the relevant regulatory frameworks.

The Best Practice Manual 'Using Organic Wastes and Composts to Remediate and Restore Land' is designed to promote and guide generic best practice in the reuse of organic wastes and products for restoring or remediating degraded land. It will be of interest to any members of the public concerned with land remediation, and particularly land managers, quarry managers, government and local agencies, non-government organisations, national park authorities, environmental consultants and higher education researchers.

1.2 Treating Waste for Restoring Land Sustainability (The TWIRLS project)

The manual is an output from the TWIRLS (Treating Waste for Restoring Land Sustainability) project - a major project designed to demonstrate the effective reuse of organic wastes to restore degraded land. The key drivers for the work are a reduction in the amount of biodegradable material going to landfill or incineration and returning derelict and/or contaminated sites back to appropriate land-use.

The TWIRLS project is based at Bangor University and funded by the European Commission Directorate General for the Environment under the LIFE-Environment III Programme (LIFE04 ENV/GB/000820) and delivered with support from Alfred McAlpine Slate Ltd, UPM-Kymmene (UK) Ltd, NAGREF - Soil Science Institute of Athens, Welsh Assembly Government and Titan Cement Co. S.A. The TWIRLS team works closely with local authorities, utilities companies, consultants and regulatory bodies including Flintshire, Conwy and Gwynedd Councils, the Environment Agency Wales, the Countryside Council for Wales, Envar, United Utilities, Dŵr Cymru and Association of Communities and Municipalities of the Attica Region in Greece.

1.2.1 TWIRLS demonstration sites

The TWIRLS project demonstrated novel techniques for co-composting a range of organic and mineral wastes, creating growing media tailored to the specific requirements of target plant species and habitats. In addition, TWIRLS assessed the effectiveness of the composting process for remediating soil contaminated with a range of organic pollutants. Composts were created at two sites in Wales: a brownfield site - Area A4 of the former Shotton Steelworks in Flintshire; and a slate quarry site in Blaenau Ffestiniog, Gwynedd. At each site and over a three-years duration, approximately 2000m^3 compost was produced under exemption to the Waste Management Licensing Regulations (WMLR) using the EcoPOD® portable, in-vessel composting system. The Shotton site was restored to a biodiverse mesotrophic grassland and the Blaenau Ffestiniog site was restored to upland acidic grassland. In addition, TWIRLS monitored the effectiveness of using de-inking paper fibre with treated sewage sludge to restore colliery shale to pasture in a project carried out by Envar at Woolley Colliery in West Yorkshire.

TWIRLS' Greece-based partners, NAGREF, the Soil Science Institute of Athens, implemented a programme of restoration at a black-schist quarry close to the Parnitha National Park, Kamariza, near Athens. At Europe's largest in-vessel composting plant near Athens, a composted mix of biodegradable municipal solid waste, green waste and treated sewage cake was produced and then used to revegetate the quarry with native tree species.

Section 2

Legal and regulatory framework and quality assurance

Section 2

Legal and regulatory framework and quality assurance

2.1 Introduction and definition of waste

The Waste Framework Directive (75/442/EEC as amended) defines waste as any "substance or object in the categories set out in Annex I which the holder discards or intends or is required to discard". Annex I lists 16 categories of wastes in total; category 'Q16' is "any materials, substances or products which are not contained in the abovementioned categories". All substances, then, either are or have the potential to become waste. This includes organic and mineral materials, *in-* and *ex- situ* contaminated soils and, currently, a range of useful materials such as composts and decontaminated soils from derelict industrial sites. While such a broad definition presents a major barrier to managing wastes in a sustainable manner, an even greater barrier is the current poor definition of the point at which waste ceases to be waste. At present, and with special relevance to this guide, both organic materials treated by composting and contaminated soils remediated *in-* or *ex- situ* remain waste. This issue is being addressed with the revision of the Waste Framework Directive (expected 2007) and the planned publication by the Environment Agency (EA) and the Waste Resources Action Programme (WRAP) of ten quality protocols for different waste-streams (the compost Quality Protocol was the first to be published in April 2007, see **Box 1**). Although any substantial change to the directive's definition of waste is unlikely, sustainable management of wastes and land remediation could benefit greatly if the EU instead were to define resource-rich 'non-waste'.[1]

In the UK, composting and waste disposal activities are controlled under the Waste Management Licensing Regulations (1994, as amended; WMLR) and regulated by the EA in England and Wales, the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment and Heritage Service (EHS). Legislation and regulatory requirements concerning land remediation and the composting and land-spreading of wastes and finished composts can be confusing, while interpretation of EU directives differs significantly between member states. This has legal, financial and practical implications for the reuse of wastes for restoring land. Before embarking on a program of restoration, which must be done within the WMLR framework and with proper consent from the relevant Local Planning Authority, practitioners should consider the pros and cons of using uncomposted wastes, producing compost on site or purchasing quality assured compost from a certified producer.

Here we explain the routes available and offer practical advice based on our experience of obtaining exemptions for composting and land-spreading a variety of wastes at two separate sites in the UK, together with planning permission (**Box 2**). Waste permitting and regulation is complex and the most appropriate route will depend upon the scale of the programme of land restoration, presence or absence of contamination, suitability and availability of different organic wastes and composts in relation to the target outcome of the restoration (see Section 3) and regulatory approval.

Guidance in this Section relates primarily to practitioners in the UK, although some comparisons with other EU countries are made. The website of the European Compost Network (ECN; www.compostnetwork.info) summarises the regulatory frameworks and quality assurance standards operated by different member states of the EU. Quality assurance standards of different EU countries, North America and Australasia are compared in Hogg *et al* (2002)[2] .

---

[1] Pongrácz and Pohjola (2003) Re-defining waste, the concept of ownership and the role of waste management. *Resources, Conservation and Recycling* **40**: 141-153.

[2] Hogg *et al* (2002) *Comparison of compost standards within the EU, North America and Australasia*. Prepared for the Waste and Resources Action Programme (WRAP), Oxon, UK. Online at www.wrap.org.uk. Accessed August 2007.

Box 1

Development of a Quality Protocol for compost produced from source-segregated organic waste materials.

By Jeremy Jacobs, Development Manager of The Composting Association (UK)

The waste protocols project has been developed in recent months by the Business Resource Efficiency and Waste (BREW) programme, the Waste and Resources Action Programme (WRAP) and the Environment Agency (EA) in consultation with The Composting Association (TCA), the Environmental Services Association and DEFRA. The protocols are only applicable within England and Wales currently. There has been in the past some uncertainty as to what constitutes a waste under the EU Waste Framework Directive and at what point full recovery of a waste occurs. The Quality Protocol (QP) for compost sets out the criteria for the production of quality compost from source-segregated biowaste. It also ensures that the recovered product (in this case compost) may be used without risk to the environment or harm to human health.

One of the additional benefits of removing the waste designation from compost is that regulatory control that previously applied can be lifted after the product leaves the processing facility. This will ease some of the burden on regulators and processors alike, both financial and human. Currently, it is necessary to obtain an exemption from the Environment Agency to spread compost to land. The cost to carry this out is not insignificant (approx £550/50ha). Once a producer has complied with the requirements of PAS 100 and the QP and no longer is producing a waste, then this cost is no longer payable. There is, however, the cost of obtaining PAS 100 and the QP. This is an annual cost which is payable to the certification body. On a direct cost comparison but ignoring the less tangible but significant benefits of producing a product as opposed to a waste, it is necessary to have more than three exemptions for your site. Over this size threshold the QP route becomes a less expensive option to follow.

The bigger prize in my opinion is that compost markets will be more readily opened to a product than a waste. Customer confidence will be greater and opportunities to promote compost with more clarity will be greatly improved. There is no obligation for a producer to comply with this protocol, however composting sites that are already undergoing certification for PAS 100 2005 (Publicly Available Specification), which is the nationally recognised specification for the process of composting, the selection of input materials, the storage handling, labelling and traceability of compost products. Sites that are already in the process of obtaining PAS 100 certification are undertaking the necessary additional requirements to comply with the QP. Since its launch, there has been a significant increase in the number of producers signing up to the QP with in excess of 100 enquiries.

The importance of product differentiation in today's marketplace is fundamental to the successful promoting and marketing of quality compost. The Quality Protocol will go a long way to assisting in this goal.

Box 2

Obtaining permissions to compost and spread wastes at two very different restoration sites in North Wales.

In June 2005, the TWIRLS project began composting a range of biodegradable wastes (including green waste, tertiary treated sewage sludge, de-inking paper fibre) and waste soil in sealed ECOPOD® composting vessels. Compost was produced at two sites, in North Wales: Shotton, Flintshire and Blaenau Ffestiniog, Gwynedd. For both sites, Paragraph 12 exemptions to the Waste Management Licensing Regulations (WMLR) were obtained from the Environment Agency (EA), allowing TWIRLS to receive 1000m^3 of wastes for composting at each site. Subsequent amendments to the WMLR have disallowed paper fibre and sewage as feedstock materials for composting under exemption. To spread compost, Paragraph 9A exemptions were obtained. As part of 9A, landowners at both sites contacted their local planning authority officers to discuss whether consent was needed for composting and/or land-spreading. The restoration trial site at Shotton is at a contaminated former steel-works site in an urban setting, surrounded by roads and approximately 250m from a large paper mill. It is less than 1km from the Dee Estuary RAMSAR site, a wetland of special conservation value. Planning consent was required and the application reviewed by full committee. The composting site at Blaenau Ffestiniog is in a rural setting, within an area of slate quarry waste next to the A470 main trunk road with terraced housing close by, adjacent to Snowdonia National Park and several SSSIs. Here, planning applications were not required for either activity, involving the same wastes, processes and machines used at Shotton. Both activities were covered in provisions of conditions set-out in consent to quarry which provided for importing soil-forming materials for restoration.

The TWIRLS project experience of working with statutory bodies and the WMLR is that advice can differ between officers and between offices. The EA as waste regulators work within an environmental protection legislation framework, whilst local planning authorities work largely within a land-use planning framework: the frameworks are not seamless and this leads to complications for the officers as well as practitioners. There are grey areas, for example under what circumstances is planning permission required to spread composted wastes? These would benefit from clarification.

TWIRLS project EcoPOD® in-vessel composting site established at Shotton, Flintshire under a Paragraph 12 exemption to the WMLR.

Mature compost spread to land at Shotton under a Paragraph 9A exemption. Unless certified Quality Protocol or PAS 100, finished compost remains waste and is subject to regulatory controls.

2.2 Buying compost and quality assurance

Several EU countries have introduced quality assurance schemes to promote confidence in the safe reuse of waste materials and allow compost to be marketed as a quality product rather than as a waste. Allowable input materials for quality assured composts differ between EU States, for example the Austrian ordinance (*Kompostverordnung* FLG II Nr. 292/2001) includes compost produced from non-source-segregated waste streams, including sewage sludge and municipal solid waste (MSW). The Compost Ordinance recognises several different grades of compost. Lower grades are not suitable for use with crops but may be suitable for land restoration and are likely to be cheaper.

A different approach has been taken in the UK where first the Publicly Available Specification for composted materials (PAS 100: 2002 and PAS 100: 2005) and then the Quality Protocol (2007) have been introduced. BSI PAS 100 is published by the British Standards Institution (BSI) and was prepared by The Composting Association with support from WRAP. PAS 100 is a processing standard which itemises the allowable source-segregated feedstocks, monitoring, output testing requirements for composts and permitted levels of contaminants.

The Quality Protocol was developed by the Department of the Environment, Food and Rural Affairs (DEFRA), WRAP and the EA following consultation with The Composting Association, industry and regulatory stakeholders (**Box 1**). The compost quality protocol sets out criteria for the production of quality compost from allowable source-segregated waste materials. Most importantly, it defines the point at which compost ceases to be waste and is therefore released from regulatory control. In addition to the assured quality, the practical value to practitioners is that exemptions to the WMLR are not required to spread Quality Protocol compost to land.

2.3 Producing compost

Table 1 lists competent authorities for the issue of authorisations to produce compost in the UK and has been reproduced from The Composting Industry Code of Practice[3], available from The Composting Association (www.compost.org.uk). The Code of Practice is an excellent guide to establishing and running composting sites safely and without causing harm to the environment and should be consulted at the outset of any restoration programme where the intention is to produce compost. Here, a summary of regulatory requirements is given with special emphasis on the use of compost for land restoration and/or bioremediation.

Table 1 Competent authorities for the issue of authorisations. Reproduced from *The Composting Industry Code of Practice*, published by The Composting Association (TCA; www.compost.org.uk).[1]

AUTHORISATION	COMPETENT AUTHORITY
Planning Permission	Local Authority County Council or Unitary Authority Department of Environment Northern Ireland (DOENI)
Waste Management Licence or Registered Exemption Pollution Prevention and Control Permit (where applicable) Liquid Discharge consents	Environment Agency (EA) Scottish Environment Protection Agency (SEPA) Environment and Heritage Service Northern Ireland (EHSNI)[1] Foul Sewer: The Water Company Surface and Groundwater Discharges: EA, SEPA, Scottish Water, DoE NI
Animal By-Products	Approval: State Veterinary Service (England) Welsh Assembly Government (Wales) Scottish Executive (Scotland) Department of Agriculture and Rural Development for Northern Ireland (Northern Ireland) Enforcement:[2] Local Authority Trading Standards officers (usually) but may include the Environmental Health Departments or others depending on the location of the facility.
Health and Safety	Health and Safety Executive (England) Health and Safety Executive for Northern Ireland

[1] The EHSNI is an Agency within the Department of Environment Northern Ireland (DOENI)
[2] The organisation for the enforcement duty various in different locations

[1] The Composting Association (2005) *The Composting Industry Code of Practice*. Published by The Composting Association, Wellingborough, Northamptonshire, UK.
[3] Scottish Executive (2001) *Scottish Vacant and Derelict Land Survey 2001*. Commentary online at www.scotland.gov.uk/publications. Accessed August 2007.

2.3.1 Planning permission

Permission from the Local Planning Authority is required to establish a composting facility by any of the routes listed in 2.3.2, even under exemption to the WMLR. Local Planning Authorities will need to see a risk assessment for composting activities (that in any case must be produced to ensure public health and gain regulatory approval). In addition to odours and bioaerosols, which are the chief concerns of the EA, Local Planning Authorities may require a risk-assessment for noise, depending on proximity to dwellings.

2.3.2 Waste management licensing regulations

In addition to planning permission, authorisation to produce compost must be obtained from the EA, which can be done concurrently with the planning application but prior to approval the EA will need to see a copy of the planning permit (or details if planning permission is not required).

Compost can be produced at a site that possesses one of the following:

- a PPC permit issued under the Pollution Prevention and Control regulations (2000, as amended)
- a Waste Management Licence issued under the Environmental Protection Act (1990)
- an exemption from the need for a Waste Management Licence (under regulation 18 of the WMLR 1994, as amended).

If a registered site is available, using it will save time and money provided that the costs (both monetary and environmental) of hauling wastes and composts to and from the site are not excessive. Acquiring a full Waste Management Licence or PPC permit for a new composting site can be a lengthy and expensive process requiring investment in site infrastructure (concrete pads, drains etc.), the services of environmental consultants to prepare the application and appointment of a technically competent manager [in possession of or seeking to obtain a relevant WAMITAB (Waste Management Industry Training and Advisory Board) certificate]. This is best considered as part of an existing business plan, integrated waste management strategy or large scale programme of restoration or land remediation (where a licence will probably be needed in any case to cover the handling of 'waste' soil).

In very large restoration projects it may not be possible to source enough compost within a reasonable distance from the site for restoration, or to produce enough compost under a Paragraph 12 exemption to the WMLR. As an alternative to obtaining a Waste Management Licence necessary to produce sufficient volumes of compost, it might be worth considering the use of locally sourced and blended uncomposted wastes spread under separate exemptions to the WMLR (see **2.4** and **Table 2**).

A Paragraph 12 exemption to the WMLR allows compost to be produced at a site that does not possess a Waste Management Licence or PPC permit. Under the exemption, a selection of different wastes can be composted in open-windrows without an impermeable pavement or sealed drainage. The amount of waste (including finished compost) that can be kept on site at any time must not exceed 1000 m^3 and the types of wastes that can be composted are restricted. The decision to restrict acceptable wastes for composting under Paragraph 12 exemptions or to produce Quality Protocol compost has been debated vigorously within the industry. Allowable waste types may change with further amendments to the WMLR and in forthcoming updates to the Quality Protocol. It is worth remembering that the list of allowable waste types for composting under a Paragraph 12 exemption is *indicative*[4] and is not exhaustive.

The EA's guidance notes on registering exemptions to the WMLR can be found together with the application forms at www.environment-agency.gov.uk/subjects/waste. Paragraph 12 exemptions must be renewed annually and when preparing the application form it is worthwhile to note the following:

- There is a presumption against granting Paragraph 12 exemptions where the proposed site is within 250 m of a 'receptor'(housing, places of work, public rights of way, livestock etc). This is due to concern over bioaerosols.
- Production of bad smells and bioaerosols (see **Section 3**) are key concerns and you should demonstrate how you intend to minimise these in your risk assessment, for example by paying close attention to feedstock C:N ratio and compost moisture content, using in-vessel systems, considering the direction of the prevailing wind in relation to any receptors, turning windrows only when wind speed and direction are favourable and damping down surfaces.
- More expensive, small to medium-sized portable in-vessel systems increase the number of waste types

[4] Environment Agency. Guidance for registering an exempt activity: Storage and composting of biodegradable waste, Paragraph 12. Online at www.environment-agency.gov.uk/subjects/waste. Accessed August 2007.

that can be composted under a Paragraph 12 exemption. Due to the perceived human health and environmental benefits of in-vessel systems, it is sometimes easier to gain regulatory approval and planning consent for these than for windrow composting (**Box 2** and Burke 2003[5]).

Contact your local EA office and/or the EA's Permitting Support Centre (08708 506506) for further advice on specific locations and waste types before submitting exemption forms. Allow at least 35 days for an exemption to be registered and the EA may request additional information or a site visit.

2.3.3 Food waste and animal by-products

The EU Animal By-Products Directive (EC 1774/2002) controls the disposal of animal by-products as well as setting targets and procedures for safely diverting animal by-products from landfill. In the UK, the Animal By-Products Regulations 2005 (ABPR; Statutory Instrument 2347/2005) provide for the directive in England and Wales. Compost produced from animal by-products (including food and catering waste) must be produced in sealed vessels that have been approved and registered by the State Veterinary Service. Investment in such infrastructure is not always warranted given the 1000 m^3 limit on the amount of waste that can be composted under exemption to the WMLR.

Nevertheless, practitioners should not shy away from purchasing composts produced from animal by-products. Indeed, digestates from the anaerobic treatment of animal wastes, kitchen and catering waste and former foodstuffs (Category 3 'low-risk' Animal By-Products) are acceptable materials for Quality Protocol compost. Despite the fact that food waste is one of the largest single fractions of the waste stream, it is estimated that (in the UK) only about 2% of the available amount is collected separately for composting or anaerobic digestion[6]. This represents a missed opportunity and food waste will increasingly feature as an ingredient in composts produced by local authorities who need to compost animal by-products to meet landfill diversion targets. It is possible to produce compost from food waste (i.e. European Waste Catalogue code 20 02 08, biodegradable kitchen and canteen waste from separately collected fractions of municipal waste) under exemption to the WMLR.

2.4 Using organic wastes and composts to restore land

2.4.1 Planning permission and conditions

Planning permission is usually required to spread soil-forming materials at a site for restoration that does not already possess a Waste Management Licence, PPC permit or previous agreement to import soil forming materials. Where organic wastes are concerned planning permission will usually be considered by committee but this depends on the volume and nature of wastes and details of the site for restoration, such as proximity to housing and areas of conservation value or scientific interest (**Box 2**).

When applying for planning permission to produce compost at the site for restoration under exemption to the WMLR, make sure that permission to spread the compost is also obtained.

Agreements between the owners of a site for restoration and the local authority are made in the context of planning conditions imposed under the Town and Country Planning Act 1990 (as amended). Such agreements apply to commercial activities occurring after 1990 and are therefore not always relevant to the restoration of urban brownfield sites, but are often relevant to quarries. The purpose of planning conditions is to formalise the restoration work required of a site owner in relation to a new planning application, i.e. to extend a quarry or construct a haul road. However, when worded correctly they also forewarn planning officers of the intent to use soil-forming materials for restoration. For example, a statement that can be made within an agreement under Section 106 of the Town and Country Planning Act 1990 (as amended) is that a site owner will import soil-forming materials for the purposes of restoration. It is worth referring to any planning conditions that exist in relation to the site for restoration since a prior agreement to use or import soil-forming materials may hasten or possibly even negate, subject to the Planning Officer's discretion, the need to make a new planning application, depending on the nature and amount of soil forming materials required.

In the UK, planning guidance is being comprehensively revised as the planning system is reformed. A summary of current legislation and policy guidance in relation to the restoration of hard rock quarries has recently been published[7]. In all cases it is advisable to

[5] Burke (2003) Green waste composting project A341 – final report for County Environmental Trust Ltd. Organic Studies Centre, Duchy College Cornwall, UK. Online at www.organicstudiescornwall.co.uk/publications.asp. Accessed August 2007.

[6] Hogg *et al* (2007) *Dealing with food waste in the UK*. Report prepared for the Waste and Resources Action Programme (WRAP) by Eunomia Research and Consulting, Bristol, UK. Online at www.wrap.org.uk. Accessed August 2007.

[7] Cripps *et al* (2007). *Reclamation Planning in hard Rock Quarries: A Guide to Good Practice*. Published by the Department of Civil and Structural Engineering, University of Sheffield, UK.

contact Local Planning Authority officers when planning restoration projects.

2.4.2 Exemptions to waste management licensing

Compost (unless Quality Protocol certified) is considered to be waste. Storage, transportation and application to land are controlled by the WMLR and exemptions permit compost and some uncomposted wastes to be spread to land for agricultural benefit (Paragraph 7A of Schedule 3 of the WMLR) or ecological improvement (Paragraph 9A of Schedule 3 of WMLR). To restore land using compost, a Paragraph 9A exemption will usually be sought. Under a Paragraph 8A exemption, sewage sludge can be spread at rates up to 250 t ha^{-1} y^{-1} provided that deleterious elements, for example heavy metals, do not accumulate in soil (see Schedule 2 of the Sludge Use in Agriculture Regulations 1989).

To spread tertiary-treated sewage sludge together with other organic wastes or composts *both* Paragraph 8A and 9A exemptions must be obtained.

A Paragraph 9A exemption requires expert witness support. To this end, it is advisable to arrange a site visit by a relevant expert, for example an ecologist or biodiversity officer from a statutory body (in the UK; Countryside Council for Wales, Natural England, Scottish Natural Heritage), ecological consultancy (the Institute of Ecology and Environmental Management have a searchable membership directory at www.ieem.org.uk), university or wildlife trust.

2.4.3 Duty of care, licensed carriers and waste transfer notes

Duty of Care[8] dictates that controlled wastes detailed in the List of Waste Regulations (2005)[9] can only be handled by EA authorised persons and require waste transfer notes that detail the nature and quantity of any controlled waste (including composts not certified under PAS 100 or the Quality Protocol) and which must accompany any transfer of waste between holders. Waste transfer notes include a written description of the waste together with the waste code as detailed in the List of Wastes. The full list of controlled wastes and their codes is available on the EA's web pages. When waste exchanges hands, both parties must sign Duty of Care forms. Waste can only be transported by licensed waste carriers registered by the EA.

2.4.4 Quality Protocol Compost

In the UK, Quality Protocol compost ceases to be waste and is released from regulatory control. This means exemptions to the WMLR need not be obtained (see **2.2**) to spread Quality Protocol compost, and it can be transported by unlicensed hauliers. There are a number of conditions and recording requirements on the producer and user of Quality Protocol compost including that (in order to be released from regulatory control) Quality Protocol compost must be used in a designated market sector (for land restoration these are defined in Section 4.2 of the Quality Protocol[10]) and contracts of supply must be maintained. When used in agriculture and horticulture, the user must keep detailed records including rates of application, soil nutrient and potentially toxic element (PTE) analysis and calculated increases in these following initial and each subsequent addition of Quality Protocol compost. The Quality Protocol does not require these measurements to be made when using Quality Protocol compost for land restoration or remediation but the responsibility of the land manager not to use compost in such a way as to adversely affect human health or the environment remains.

Important considerations when deciding whether to use PAS 100, Quality Protocol or non-quality assured composts include:

- the monetary cost per tonne of certified compost
- monetary and environmental costs of haulage from the nearest certified site
- cost and time taken to register an exemption to the WMLR for non-Quality Protocol compost
- cost and time taken to seek planning permission.

The Local Planning Authority may request that planning permission is obtained prior to spreading Quality Protocol compost. However, as it is no longer 'waste' in law, obtaining permission to spread Quality Protocol compost should be easier than for non-Quality Protocol compost, which remains waste. Depending on the amount of Quality Protocol compost involved, the decision to grant permission may be made at the discretion of two planning officers rather than by a committee.

---

[8] The Environmental Protection (Duty of Care) Regulations 1991 as amended by regulation 19 of the landfill (England and Wales) Regulations 2002.

[9] Environment Agency (April 2006) *Using the list of wastes to code waste for waste transfer notes, PPC permits and Waste Management Licenses in England and Wales. Living Guidance from the Environment Agency. Version 1*.Online at www.environment-agency.gov.uk/business. Accessed August 2007.

[10] Environment Agency and Waste and Resources Action Programme (April 2007) *Quality Protocol Compost. The quality protocol for the production and use of quality compost from source-segregated biodegradable waste*. Online at www.environment-agency.gov.uk/subjects/waste & http://www.wrap.org.uk/composting/quality_protocol.html.

2.4.5 BS 3882: 2007 Specification for topsoil and requirements for use

BS3882: 2007 specifies requirements for topsoils that are moved or traded, including manufactured topsoils defined as 'material produced by combining mineral matter and organic matter of suitable quality (and where appropriate, fertilizer and lime) and which provides the same function as topsoil'. In this case the function of topsoil is to support healthy plant growth.

2.4.6 Blending materials

Several of the wastes that are not listed as allowable for composting under exemption, including de-inking paper fibre, tertiary treated sewage sludge and non-biodegradable mineral fines, are potentially valuable components of constructed soil or compost designed for specific vegetation types (**Section 3** and **Box 2**). To comply with the WMLR, these wastes must either be spread separately, mixed together with finished compost or composted at a site possessing a full Waste Management Licence or PPC permit. When such materials are mixed with quality assured compost the mixture is classed as waste and can only be spread under a Paragraph 9A exemption to the WMLR.

2.5 Using organic wastes and composts to remediate contaminated land

Regulatory issues surrounding contaminated soil are complex, particularly when considering remediation using organic wastes. The Brownfield Guide[11] published by English Partnerships and available as a free download or CD ROM from www.englishpartnerships.co.uk/publications is an excellent guide to the current legislation and the regulatory position of the EA. Here, we deal briefly with remediating contaminated soil using organic wastes.

2.5.1 Hazardous and non-hazardous waste – WM2 and List of Wastes

Contaminated soil is waste as defined by the List of Waste (LOW) regulations. Whether or not it can be composted without a Waste Management Licence or PPC permit depends on the degree of contamination and the quantity of contaminated soil needing to be excavated and treated.

The EA's *Technical Guidance WM2: Interpretation and definition of hazardous waste*[12] provides guidance on the identification and assessment of hazardous wastes based on the Hazardous Waste Directive (Council Directive 91/689/EC). 'Contaminated' soil (LOW code 17 05 03; soil and stones containing dangerous substances) is not defined as hazardous *per se*. Instead, it is a 'mirror entry', meaning that it must be assessed for possession of 14 hazardous properties (identified in Annexe III of the Hazardous Waste Directive) according to methodology listed in Appendix C of WM2 before being classed as hazardous or non-hazardous.

2.5.2 Soil Guideline Values

Assessing soil according to the methods listed in WM2 can be expensive and laborious, but is necessary to safeguard human and environmental health. The introduction of Soil Guideline Values: threshold levels for contaminants has been requested from several quarters to simplify the process of assessing contamination. Although the publication of guideline values will assist practitioners, they are not a substitute for the current risk assessment approach based on the pollutant-pathway-receptor model.

Soil deemed as hazardous according to the criteria in WM2 cannot be composted under exemption to the WMLR; a Waste Management Licence or PPC permit is required with the nature of the waste specified in the licence or permit. Non-hazardous contaminated soil can be composted *with full containment* (i.e. using in-vessel systems) under a Paragraph 12 exemption to the WMLR as it is listed as an allowable feedstock material.[13]

2.5.3 Mobile Treatment Licences

The introduction in recent years of Mobile Treatment Licences has been broadly welcomed by the land remediation industry since the new Mobile Treatment Licensing regime simplifies and expedites the process of obtaining regulatory approval for a variety of land remediation activities. The Mobile Treatment Licence has replaced the original Mobile Plant Licence, since the licences are used to give regulatory approval for tried and tested remediation technologies rather than just the plant used. Extensive guidance on applying for and using Mobile Treatment Licences can be found on the EA's web pages at www.environment-agency.gov.uk/business and in the The Land Remediation Yearbook 2007[14]

[11] English Partnerships (2006) *The brownfield guide. A practitioners guide to land reuse in England*. English Partnerships, London. Online at www.englishpartnerships.co.uk/publications. Accessed August 2007.

[12] Environment Agency (2003, updated Oct 2006) *Technical Guidance WM2: Interpretation of the Definition and Classification of Hazardous Waste. 2nd Edition, version 2.1*. www.environment-agency.gov.uk/subjects/waste. Accessed August 2007.

[13] Environment Agency Form WMX12: Storage and composting of biodegradable waste – exempt activity. Online at www.environment-agency.gov.uk/subjects/waste. Accessed August 2007.

[14] The Environmental Industries Commission (2007) The Land Remediation Yearbook 2007. The Environmental Industries Commission Business Services, Manchester, UK. Online at www.eic-yearbook.co.uk. Accessed August 2007.

published by The Environmental Industries Commission and available online at www.eic-yearbook.co.uk.

2.5.4 Bioremediation using uncomposted wastes

Certain wastes and composts can be applied to contaminated sites without a Waste Management Licence or PPC permit, under exemption to WMLR, significantly reducing the cost and regulation involved. The legal requirements of treating contaminated soil in this way are clearer than for co-composting and it is less expensive to obtain permissions without having to pay for analysis costs necessary to test contaminated soil according to WM2. Quality Protocol compost is exempt from regulatory control and can be spread without obtaining exemptions to the WMLR provided that the conditions of the Quality Protocol (including use in a designated market sector) are met.

2.6 Low risk activities

The EA has identified a number of low risk activities that it does not believe justify regulation under the WMLR. Neither composting nor the application of composted waste materials to land are usually considered under the low risk regime but of special relevance to the restoration of quarries is the manufacture of topsoil from water treatment sludges and quarry by-products/wastes (**Table 2**).

Table 2 Low risk activity relevant to quarry restoration in England and Wales (from: *Environment Agency Guidance of Low Risk Waste Activities*, Version 21, March 2007.)

Ref. No.	Date	Activity Description
LRW 064	01/11/05	The blending of water treatment work sludges with quarry wastes to a recognised British Standard. The use of topsoil made from blending water treatment work sludges and quarry by-products in the final restoration layer of the quarry where it is produced.

It is feasible that a site owner will need neither planning permission nor authorisation from the EA to import water treatment work sludges. Seek clarification both from the Local Planning Authority and the EA, especially as definitions of low risk activities are frequently reviewed.

2.7 Nitrates Directive

It is worth noting that the EC Nitrates Directive (91/676/EC) applies only to agricultural land and not to post-industrial sites. Under the Directive, rates of application of composts and wastes to agricultural land within designated Nitrate Vulnerable Zones (NVZs) must not exceed 250 kg total N ha^{-1} y^{-1}. The practical implication of this is that despite the relatively low availability and mobility of N in composts and many organic wastes, their use as organic fertilisers is restricted to rates as low as 25 t ha^{-1} y^{-1}.

2.8 Health and safety

Safety is central to any restoration programme. Hazards at brownfield and quarry sites include landslides and falling stones, steep drops, sharp edges, unstable structures, voids, deep-water and contaminated land and water. Landowners have common law responsibilities for the safety of visitors and trespassers as well as responsibilities under the Occupiers Liability Act 1957 and 1984. At the outset of restoration planning, a decision must be made about which, if any, parts of the restored site will be open to public access. Hazards should be removed or rendered safe or otherwise public access restricted. The higher the perceived levels of public after-use, the more comprehensive the work required to remove hazards.[15]

A number of regulations apply to the safe operation of composting sites and biogas plants including Control of Substances Hazardous to Health (COSHH), Personal Protective Equipment (PPE), Manual Handling Operations and Noise at Work Regulations. These regulations are summarised in a number of publications produced by The Composting Association[16,17] and will not be expanded upon here except to note that the safe routing of vehicles has been identified by the Health and Safety Executive (HSE) as a major issue that should be addressed.[13] Exposure of workers to bioaerosols is also of special concern (see **Section 3**) and should be addressed using risk assessment and Hazard Analysis and Critical Control Point (HACCP) planning.

[15] Williamson *et al* (2003) Restoring habitats of high conservation value after quarrying: best practice manual. University of Wales, Bangor.

[16] The Composting Association (2004) *Health and Safety at Composting Sites: A Guide for Site Managers*. Published by The Composting Association, Wellingborough, Northamptonshire, UK.

[17] The Composting Association (2005) *The Composting Industry Code of Practice*. Published by The Composting Association, Wellingborough, Northamptonshire, UK.

2.9 Future changes in policy and legislation likely to affect composting and land remediation

A variety of articles summarising anticipated changes in UK and EU legislation with regard to contaminated land remediation, soil protection and the definition of waste can be found in The Land Remediation Yearbook 2007.[18] The most important changes include, in 2007, an expected revision to the Waste Framework Directive and, in 2009, the adoption by the European Parliament of the Thematic Strategy on Soil Protection. Further information on the strategy can be found on the web pages of the EC Directorate General for the Environment at www.ec.europa.eu/environment/soil/index.htm.

Key components of the strategy include a requirement for member states to identify, make public and remediate all contaminated sites in their national territory. Article 10 of COM (2006) 232[19] defines contaminated sites as having

'a confirmed presence, caused by man, of dangerous substances of such a level that Member States consider they pose a significant risk to human health or the environment .'

Within 25 years of transposition of the thematic strategy into national law, member states must have completed the inventory of contaminated sites and report to the Commission.

2.10 Summary – specific advice for UK practitioners

- Composting and land-spreading of wastes are controlled under the WMLR and regulated by the EA, SEPA and EHS. Permission from the regulatory body is almost always required to produce compost. This can be obtained via a PPC permit, a Waste Management Licence or under a Paragraph 12 exemption to the WMLR.

- As a quality assured product, Quality Protocol compost is released from regulatory control and can be spread without an exemption to the WMLR. At present, an exemption to the WMLR should not be required to spread BSI PAS: 100 compost.

- Exemptions to the WMLR are required to spread non-Quality Protocol composts and wastes and must be renewed annually. Apply for a Paragraph 9A exemption to use non-Quality Protocol composts and uncomposted wastes for ecological improvement. Apply for a Paragraph 8A exemption to use sewage sludge for land restoration. When using sewage together with other organic wastes *both* Paragraph 8A and 9A exemptions are required. Allow at least 35 days for an exemption to be registered.

- Permission from a Local Planning Authority is almost always required to produce compost. Consent is often required to spread composts and wastes depending on the scale and details of the proposed restoration work and site location (**Box 2**).

- Various regulatory requirements must be satisfied in order to remediate contaminated sites using wastes. Contaminated soil is defined as waste and, as such, controlled under the WMLR. Contaminated soil is either hazardous or non-hazardous as defined by the Hazardous Waste Directive and EA guidance WM2.

- Hazardous waste cannot normally be co-composted under exemption to the WMLR; a Waste Management Licence or PPC permit is required. Non-hazardous waste (such as green waste and waste soil not deemed to be hazardous according to WM2) can be composted under a Paragraph 12 exemption to the WMLR provided that not more than 1000m^3 of waste is kept at the exempt site at any time.

- Mobile Treatment Licences simplify the process of obtaining regulatory permission to remediate land using tried and tested technologies. Portable in-vessel composting technology is not dealt with under the Mobile Treatment Licensing regime.

- Uncomposted wastes can be applied to contaminated sites for the purposes of bioremediation according to Paragraph 8A and 9A exemptions to the WMLR.

- A number of Health and Safety regulations apply to composting and land restoration sites. These include Control of Substances Hazardous to Health (COSHH), Personal Protective Equipment (PPE), Manual Handling Operations and Noise at Work

[18] The Environmental Industries Commission (2007) The Land Remediation Yearbook 2007. The Environmental Industries Commission Business Services, Manchester, UK. Online at www.eic-yearbook.co.uk. Accessed August 2007.

[19] Commission of the European Communities COM (2006) 232 Proposal of the EU Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC.

Regulations. Minimising production of bioaerosols is a key concern of regulators: site managers should address this using risk assessment and Hazard Analysis and Critical Control Point (HACCP) planning.

- National regulations and policy guidance change regularly. In all cases contact the EA and the relevant Local Planning Authority for guidance before producing compost or embarking on a programme of bioremediation using compost or wastes.

- At a European level, a revised Waste Framework Directive (expected 2007) and the EC Thematic Strategy on Soil Protection (expected transposition by UK government in 2010) will greatly affect both waste management and land remediation practitioners.

Section 3

Using organic wastes and composts to restore land

'Behold this compost! Behold it well…!
It grows such sweet things out of such corruptions…'

Walt Whitman (1819 – 1892), This Compost

Section 3

Using organic wastes and composts to restore land

3.1 Introduction and definitions

The terms 'brownfield' and 'derelict land' are not the same. The Oxford English Dictionary defines the adjective 'brownfield' as simply '(of an urban site) having had previous development on it'. In 1991 the then Department for the Environment defined 'derelict' land as 'so damaged by industrial or other development that it is incapable of beneficial use without treatment'.[1] Thus, brownfield land *may* be derelict and require treatment to restore it to beneficial use but, equally, brownfield sites may have high conservation, aesthetic, amenity or heritage value and do not necessarily require treatment. It would be irresponsible to make recommendations for restoring post-industrial sites without first acknowledging their existing conservation value, particularly as refuges for unusual invertebrates (**Boxes 3 and 4**), early successional plants (**Box 5**) and heritage value (**Box 6**). Whilst the focus of this manual is not on-site assessment and stakeholder engagement (several excellent guides to this are already available, see **Appendix I**), the authors advocate thorough biodiversity assessments at the planning stage of any restoration project. Developers and regulators need to recognise the potential wildlife value of post-industrial sites and, at the very least, incorporate existing features and habitats of conservation value. Habitat creation has great potential to increase biodiversity, but also a low intervention approach is a genuine restoration option for areas within sites supporting scarce species. There is a genuine danger that rare species surviving at post-industrial sites could be lost as a result of wholesale land restoration.

3.1.1 Extent of post-industrial land in the EU

Quantifying the extent of brownfield and post-industrial sites within the EU is difficult as reports from community members are not always directly comparable (although the dictionary definition of land 'having had previous development on it' is most often used). There are 62,700 ha of previously developed land in England,[2] and 10,600 ha in Scotland[3] (in Germany there are 128,000 ha,[2] The Netherlands 9000 to 11,000 ha,[2] Belgium/Wallonia 9000 ha). Wales currently lacks a single, inclusive database but a partnership between the Welsh Assembly Government Department for the Economy and Transport and Environment Agency Wales is currently (2007) working towards this. The overall rate of land reclamation in the UK currently exceeds the rate of land abandonment as government policy stipulates that, wherever possible, new homes and industry should utilise previously developed land. Regional differences exist where high land values and pressure for housing drives restoration of metropolitan urban sites at a faster rate than that of rural sites. For example previously developed land accounts for only 2.4% of all developed land in London, compared with 7.4% in North West England.[4] In rural areas with low population density, post-industrial sites are more likely to be restored with wildlife conservation in mind. This is particularly true for quarries with some 17% of permitted aggregate reserves in England and Wales found in National Parks and Areas of Outstanding Natural Beauty.[5] There is, however, considerable potential for some quarries to be restored to a mixture of housing and green-spaces for conservation or amenity use.

3.1.2 Aims and targets of land restoration

While it is important to have a clearly defined restoration aim, it is not appropriate to define the target too narrowly. Natural establishment of vegetation is unpredictable and a range of different outcomes may each have environmental value. It may be more realistic to identify those outcomes that are positively undesirable (e.g. poor establishment of vegetation cover, or dominance by species that cause harm or competitively exclude others), rather than trying to assess how closely vegetation conforms to a narrowly-defined target that in reality may be very difficult to achieve.

Put simply, the aim of land restoration is to return land to beneficial use. Post-industrial sites can be restored to

---

[1] Department of Environment (1995) *Survey of derelict land in England*, 1993. HMSO, London.

[2] Department for Communities and Local Government: London (2007) *Previously-Developed land that may be available for Development: England 2006. Results from the National Land Use Database of Previously-Developed Land*. Department for Communities and Local Government Publications, Wetherby, UK. Online at www.communities.gov.uk. Accessed August 2007.

[3] Scottish Executive (2001) Scottish *Vacant and Derelict Land Survey 2001*. Commentary online at www.scotland.gov.uk/publications. Accessed August 2007.

[4] Grimski and Ferber (2001) Urban brownfields in Europe. *Land Remediation and Reclamation* **9**: 143-148.

[5] Cripps *et al* (2007). *Reclamation Planning in hard Rock Quarries*: A Guide to Good Practice. Published by the Department of Civil and Structural Engineering, University of Sheffield, UK.

‘soft’ or ‘hard’ end uses: the former usually involves reinstatement of soils and vegetation for amenity use, agriculture or wildlife conservation; the latter includes housing and developments for industry and leisure, often together with some green spaces. Some of the most successful schemes have involved reinstatement of post-industrial land to mixed use (**Box 7**) incorporating conservation and amenity green spaces, industrial developments and housing. Attempts to restore post-industrial sites to *productive* agriculture or forestry have rarely been successful but community woodland is an achievable target in restoration programmes as exemplified by the Mersey Forest[6], a large proportion of which has been established on brownfield land using organic wastes and composts.

There are a number of manuals and guides (**Appendix I**) that detail aspects of best practice for land restoration, including site survey, defining appropriate and realistic targets for restoration, engaging stakeholders, evaluating success and the ecological theory behind the concept of habitat creation. **Table 3.1** lists the most common objectives of restoration programmes. The focus here is on the effective and safe reuse of organic wastes and composts as soil-forming materials for restoring land to soft end uses, principally habitats of conservation or amenity value or cultivation of bioenergy crops. Using organic materials to remediate contaminated sites is dealt with in **Section 4**.

3.1.3 Bioenergy crops

Provided that adequate consideration is given to the existing wildlife or heritage value of post-industrial sites and notwithstanding the competing pressure for housing, cultivating bioenergy crops at brownfield sites represents an opportunity to link waste management, land remediation and sustainable bioenergy generation whilst providing an income to fund sustained restoration. In the UK, the most common bioenergy crops are short-rotation willow (*Salix*) coppice, poplar (*Populus*) and *Miscanthus* (elephant) grass. The fast-growing species favoured as bioenergy crops are also some of the most effective ‘phytoremediators’ of contaminated soils. The potential for cultivating bioenergy crops at brownfield sites has been reviewed by ADAS[7] and DEFRA publish best practice guidelines for growing bioenergy crops in short rotation coppice.[8]

Since the EC Nitrates Directive (91/676/EC) does not encompass brownfield sites, there are far fewer restrictions on amounts of organic materials that can be applied to brownfield sites than to agricultural land that might otherwise be used to grow bioenergy crops.

Nitrogen (N) in organic wastes and composts can be applied to meet the calculated requirements of bioenergy crops, substantially reducing (or negating) the need for mineral N and phosphorus (P) fertilisers with environmental benefits in the form of reduced carbon emissions associated with production and importation of fertilisers. This is of course on the assumption that best practice spreading guidelines are followed.

The planned expansion in use of biofuels, for example in combined heat and power generators, will create significant amounts of ash. EU member states use different disposal methods, including pelletisation (to increase stability and reduction of wind-blown particles) or co-composting together with land disposal. In the UK, without a consensus view on sustainable disposal, it is likely that significant amounts may be disposed of in landfill. Theoretically, there is no reason why ash cannot be returned to land used to grow bioenergy crops and for practical and health and safety purposes should be applied in a stabilised form to return vital micronutrients to soil that might otherwise decline with frequent cropping.

[6] Mersey Forest (2000) *Creating community woodland on closed landfill sites*. Published by The Mersey Forest, Warrington, UK.

[8] ADAS Consultants (2002) *Bioenery Crops and Bioremediation – A review*. Online at www.defra.gov.uk. Accessed August 2007.

[7] DEFRA (2002) *Growing short rotation coppice. Best Practice Guidelines*. Online at www.defra.gov.uk. Accessed August 2007.

Table 3.1 Objectives of restoration schemes, modified from Williamson *et al*. (2003).[9]

OBJECTIVE OF RESTORATION	PROPOSED OUTCOME
Safety	Decontamination, waste tip stabilisation
Biodiversity conservation	Conserving / restoring individual species or habitats, genetic resources, useful study sites
Amenity and recreation	Public access, study/interpretation sites
Landscape aesthetics	Improved visual quality of landscape, sympathetic to surroundings, softening outline of man-made structures
Earth science and industrial archaeology	Preserving geological value and cultural heritage
Ecosystem services	Carbon sequestration, flood protection, filtering pollution
Agriculture and forestry	Land supports pasture, arable or timber for commercial gain
Biofuels	Production of plant biomass (often short rotation willow coppice or Miscanthus grass) to burn for heat and/or power generation
Development	Hard end uses, e.g. industry, housing
Utilisation of waste	Recovery of secondary aggregate e.g. quarry waste or waste sand
Treatment / disposal of waste	Use of waste organic or mineral materials as soil forming and landscaping resources
Mixed use	For example, retail or housing development with amenity green spaces, geological and archaeological features preserved and highlighted. Waste materials used as soil-forming materials for habitat creation and carbon sequestration.

[9] Williamson *et al* (2003) *Restoring habitats of high conservation value after quarrying: best practice manual*. University of Wales, Bangor.

3.2 Advantages and challenges of using organic wastes and composts

3.2.1 Specific environmental benefits

Due to the production of methane, landfilling is not seen as a sustainable disposal option for organic wastes that, ideally, should be used to recover energy (e.g. through anaerobic digestion) and return organic matter and essential plant nutrients to soil. Using untreated and composted wastes for large-scale land restoration and vegetation re-establishment has the potential to mitigate low levels of soil organic matter, offset anthropogenic emissions of CO_2 and increase biodiversity whilst avoiding the unacceptably high environmental costs of extracting peat. When handled and mixed correctly most organic and mineral waste materials are suitable for restoring post-industrial sites to green spaces of conservation and/or amenity value or, alternatively, as places to produce biofuels provided that i) fertility requirements of the target vegetation are met, managed and not greatly exceeded and ii) amounts of undesirable elements in the waste materials do not pose a threat to human health or the environment.

3.2.2 Challenges – health and safety and undesirable elements

Organic wastes and composts contain undesirable and potentially toxic elements (PTEs) that have the potential to effect human health and cause damage to, or accumulate in, sensitive ecosystems. Using wastes effectively is about managing environmental and human health risks whilst recognising the specific benefits they offer, engaging stakeholders at every stage, and continuous testing.

In any large restoration project, the cost of identifying and testing suitable organic wastes and composts to use as soil-forming materials is not great. While chemical analysis is a requirement of both the BSI PAS 100 processing standard for green waste compost and BS 3882: 2007 Specification for topsoil and requirements for use, chemical data are often available free of charge, for example utilities companies keep good records of the heavy metal content of tertiary treated sewage 'cake'. Composting sites seeking accreditation should also be able to make chemical data available. Obtaining permissions from the Waste Management Licensing Regulations (the WMLR), for example to land-spread wastes or composts under exemption, requires that both the organic wastes and the receiving soil are analysed. When analysis is required, regulators prefer and sometimes stipulate that a laboratory accredited under the Environment Agency's Monitoring Certification Scheme (MCERTS) is used.

3.2.2.1 Human pathogens, plant pathogens and bioaerosols

Concerns about the presence in wastes of potentially harmful micro-organisms such as pathogenic strains of *E. coli, Salmonella* and *Aspergillus fumigatus* (farmers lung) and plant diseases are a significant barrier to the use of composted waste materials in horticulture and agriculture.[10] The most likely route of exposure to pathogens is via the production of bioaerosols, potentially pathogenic airborne organisms (fungi, bacteria, viruses), or compounds produced by micro-organisms, e.g. endotoxins. Steps must be taken to minimise generation of and potential exposure to bioaerosols. The Environment Agency (EA) will require a substantial risk assessment where composting sites are to be established within 250 m of a receptor and land-spreading of organic wastes is also of concern. Risk assessments should be carried out whether or not they are required by regulators since *workers are at greatest risk of exposure to bioaerosols.*[11]

Untreated green waste can actually contain greater viable populations of pathogens than treated sewage sludge,[12] particularly where enhanced sewage treatment methods (e.g. UV treatment or high-power ultrasound) have been used. Workers at green waste composting sites are potentially exposed to high levels of bioaerosols[13] and there is evidence that they suffer increased health complaints as a consequence.[14] The greatest potential for exposure to bioaerosols occurs when organic wastes and composts are agitated during shredding, mixing, turning, screening and spreading. These processes should be given adequate consideration in a process Hazard Analysis and Critical Control Point (HACCP) plan.

Risks associated with handling tertiary-treated sewage should be minimised by following health and safety precautions established by the Health and Safety

[10] Noble and Roberts (2003) A review of the literature on eradication of plant pathogens and nematodes during composting. Prepared for the Waste and Resources Action Programme (WRAP), Oxon UK. Online at www.wrap.org.uk. Accessed August 2007.

[11] Pillai (2007) Bioaerosols from land-applied biosolids: Issues and needs. Water, Environment Research 79: 270.

[12] Williamson *et al* (2006) Pathogen survival patterns in waste-derived composts destined for land restoration. Proceeding of Waste 2006 Conference. Copies from The Waste Conference Ltd., University of Warwick Science Park, Coventry, UK.

[13] Sancez-Monedero (2005) Bioaerosol generation at large-scale green waste composting plants. Journal of the Air and Waste Management Association 55: 612-618.

[14] Bunger *et al* (2000) Health complaints and immunological markers of exposure to bioaerosols among biowaste collectors and compost works. Occupational and Environmental Medicine 57: 458-464.

Executive (HSE) (guidance online at http://www.hse.gov.uk/pubns). Also consult the Safe Sludge Matrix, which is published by ADAS and available online at www.adas.co.uk. Both the Composting Association Code of Practice (available to purchase online at www.compost.org.uk) and the EA's Technical Guidance on Composting Operations[15] consider bioaerosols and give advice for completing HACCP plans for composting sites.

At least one study has demonstrated that post-treatment increases in amounts of *Salmonella* in tertiary-treated sewage sludge are more likely caused by infection from external sources (rainfall and bird faeces) than by re-growth of indigenous microflora.[16] This is equally applicable for quality assured composts maturing in the open and highlights the benefits of storing compost under cover and of microbiological testing of finished compost where possible.

Table 3.2 Recommended minimum conditions for sanitisation (biological) of input materials for composting. Redrawn from BSI PAS 100: 2005.

System type	Minimum duration	Minimum temperature	Minimum turning or mixing
Windrow	14 days	> 55 °C in core zone	5 x during 14 days
	7 days	> 65 °C in core zone	2 x during 7 days
In-vessel	2 days	> 60 °C in all appropriate zones of composting mass	Optional
	1 hour	> 70 °C in all appropriate zones	N/A
Aerated static pile with insulating layer	7 days	> 60 °C in all zones of composting mass	N/A

Picture 1 Bioaerosols, potentially pathogenic airborne organisms (fungi, bacteria, viruses) are a key concern of the Environment Agency, which requires a risk assessment where composting sites are to be established within 250m of a receptor. Peak production of bioaerosols occurs during agitation (mixing, shredding, turning, screening and spreading) of organic waste materials and composts; greatest risk is to staff. Here, a portable air sampler is used to inoculate culture media to estimate amounts of bioaerosols at the TWIRLS project EcoPOD® in-vessel composting site in Flintshire.

[15] Environment Agency (2001) *Technical Guidance on Composting Operations*. Online at www.netregs.gov.uk/netregs/processes/636862. Accessed August 2007.

[16] Zaleski *et al* (2005) Potential regrowth and recolonisation of salmonellae and indicators in biosolids and biosolid-amended soil. *Applied and Environmental Microbiology* **71**: 3701-3708.

3.2.2.2 Weed seeds

Organic wastes, composts and imported topsoils can contain weed seeds. Peak 'pathogen-kill' temperature reached during composting combined with maintenance of thermophillic conditions over several weeks is sufficient to kill most weed seeds but species vary in their ability to tolerate high temperature. For this reason germination tests should always be carried out using the finished compost. These are a requirement of the BSI PAS 100 processing standard.

Picture 2 Aubergine and tomato plants germinated from tertiary treated sewage sludge used as a feedstock for composting at TWIRLS project EcoPOD® in-vessel composting sites. Although these annuals are unlikely to cause problems, the ability of seeds of more pernicious weeds to survive both anaerobic treatment and subsequent aerobic composting should not be underestimated. This emphasises the importance of reaching sanitisation temperatures during composting in order to avoid potentially expensive management of restored/created habitats to reduce the frequency of invasive species. Germination tests should always be performed prior to using large volumes of soil-forming materials.

3.2.2.3 Metals

Organic wastes and composts contain a range of metals (**Table 3.3**). Feedstock wastes should be tested prior to treatment by composting or anaerobic digestion and the finished product must be tested before being spread to land. Consideration must be given at the planning stage as to how loss of mass during composting or digestion (usually between 30 and 70%) will increase the concentration of metals in the finished product or solid digestate. Care must be taken to not let undesirable metals accumulate in soil. This means testing the soil before the initial application (and ideally afterwards too) and each subsequent application. Providing soil and organic waste analyses is in any case a requirement of land-spreading exemptions to the WMLR and a requirement of using Quality Protocol compost without an exemption.

It is important to dispel a few commonly held misconceptions with regards to the heavy metal contents of different organic wastes. Metal contamination is not exclusively a problem of sewage sludge and amounts of metals in treated sludge have declined year on year as technological advances and investment by utilities companies have increased the efficiency of treatment. Amounts of metals are often higher in sewage than in many of the other organic wastes and composts commonly used for land restoration, but this is not always the case and even quality assured green waste composts must be used at sensible rates that do not allow metals to accumulate in soil. Metal content of sewage depends upon a number of factors including quality of influent waste water, which is highest in urban industrial areas. Again the emphasis is on using wastes at appropriate rates to prevent accumulation of metals in soil.

3.2.2.4 Organic pollutants

Classes of organic pollutants that may be present in waste materials include a range of Persistent Organic Pollutants (POPs). We know far less about organic pollutants than metals, despite the well documented and arguably greater effects that POPs and particularly endocrine disrupting compounds (EDCs) have on the environment.[17] EDCs have the potential to disrupt sexual differentiation in a variety of organisms with populations of aquatic species most at risk. Presently there is no compelling evidence to suggest that EDCs in organic wastes are a threat to human health since exposure to natural EDCs in our diets (e.g. phytoestrogens in soya) likely exceeds all other sources.[18] However, since many EDCs are biologically active at very small concentrations (as low as 10 parts per trillion in freshwater) the potential for harm to the environment is significant and depends on:

i) the amounts of EDCs in waste materials
ii) the potential for EDCs to reach sensitive target organisms (usually by leaching to watercourses)
iii) the potential for EDCs to bioaccumulate and
iv) their rate of degradation.

From the perspective of land restoration and waste management within the EU, sewage sludge is the greatest source of EDCs. Through UK Water Industry

Research (UKWIR), utilities companies have commissioned research into new technologies for reducing amounts of EDCs in effluent and treated sewage sludge produced by wastewater treatment works. Controls recently introduced by the EU on the use of a variety of potentially harmful organic pollutants by industry will lead to declining amounts of these chemicals in sewage.

Historically (pre 2000), de-inking paper fibre has also contained significant amounts of APE surfactants (and their breakdown products). In the EU, regulators and the pulp and paper industry are aware of the environmental concerns and have been proactive in restricting use of APE surfactants for de-inking (outside of the EU use of APE surfactants may continue and it is important to ask suppliers of de-inking paper fibre for information). Paper mills in the EU have replaced APE surfactants with less harmful fatty-acid based compounds that do not degrade to produce nonyl-phenol. Contaminated sites may also harbour EDCs and some approaches for dealing with these are suggested in **Section 4**.

Table 3.3 Concentration of a selection of metals determined by the University of Wales (Bangor and Aberystwyth) using Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) in samples of composted green waste (not produced to BSI PAS 100), de-inking paper fibre and tertiary-treated and de-watered sewage sludge from an urban water treatment works. BSI PAS 100: 2005 limits on acceptable levels are given for comparison.

Element (mg kg^{-1} dry weight)	**Green waste compost**	**Paper fibre**	**Sewage sludge**	**PAS 100 limit**
Vanadium	17	5.4		
Chromium	10	8.8	47	100
Cobalt	2.5	1.4		
Nickel	3.7	2.8	32	50
Copper	28	114	370	200
Zinc	81	14	788	400
Arsenic	6.9	6.4	6.6	
Selenium	23	6.4		
Cadmium	0.6	0.1	1	1.5
Tin	1.6	0.5		
Antimony	0.2	nd		
Mercury	0.1	0.2	1.9	1
Lead	97	9.3	200	200

[17] WHO/PCS/EDC/02.2 World Health Organisation International Programme on Chemical Safety (2002) *Global assessment of the state-of-the-science of endocrine disruptors*. Online at www.who.int/ipcs/pupblications/new_issues/endocrine_disruptors. Accessed August 2007.

[18] Safe (2001) Endocrine disruptors and human health – is there a problem? An update. Environmental Health Perspectives **109**: A250-1.

3.3 Choosing and purchasing organic wastes and composts

Many organic wastes are suitable for use in land restoration and they cannot all be considered in this manual. Here, tertiary-treated sewage sludge and de-inking paper fibre are explored in more detail since they are ubiquitous high-volume wastes with a long history of use in land restoration and land disposal. Equally, we consider composted green waste and green waste that has not been composted. Organic compost-like outputs from Mechanical Biological Treatment (MBT) of non-source segregated wastes (usually the organic fraction of household waste) and solid digestates from anaerobic digestion (most frequently of food-waste) are also covered since they represent valuable sources of carbon and plant nutrients, already produced in large volumes by some EU countries (e.g. Sweden, Germany). Residual biodegradable materials produced as outputs from MBT and anaerobic digestion will become increasingly available in the UK as local authorities begin to treat food and municipal solid waste (MSW) to meet landfill diversion targets that cannot be attained by composting green waste alone.

3.3.1 Green waste composts

The volume of green waste compost used in land restoration in the UK is increasing greatly (a practitioner's example is given in **Box 8**) as a direct consequence of the requirement to divert biodegradable wastes from landfill, increased funding opportunities and the restrictions on using organic wastes in agriculture set by the Nitrates Directive. Many composting sites owned or operated by local government or by waste management companies produce compost according to the requirements of the BSI PAS 100 processing standard and the newly introduced Quality Protocol (see **Section 2**).

The advantages of purchasing quality assured compost are summarised in **Table 3.4**. In addition to the assured quality, the practical value to practitioners of using quality assured compost is that exemptions to the WMLR are either simpler to obtain or not required to spread compost to land. A full list of producers supplying BSI PAS 100 accredited compost can be found on the website of the Waste and Resources Action Programme (WRAP) at www.wrap.org.uk. WRAP also publish a buying guide to peat-free and reduced peat products. There may be cost savings associated with purchasing compost that has not been produced according to a recognised standard and **Table 3.4** attempts a brief cost-benefit comparison.

Table 3.4 Cost-benefit comparison of quality assured (BSI PAS 100 or Quality Protocol) or other composts, compost like outputs (CLOs) from Mechanical Biological Treatment (MBT) of the organic fraction of municipal solid waste, solid digestates from anaerobic digestion (usually of kitchen waste or manure together with garden waste), tertiary-treated sewage sludge and de-inking paper fibre. All of the wastes and composts listed are potentially valuable sources of organic matter and nutrients for use in land restoration and bioremediation but differ in price, quality and degree of regulation.

Soil-forming material	Cost	Regulation / exemptions	Key characteristics / benefits
PAS 100 and Quality Protocol composts	£3 - £13 per t + haulage*	Not required**	PAS 100 compost is produced from green waste. Quality Protocol compost can be produced from a range of allowable source-segregated waste materials including green wastes, Category 3 animal by-products and digestates from anaerobic digestion. Principle benefit is assured quality. Metals, pathogens, contamination (e.g. glass, plastic) and viable weed seeds below PAS 100 limits. Likely to be more expensive than non-QA compost but no need to pay to register a land-spreading exemption unless blending with other wastes. Compost analysis provided by supplier. For land restoration there is no requirement for the user to keep records unless to satisfy the EA that Quality Protocol compost is being used in the designated market sector of land restoration and reclamation.1
Compost (not quality assured)	Varies + haulage	Paragraph 9A £564† £412 to renew	Potentially of equivalent quality to PAS 100 or Quality Protocol compost but not assured therefore an exemption will need to be registered. In summer, large volumes may be available at low cost from some local authority sites. Analysis of compost and soils required to landspread. Compost analysis may not be available from supplier unless working toward PAS 100 or Quality Protocol accreditation.
CLOs from Mechanical Biological Treatment of Municipal Solid waste	Free, supplier may pay haulage	Paragraph 9A £564 £412 to renew	CLOs from MBT are produced from non-source segregated materials (usually the organic fraction of household waste). Main concerns about CLOs from MBT are contamination by plastic and sharps. Facilities differ in capability to remove contamination. CLO analysis required, provided by supplier. Receiving soils must also be tested

Table 3.4 continued

Soil-forming material	Cost	Regulation / exemptions	Key characteristics / benefits
Digestate from Anaerobic Digestion	Free, supplier may pay haulage	Paragraph 9A £564 £412 to renew	Digestate from anaerobic digestion is less likely to be contaminated by plastic and sharps. Digestate analysis required, provided by supplier. Receiving soils must also be tested.
Tertiary-treated sewage sludge	Free, supplier often pays haulage	Paragraph 8A £564 £412 to renew	High organic matter and nutrient content with much N and P in slow release forms. Long history of use in land restoration but nutrient availability needs to be reduced for creating biodiverse habitats. May contain copper, cadmium, zinc, lead and mercury in excess of PAS 100 compost limits but amounts of metals likely to be lower if obtained from rural waste water treatment works. May also contain significant chromium and nickel. Likely to contain significant amounts of endocrine disrupting chemicals. Pay particular attention to best practice guidelines when spreading. Sewage analysis required, provided by supplier. Receiving soils must also be tested.
De-inking paper fibre	Free, supplier often pays haulage	Paragraph 9A £564 £412 to renew	By-product of recycling paper. High carbon content, much of which is in molecules that decompose slowly hence ideal for increasing soil C storage, organic matter and water holding capacity. Long history of use for land restoration. Plant macronutrients (N, P, K) very low/absent so must be blended with other materials i.e. sewage for plant establishment. Useful for reducing fertility and increasing water holding capacity of green waste compost. Likely to contain a significant amount of copper but beneath PAS 100 limit. In the EU, does not contain EDCs. Outside of the EU may contain significant amounts of EDCs – ask supplier for details of de-inking surfactants used. Paper fibre analysis required, provided by supplier. Receiving soils must also be tested.

[*] Based on a survey of more than 5 suppliers.

[**] The Quality Protocol for the production and use of quality compost from source-segregated biodegradable wastes. Regulation of the composting sector following publication of the protocol. Regulatory position statement dated 15th March, 2007. Online at www.environment-agency.gov.uk/commondata/acrobat/reg_1721807.pdf.

[†] Prices as at August 2007.

[1] Environment Agency and Waste and Resources Action Programme (April 2007) Quality Protocol Compost. The quality protocol for the production and use of quality compost from source-segregated biodegradable waste. Online at www.environment-agency.gov.uk/subjects/waste and http://www.wrap.org.uk/composting/quality_protocol.html.

Table 3.5 Typical dry matter, C:N ratio, pH and nutrient contents of green waste composts, compost -like outputs (CLOs) from Mechanical Biological Treatment (MBT) of the organic fraction of municipal solid waste, solid digestates from anaerobic digestion (usually of kitchen waste or manure together with garden waste), tertiary-treated sewage sludge and de-inking paper fibre. Values were obtained from several different sources (see footnotes) and are expressed as kg t^{-1} on a fresh weight basis. Outputs from biological treatment of organic wastes are inherently variable and depend primarily on characteristics of the input wastes, thus these figures are indicative only.

Soil-forming material	% dry matter	C: N	pH	Nitrogen (N)		Phosphorus (P)		Potassium (K_2O)	Sulphur (SO_3)	Magnesium (MgO)	Calcium (CaO)
				Total	Available*	Total	Available**	Total	Total	Total	Total
Green waste compost	55 [A]	15 [A]	8.0 [A]	3.8 [A]	0.06 [B]	1.8 [A]	0.1 [B]	2.8 [A]	0.8 [A]	1.1 [A]	10 [A]
Municipal Solid Waste compost	55 [B]	25 [B]	7.3 [B]	5.3 [B]	0.07 [B]	0.52 [B]	0.02 [B]	6.9 [B]			39 [B]
Solid digestate from Anaerobic Digestion	38 [C]			9.9 [C]		4.6 [C]		3.3 [C]		3.2 [C]	15 [D]
Tertiary-treated sewage	25 [E]	12 [A]	6.0 [A]	7.5 [E]	0.75 [E]	9 [E]	4.5 [E]	Trace [E]	6 [E]	1.3 [E]	
De-inking paper fibre	67 [F]	>150 [F]	7.7 [F]	1.7 [F]	0.01 [F]	0.21 [F]	0.02 [F]	0.34 [G]	0.21 [G]	1.7 [G]	

* Available nitrogen is sum of soluble NO_3^- and NH_4^+. ** Available phosphorus is Olsen extractable PO_4^{3-}-P.

[A] Data re-expressed (assuming a dry matter content of 50%) from Ward and Litterick (2004) *Assessment of the potential variation in composted materials across the UK*. Prepared for the Waste and Resources Action Programme (WRAP), Oxon UK. Online at www.wrap.org.uk. Accessed August 2007.

[B] Data are mean of at least six representative samples analysed by the University of Wales, Bangor.

[C] Data from German anaerobic digestion plants processing 20% manure and 80% 'biobin' (kitchen and garden) waste. Re-expressed (assuming a dry matter content of 38% w/w) from Barth (2005) *Product and Application Differences of Compost and AD-Residues Based on Different Raw Materials, Treatment Technologies and Collection Areas*. Prepared for the Waste and Resources Action Programme (WRAP), Oxon UK. Online at www.wrap.org.uk. Accessed August 2007.

[D] Data are mean of at least three measurements reported in peer-reviewed scientific literature and UK product specifications.

[E] Data from MAFF (2000) *Fertiliser recommendations for agricultural and horticultural crops (RB209). 7th edition*. In revision. Online at http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm. Accessed August 2007.

[F] Data are mean of at least 10 representative samples from Shotton Paper (UPM Kymmene UK Ltd.) analysed by the University of Wales, Bangor.

[G] Data are mean of samples collected each month between May 2005 and March 2006 from Shotton Paper and analysed for Smith Grant LLP, Ruabon, Wrexham, UK.

3.3.2 Untreated green waste

Treating green waste by composting produces a quality product which, when mature, possesses physical and chemical characteristics suitable for propagating plants. Composting also decreases the mass of waste requiring disposal. However, when handled correctly, untreated green waste can also be a valuable soil-forming material and its use without treatment brings several key environmental benefits in terms of reduced CO_2 emissions associated with composting infrastructure and fuel use. Green waste does not necessarily require treatment to reduce pathogens and PTEs, indeed many batches of shredded untreated green waste delivered to composting sites meet standards for metals and pathogens specified by BSI PAS 100 for finished compost. Freshly applied green waste that has not been composted is not generally a suitable substrate for seeding and there is also a risk that untreated green waste will contain weed seeds. Untreated green waste can be incorporated with existing low organic matter soils at sites for restoration and then topped with an application of compost and left to settle for one month (during which most of the mass loss due to decomposition will occur) before seeding.

3.3.3 Tertiary-treated sewage sludge

Tertiary-treated and de-watered sewage sludge (also known as 'cake' or 'biosolids') is widely available and has a long history of use in agriculture, land restoration and bioremediation[19,20]. In the EU, the preferred disposal route is to land. Sewage sludge is an excellent source of organic matter and plant nutrients, containing large amounts of N (of which 10-20% is available in the year of application, depending on soil type and method of application[21]) and P. Of all the wastes considered here, sewage contains the most plant available P, with ca 4.5 kg of available P per tonne on a fresh weight basis.

In addition to previously mentioned concerns regarding PTEs in sewage, successful use of sewage in land restoration depends on fertility management. It is advisable to use sewage in combination with other less fertile organic wastes and composts where the aim is to create habitats of conservation value.

3.3.4 De-inking paper fibre

De-inking paper fibre (or paper 'sludge') is mostly composed of short wood fibres including lignin, cellulose and hemicellulose.[22] Paper fibre, long used on agricultural land and in land restoration, is a valuable soil-forming material and its high carbon content (much of which is held in molecules that resist microbial degradation) make it particularly suitable for increasing soil organic matter content and carbon storage with consequent improvements in water holding capacity. The benefits of adding paper fibre to agricultural soils are reported in a number of studies[23,24] and the value to crops of compost produced from paper fibre is recognised by the Composting Council of Canada.[25]

In the UK, as paper mills move towards using pulp in newly installed combined heat and power systems, the amount of fibre available is likely to diminish. However, overall amounts of de-inking paper sludge are increasing and it is expected that quantities will remain available for land restoration, especially when practitioners foster meaningful partnerships with paper manufacturers.

3.3.5 Compost like outputs and composted municipal solid waste

Mechanical Biological Treatment (MBT) is a generic term for an integration of several processes[26] designed to recover recyclable materials, and sometimes energy from bulk household waste (Municipal Solid waste; MSW), and reduce the volume of residual material sent to landfill. All MBT systems include an initial mechanical shredding and screening stage. Fine material separated at this stage, often using a trommel screen, has high organic matter content and is treated either by aerobic composting or anaerobic digestion. While the biological output from MBT is then either compost or digestate the term 'Compost Like Output' (CLO) is generally used. Depending on the quality of post-treatment screening and cleaning, CLOs, not being produced from

[19] Sopper (1993) *Municipal sludge use in land reclamation*. Lewis Publishers (CRC Press), Boca Raton, Florida, USA.

[20] Enviros (2004) *The Beneficial use of Sewage Sludge in Land Reclamation*. Published by Water UK, London. Online at www.water.org.uk. Accessed August 2007.

[21] MAFF (2000) *Fertiliser recommendations for agricultural and horticultural crops (RB209). 7th edition*. In revision. Online at http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm. Accessed August 2007.

[22] Chantigny *et al* (2000) Decomposition of de-inking paper sludge in agricultural soils as characterized by carbohydrate analysis. Soil Biology and Biochemistry **32**: 1561-1570.

[23] Chantigny *et al* (1999). Aggregation and organic matter decomposition in soils amended with de-inking paper sludge. *Soil Science Society of America Journal* **63**, pp. 1214–1221

[24] Gagnon *et al* (2001) Organic matter and aggregation in a degraded potato soil as affected by raw and composted pulp residue. *Biology and Fertility of soils* **34**: 441-447.

[25] Composting Council of Canada, online at www.compost.org/cccPaperMillResidueCompost. Accessed August 2007.

[26] Enviros and the University of Birmingham (2004) *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*. Published by DEFRA, Online at www.defra.gov.uk/environment/waste/research/health/index.htm. Accessed August 2007.

source-segregated materials, are more likely to be contaminated with metals, plastics, glass and sharps than green waste composts but, nevertheless, are a valuable source of organic matter and often contain greater amounts of plant nutrients. Operation of Europe's largest in-vessel composting facility at Attica's MBT plant, Greece, is described in **Box 9**.

Land restoration and cultivation of bioenergy crops are promising disposal routes (especially since use of CLOs in agriculture is more restricted than the other organic wastes and composts covered in this manual), but concerns regarding contaminants mean that at present CLOs are often either landfilled or used for daily cover at landfill sites.

3.3.6 Solid digestates from anaerobic digestion

An emerging technology, anaerobic digestion is the biological treatment of organic wastes (usually food waste or manure in mixture with green waste) in the absence of oxygen to yield methane (biogas) that can be used for heat and electricity generation or upgraded for use as vehicle fuel. Several different technologies exist for the treatment of wastes either at mesophillic (*ca* 37 °C) or thermophillic (*ca* 55 °C) temperatures to produce both liquid and solid outputs (digestates). A relatively short (1-2 weeks) post-composting stage carried out undercover drives off gases and odours produced during treatment. Liquid outputs can be applied to agricultural land as a valuable source of P. Solid outputs are more valuable in land restoration since they contain organic matter and are a valuable source of plant nutrients (**Table 3.5**). Levels of N, P and K are often higher in digestates than in green waste composts due to the characteristics of the input materials.

3.4 Producing compost for land restoration

3.4.1 Definition of composting

Composting is managed decomposition under aerobic conditions where oxygen is consumed by micro-organisms and CO_2 and water vapour are released along with trace amounts of other gases. Composting might be thought of as a semi-natural process, whilst decomposition of organic matter is a natural and crucial component of the carbon cycle. Composting facilitates optimum conditions for the biological oxidation of organic matter and hence may return carbon to the atmosphere more quickly than when wastes are spread to land without composting.

Composting results in a loss of mass of the input materials, known as 'feedstocks'. The rate of composting and the degree of mass loss mostly depend on the initial chemical characteristics of the feedstocks, which can be mixed to provide micro-organisms with a balanced supply of carbon and nitrogen.

3.4.2 Creating novel composts from mixed organic and mineral wastes

Although the full spectrum of essential plant nutrients can be found within the range of freely available waste materials, for land restoration it will almost certainly be necessary to blend several materials in order to more closely match the nutrient requirements of the target vegetation. Blending different waste materials creates substitute 'soils' with physicochemical characteristics [e.g. pH, WHC, N and P availability] more similar to those of natural soils (**Box 10**). It is also possible to mix mineral wastes together with organic wastes to produce topsoil conforming to a recognised British Standard (BS 3882: 2007 Specification for topsoil and requirements for use). A variety of mineral wastes and by-products (contaminated soils are considered in **Section 4**) can be composted in combination with organic wastes, blended with finished composts or organic wastes, or applied separately to the same site. Construction and excavation wastes are the single biggest waste stream in the UK; recycling them back to land in combination with organic wastes presents a significant opportunity to divert wastes from landfill.

Waste materials can be intimately mixed or applied separately to the same site. The former technique is more effective in producing soil-forming material of consistent quality and specialised plant is not required. A 360° tracked excavator can mix 2-3 t batches effectively within 10-15 minutes,[27] is highly portable and able to traverse rough terrain. It is also possible to mix wastes pre- or post-composting using a cattle feed mixer wagon (**Box 11**). The TWIRLS project found a twin vertical screw auger mixer wagon (**Picture 3**) to be more effective than a mixer wagon with horizontal augers. This technique allowed volumes of *ca* 16m^3 to be thoroughly mixed within 20 minutes and dispensed by conveyor into waiting trucks or composting vessels, minimising double handling. Although slightly less portable than a tracked excavator, a significant advantage of using a mixer wagon is the ability to accurately weigh different components of the mixture using the wagon's onboard scales. It is also possible to reduce contamination from, and loss of material to, the ground, which may be a significant problem when working at a site for restoration that does not have a concrete pad.

[27] Martin Lamb, TRL Centre for Sustainability (2006) *Increased recycling of quarry, biodegradable, green, construction, demolition and excavation waste stream through the manufacture of soils.* Published by the Waste and Resources Action Programme (WRAP), Oxon, UK. Online at www.wrap.org.uk. Accessed August 2007.

Picture 3 The TWIRLS project used a Biga twin-screw vertical auger cattle feed mixer wagon to blend different organic and mineral waste materials together pre- or post-composting. Here, de-inking paper fibre is mixed with tertiary-treated sewage sludge and slate mineral fines to produce low fertility soil-forming materials for slate quarry restoration. In addition to the excellent mixing, an advantage of using the mixer wagon is the ability to weigh wastes accurately using on-board scales and dispense wastes directly into waiting plant to minimise double handling.

When composting different organic and mineral wastes in combination it is necessary to consider the effect on temperature during composting. Adding mineral fines to organic feedstocks can enhance the composting process by stimulating activity of micro-organisms[28] but too high proportions can decrease temperatures during composting. For example, Williamson *et al* (2006)[29] report that inclusion of slate mineral fines as 40% of feedstock dry weight with tertiary treated sewage sludge and green waste depressed peak temperatures, resulting in poorer pathogen kill and greater germination of weeds from the finished compost (**Picture 2**).

In general, it is better to mix mineral wastes with maturing or stable compost than to include them as feedstocks for composting. For example a project commissioned by WRAP and lead by Hampshire County Council demonstrated that construction, demolition and excavation wastes could be blended with green waste compost to produce topsoil conforming to BS 3882: 2007 Specification for topsoil and requirements for use.[30]

3.4.3 Establishing a composting site

The Composting Industry Code of Practice[31] published by The Composting Association (www.compost.org.uk) contains detailed advice and best practice guidelines for establishing and operating composting sites. The EA's Technical Guidance on Composting Operations[32] is highly authoritative and worth consulting for regulatory as well as technical information such as specifications for concrete pavements, example site plans and details of appropriate plant. Existing land use, transport infrastructure and distance from receptors should be considered when establishing any composting site.

3.4.4 Pre-composting

Feedstock waste for composting is first delivered to a reception area, inspected for quality and waste transfer notes exchanged. Poor quality consignments, for example those containing significant amounts of non-biodegradable contaminants, may be refused at the gate. Wastes not specified in the Waste Management Licence or Paragraph 12 exemption must be returned to a facility licensed to treat them or removed to a licensed landfill site. The waste is then shredded to decrease particle size (smaller particle size = greater surface area for colonisation by micro-organisms = faster decomposition) and, if appropriate, mixed with other wastes to give a target C:N ratio of between 20 and 40. It is sometimes necessary to add a bulking agent to increase porosity and infiltration of oxygen. Bulking agents are not essential when composting green waste, which usually contains some woody material. Bulking agents such as woodchips or recycled oversize may be necessary when composting moist feedstocks, food waste, green waste containing a high percentage of grass clippings, or mixtures of tertiary treated sewage with

[28] O'Brien *et al* (1999) Container production of tomato with food by-products compost and mineral fines. *Journal of Plant Nutrition* 22: 445-457.

[29] Williamson *et al* (2006) Pathogen survival patterns in waste-derived composts destined for land restoration. *Proceeding of Waste 2006 Conference. Copies from The Waste Conference Ltd.*, University of Warwick Science Park, Coventry, UK.

[30] Martin Lamb, TRL Centre for Sustainability (2006) *Increased recycling of quarry, biodegradable, green, construction, demolition and excavation waste stream through the manufacture of soils.* Published by the Waste and Resources Action Programme (WRAP), Oxon, UK. Online at www.wrap.org.uk. Accessed August 2007.

[31] The Composting Association (2005) The Composting Industry Code of Practice. Published by The Composting Association, Wellingborough, Northamptonshire, UK.

[32] Environment Agency (2001) Technical Guidance on Composting Operations. Online at www.netregs.gov.uk/netregs/processes/636862. Accessed August 2007.

other feedstock materials. It is recommended that for composting food waste by any of the methods described below, a minimum of 25% of structural material should be included.[33]

3.4.5 Choice of composting technology

Aerobic composting can either be performed using open-air windrows (mechanically turned or 'static pile'), windrows inside sheds or bays, or by placing composting material in sealed vessels. In-vessel systems are space efficient, may offer greater process control and faster composting time (**Table 3.6**), and help to reduce the production of unpleasant odours and bioaerosols. However, they are more expensive and consume more materials and energy and need only be used where i) regulators stipulate their use, e.g. for composting animal by-products, or ii) they offer real environmental and human health benefits (e.g. reduced exposure to bioaerosols, treatment of exhaust gases). In some cases regulatory approval and planning consent are more likely to be given due to *perceived* benefits of in-vessel systems although the overall environmental impact of an in-vessel system may be greater when infrastructure and fuel use are considered.

In general, the chemical characteristics of finished composts produced aerobically are not related to composting technology (windrow vs in-vessel).[34] Input materials determine the nutritional quality of compost.

Table 3.6 Typical composting times for selected methods and materials. Redrawn from the Environment Agency's Technical Guidance on Composting Operations (2001).

Method	Materials	Range	Typical	Maturing time
Passive composting	Leaves Manure	2 – 3 years 6 months to 2 years	2 years 1 year	- -
Windrow -infrequent turning (front end loader)	Leaves Manure	6 months to 1 year 4 – 8 months	9 months 6 months	4 months 1 – 2 months
Windrow -frequent turning (special turner)	Manure	1 – 4 months	2 months	1 – 2 months
Passively aerated windrow	Manure + bedding Fish wastes + peat moss	10 – 12 weeks 8 – 10 weeks	- -	1 – 2 months 1 – 2 months
Aerated static pile	Sludge + wood chips	3 – 5 weeks	4 weeks	1 – 2 months
Rectangular agitated bed	Sludge + green waste or manure + sawdust	2 – 4 weeks	3 weeks	1 – 2 months
Rotating drums	Sludge and / or solid wastes	3 – 8 days	-	2 months (+ windrowing)

[33] Hogg *et al* (2007) Dealing with food waste in the UK. Report prepared for the Waste and Resources Action Programme (WRAP) by Eunomia Research and Consulting, Bristol, UK. Online at www.wrap.org.uk

[34] Barth (2005) Product and Application Differences of Compost and AD-Residues Based on Different Raw Materials, Treatment Technologies and Collection Areas. Prepared for the Waste and Resources Action Programme (WRAP), Oxon UK. Online at www.wrap.org.uk. Accessed August 2007.

3.4.5.1 Windrow composting

Composting in mechanically turned open-air windrows is by far the most common method and is used by nearly all local authorities in the UK, primarily to treat green waste. At licensed sites, windrow composting is normally carried out on concrete pads with sealed drainage. After shredding to *ca* 50 mm, green waste is formed into windrows - mounds approximately 3.5 m high, 4 m wide and as long as space and feedstock volumes permit, but usually around 6 m. Dimensions vary according to feedstock wastes and the plant used to turn them. Dense materials, such as manures or tertiary treated sewage sludge should not be stacked more than 1.5 m high since diffusion of oxygen through the composting mass is restricted. Light materials, such as green waste can be formed into mounds as high as 6 m, provided that the frequency and method of turning are sufficient to avoid anaerobic zones at the centre of the windrow.

Wastes are turned using a loading shovel or specialised compost turner (**Picture 4**) to increase aeration and ensure that all organic matter comes into contact with composting micro-organisms. Frequency of turning usually reduces throughout the composting process with requirement for oxygen peaking during the thermophillic phase. Minimum turning frequencies are specified when composting in accordance with BSI PAS 100. When composting animal by-products in windrows (housed in sheds) compost must be turned every two days during sanitisation.[35]

Picture 4 Composting, even in open-air windrows, is an increasingly mechanised process. Green waste is usually shredded to 50 mm prior to composting, windrows are mechanically turned and the finished compost is screened to remove over-size and produce a high quality product. Here a 'straddle' turner is used to turn a green waste windrow at Little Bushey Warren, near Basingstoke, the UK's largest composting facility owned and operated by Veolia ES Onyx Ltd., processing *ca* 50,000 t per annum.

Windrow composting may not provide sufficient aeration when composting tertiary-treated sewage sludge in combination with other organic waste materials. Additional aeration is required since the high density and moisture content of sewage restricts diffusion of oxygen into the composting mass and can lead to the production of methane and unpleasant odours. Sewage can be composted in aerated static piles, which are similar to windrows but are not turned mechanically. Instead forced aeration is provided by means of an aeration plenum, pipe or trench. Finished compost is sometimes used to cover the static pile to provide insulation.

3.4.5.2 Static in-vessel systems

Sealed systems come in many shapes and sizes including housed windrows, tunnels, agitated bays, bins, rotating drums and modular containerised systems. For processing some controlled wastes (such as animal by-products) regulators may specify a covered waste reception area as well as a highly impermeable surface area for post-composting activities and a storage area for finished product.[36]

A feature common to all in-vessel systems (and aerated static piles) is mechanical aeration. This is usually provided using aeration fans to either blow or suck air through the composting mass and is achieved in various ways depending on the design of the system. The aeration regime in technically advanced systems is often computer controlled and linked to one or more process control parameters (most commonly temperature); some systems re-circulate moist air to maintain moisture content of the composting mass.

A significant advantage of some in-vessel systems is the ability to capture and treat gases emitted from the composting mass. Amounts of bioaerosols, odours, and ammonia can be reduced using burners, biological filters or chemical scrubbers. In the future 'carbon-capture' technologies may also be incorporated and this may alter the environmental cost/benefit comparison between windrow and in-vessel systems.

3.4.5.3 Portable systems

When considering co-composting as method of remediating contaminated soil portable on-site in-vessel systems (see **Section 4**) may offer a significant advantage since the need to transport contaminated soil (potentially creating source-receptor linkages and requiring licensed couriers) is avoided. Regulatory approval for composting at unlicensed sites is also more likely where in-vessel systems are used due to the real or perceived human health and environmental benefits.

[35] The Composting Association (2005) *The Composting Industry Code of Practice*. Published by The Composting Association, Wellingborough, Northamptonshire, UK.

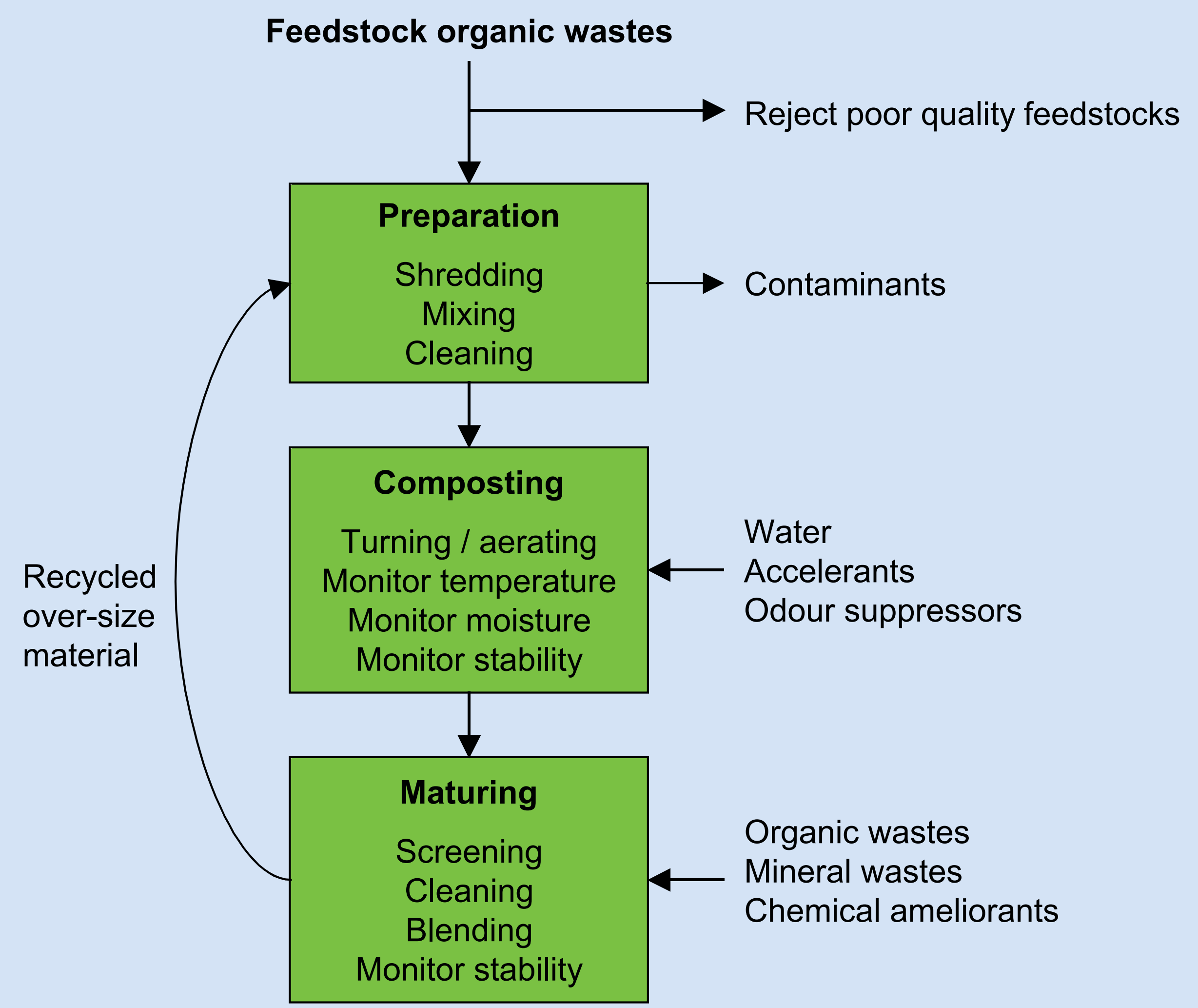
[36] Environment Agency (2001) *Technical Guidance on Composting Operations*. Online at www.netregs.gov.uk/netregs/processes/636862. Accessed August 2007.

Portable composting vessels include the EcoPOD® system, bins, modified tankers and shipping containers. As with static systems, the composting mass must be aerated and in portable systems this is usually achieved by using fans. In the EcoPOD® system, a perforated plastic pipe is inserted automatically into each plastic composting vessel as the vessels are loaded with feedstock wastes. The pipe is then connected to a timed aeration fan, powered by a diesel generator.

3.4.6 Monitoring and controlling the composting process

Managed composting involves monitoring a number of process control variables, primarily, temperature, moisture content and stability. Monitoring systems vary in sophistication, from experienced operators performing 'squeeze tests' to assess moisture content during windrow composting to continuous online electronic analysis in technically advanced in-vessel systems. Monitoring

Figure 3.1 The composting process, simple flow diagram. Feedstock organic wastes are inspected for quality with poor quality feedstocks rejected at the gate. Wastes are then shredded, cleaned (i.e. plastic and glass contamination is removed) and mixed (if appropriate) before being formed into windrows or loaded into sealed vessels. Temperature and moisture content are monitored during composting and water is added if required. Commercially available accelerants and odour suppressors are sometimes used. Compost is screened to remove oversize, reduce contamination and produce the desired grade of product before or after maturation. At this stage untreated waste materials or chemical ameliorants can be blended with the compost and stability indicators are monitored until maturation is deemed complete.



frequencies and locations are stipulated for composting sites run according to BSI PAS 100 processing standards. For accredited and non-accredited sites alike, monitoring frequencies should be identified in a HACCP plan.

3.4.6.1 Temperature

Temperature monitoring is necessary to ensure that pathogen kill and weed sterilisation temperatures are met (**Table 3.2**) during the thermophillic phase of composting. Compost temperature depends upon a number of factors: chemical characteristics of the feedstock wastes, surface area to volume ratio of the composting mass, and aeration regime. Temperature can vary substantially in a windrow and is likely to be cooler at the surface. Measurements should be taken at a number of different locations and depths using a temperature probe. A number of data logging systems, including wireless systems (e.g. see www.tinytag.info), are available (**Picture 5**).

It is also necessary to ensure that temperatures do not rise high enough to impair microbiological activity or risk spontaneous combustion. If compost temperatures exceed 80°C it may be necessary to add water or adjust the frequency of turning or the forced aeration regime.

Picture 5 A variety of systems are available for monitoring and recording temperature during composting . Here, a radio-linked Tinytag temperature probe and data logger is inserted into an EcoPOD® sealed composting vessel.

3.4.6.2 Moisture

The composting process depends upon diffusion of microbial enzymes in water films: optimal moisture content is between 40 and 65% and decomposition will proceed only very slowly at moisture contents of less than 10%. There is also a risk of spontaneous combustion if the composting mass becomes too dry. Moisture can be monitored using a moisture probe or meter, or by taking samples, weighing, drying and re-weighing. Water should be added if the compost moisture content falls below 40%, particularly during the thermophillic phase of composting. Initial moisture content of feedstock wastes can be increased using stored leachate but it is not advisable to add leachate to compost once sanitisation temperatures have been reached due to the risk of reinfection.

3.4.6.3 Stability

Use of unstable compost in land restoration is of potential concern since germination of seeds can be inhibited. In contrast, for bioremediation it may be better to use unstable compost where rates of transformation of organic pollutants, or chelation of metals to organic compounds, are likely related to microbiological activity. For bioremediation it may be possible to reduce maturation time substantially, allowing compost to stabilise after application but before attempting plant establishment.

Stability can be monitored in a number of ways, including measuring evolution of CO_2 or electrical conductivity, but there is no single method of test and stability limit agreed amongst EU members.[37] The 'self-heating test' is a widely used method and can be performed on site with a minimum amount of equipment. Full method details for the self-heating test are available online in the EA's *Technical Guidance for Composting Operations*.[38]

3.4.6.4 Accelerants and odour suppressors

There have been few peer-reviewed studies into the efficacy of compost accelerants: additives designed to accelerate the composting process (thus increasing throughput) by providing microbial innocula and/or growth substrates. One study[39] found that a commercial accelerant increased compost temperature and reduced emissions of ammonia from composting beef manure, both desirable outcomes. Different accelerants are commercially available and are used at several large composting sites in the UK.

Production of odours is a key concern of regulatory bodies and obtaining permission to compost will

[37] The Composting Association (2005) *The Composting Industry Code of Practice*. Published by The Composting Association, Wellingborough, Northamptonshire, UK.

[38] Environment Agency (2001) *Technical Guidance on Composting Operations*. Online at www.netregs.gov.uk/netregs/processes/636862. Accessed August 2007

[39] Sasaki *et al* (2006) Effect of commercial microbiological additive on beef manure compost in the composting process. *Animal Science Journal* **77**: 545-548.

depend on the applicant demonstrating that systems are in place to minimise this. Maintaining proper control over compost moisture content and feedstock C:N ratio will reduce odour generation; it is also necessary to pay attention to wind-speed and direction when turning windrows. It is inevitable that some odours will be produced and for this reason a number of companies produce odour neutralisers - non-toxic formulations that can either be mixed with compost or sprayed as aerosols onto windrows, around the perimeter of composting sites or inside composting sheds or bays. Spray systems are available in various sizes and as portable or static versions. Costs vary accordingly.

3.4.7 Processing and storing finished compost

The amount of time and effort put into refining and maturing compost depends on the degree of contamination of the feedstock materials, the efficiency of cleaning at the pre-composting stage and the intended use. Stable compost, screened to at least 10mm, is best for establishing vegetation by direct seeding soon after the compost has been spread. In contrast, maturation is not necessary for bioremediation where very active microbial populations are desirable. In some cases, to increase throughput at the composting site, immature compost may be spread to the site for restoration up to two months before seeding/planting.

Where possible, finished or maturing compost should be kept under cover to prevent leaching of nutrients by rain, contamination by weed seeds or reinfection by pathogens (e.g. in bird faeces).

Picture 6 Finished green waste compost produced at a local authority composting site is screened to remove plastic contaminants.

3.5 Using organic wastes and composts to create habitats of conservation value

Creating biodiverse habitats using wastes or other soil-forming materials (e.g. translocated topsoil or peat) is complicated. Balanced, natural habitats develop over many years and a particular habitat cannot be created by constructing a soil, identical in every feature to a target natural soil and then seeding with the full range of target species. In all cases, germination tests and preliminary field trials are essential before proceeding with large-scale restoration.

3.5.1 Managing fertility

The approach to improving substrate fertility for restoration requires careful consideration. Availability of N is most likely to limit initial plant establishment whilst organic products and wastes that are suitable for land restoration contain levels of plant available P in excess of natural soils. That even green waste composts can be *too fertile* may be surprising to some producers of horticultural composts, where the focus is sometimes on increasing compost fertility. However, composts often contain amounts of plant available P far higher than soils supporting biodiverse grassland[40] or heathland.[41] Indeed, the rarest species persist under conditions of P limitation.[42] Whilst this is not necessarily a problem for creating managed amenity grassland, it may present problems for creating biodiverse self-sustaining habitats that do not need to be managed intensively.

The challenge then is to add sufficient nutrients to enable plants and microbial processes to become established with the ultimate aim of producing an ecosystem where nutrients are recycled between plants and soil by a properly functioning microbial biomass. At bare sites, low in nutrients and organic matter, sufficient amounts of soil-forming materials must be added to avoid nutrient deficiency and drought during early plant establishment. Adding amounts of nutrients found in target natural soils is likely to be insufficient since this does not take into account the very high flux (exchange) of nutrients between plants and soil. In this case it is necessary to *add more nutrients than would normally be found in the target soils* and then actively manage the developing vegetation to reduce or increase fertility as indicated by performance of target species and levels of nutrients in soil.

Amounts and availabilities of nutrients in mineral fertiliser are well characterised. Mineral fertiliser is

[40] McCrea *et al* (2001) Relationships between soil characteristics and species richness in two botanically heterogenous created meadows in the urban English West Midlands. *Biological Conservation* **97**: 171-180.

[41] Pywell *et al* (2002) The potential for lowland heath regeneration following plantation removal. *Biological Conservation* **108**: 247-258.

[42] Wassen *et al* (2005) Endangered species persist under conditions of phosphorus limitation. *Nature* **437**: 547-550.

commonly applied at 100 kg N ha^{-1} to reclamation plantings but accumulation of organic matter is slow without subsequent top dressings and relatively few examples of self-sustaining systems exist with this management.[43] Organic wastes and composts offer clear advantages over mineral fertiliser as they contain water holding organic matter, nutrients in slow release forms and the micro-organisms needed to release them. A complication with using organic products and wastes is that they vary in their ability to supply nutrients and there is a good deal of uncertainty regarding the patterns of nutrient release from different materials over time. Sewage has been studied most because of its long history of use in agriculture. Release of N and P from green waste composts is not very well understood and nutrient release from MSW composts and solid digestates from anaerobic digestion even less so.

The TWIRLS project established a large field trial (**Box 12**) to find out how well a range of composted materials could be used for restoration and found that after two years, biomass and biodiversity in created mesotrophic grassland plots were greater (plots most similar to target habitat, National Vegetation Classification MG5b) where composted waste materials were applied at a rate of 500 wet t ha^{-1} than when composts were applied at half this rate, or not at all, to a sandy site containing very low existing levels of nutrients and organic matter. The rate of 500 t ha^{-1} provided approximately 2100 kg total N ha^{-1} (of which a maximum of 100 kg N ha^{-1} is immediately available) and 80 kg plant available P ha^{-1}.

On the basis of these findings and a review of current literature, we suggest rates of P addition suitable for creating a variety of target habitats (**Table 3.7**). Availability of nutrients varies substantially between different organic wastes and composts (green waste compost is provided for comparison) and practitioners must assess nutrient availability from soil-forming materials prior to their use over a large area. In all but the highest rate of application, available N will be supplied at less than <100 kg ha^{-1} and it is advisable to raise plant available N in soil-forming materials (to at least 100 kg ha^{-1}). Since there are few organic wastes or products that contain more N than P, it may be necessary to apply slow release mineral N fertiliser in the year of site establishment, or soluble N fertiliser for two years after site establishment.

We assume that supply of other nutrients (for example, K, Mg, Ca) will be adequate from most organic wastes and composts for creating habitats of conservation value at these rates of N and P addition. A possible exception, when sewage sludge comprises a large proportion of soil-forming materials, is available K (potassium; potash). However, previous restoration experiments (**Boxes 13 and 14**) have demonstrated that nutrients available from sewage are sufficient for creating woodland on bare quarry sites without additional K. For restoring land to productive land use, e.g. bioenergy crops, it may be necessary to add extra K, for example in green waste compost and by recycling stabilised wood ash back to land.

Table 3.7 Soil phosphorus guidelines for creating habitats of conservation value. Recommended amount of P was determined experimentally for neutral grassland in a two-year habitat creation trial and has been adjusted for other habitats by reviewing the available literature. Equivalent rates of application of typical green waste compost are provided; in all cases practitioners must assess availability of nutrients in soil-forming materials and the existing soil and apply soil-forming materials on the basis of *plant available NOT total* nutrients.

Habitat	Available P (kg ha^{-1})	Equivalent rate green waste compost (wet t ha^{-1})
Neutral grassland	80	500
Acid grassland	50	315
Calcareous grassland	50	315
Heathland	30	190
Woodland	80	500
Wetland	60	380

[43] Marrs (1989) Nitrogen accumulation, cycling and the restoration of ecosystems on derelict land. **Soil Use & Management**, **5**, 127-134.

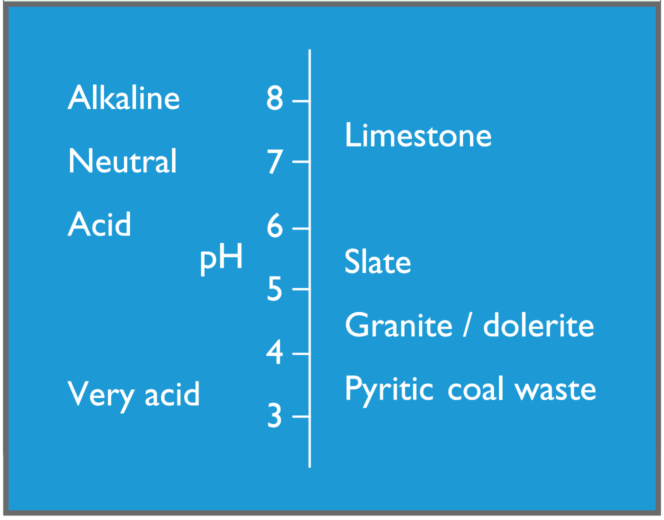
Amounts of P recommended in **Table 3.7** are as much as six-fold the amount present in natural soils supporting the equivalent vegetation. This may seem high but it is better to add enough P to enable successful establishment of vegetation at bare sites than to add insufficient P and risk failure. Levels of P in soil will quickly drop as plant biomass increases but implicit in this approach is the need to monitor developing vegetation and soils and manage fertility. This is best achieved by removing biomass by cutting, grazing or burning as is appropriate for the vegetation type. If it is necessary to use organic waste materials or products at rates that will supply nutrients in excess of the recommendations in **Table 3.7**, for example to produce a rooting depth of greater than 10 cm, fertility can be reduced by:

- mixing high nutrient organic wastes and composts with low nutrient organic or mineral materials prior to land-spreading
- incorporating soil-forming materials with pre-existing nutrient poor soils at the site for restoration
- chemically ameliorating soil-forming materials to reducing availabilities of key nutrients without altering availability of nutrients that may limit vegetation establishment, for example to reduce availability of P but not N and K.

3.5.2 Adjusting pH

Soil pH is a critical factor in determining which plants will establish successfully and how different sown, planted or naturally established species will interact with each other; pH also influences soil nutrient availability with P most available between pH 6 and 7. The substrate pH at the site for restoration must be taken into account when considering suitable target vegetation. The pH of rock wastes produced by mining or quarrying varies (**Table 3.8**) from alkaline (limestone) to very acidic (pyritic coal waste). It is often desirable to work with the existing pH, e.g. by creating calcareous grassland on alkaline wastes, but it may be necessary to adjust the pH of the substrate or soil-forming materials, for example to remediate very acidic coal waste or to create substitutes for acid soils in upland areas. Organic wastes are commonly of neutral pH irrespective of the pH of the feedstock materials; compost is usually between pH 7 and 8.

Table 3.8 Typical pH values for different rock wastes after initial weathering. Redrawn from Williamson *et al* (2003).[44]



3.5.2.1 Lowering pH

That composts and many organic wastes are commonly of neutral pH *may* make them unsuitable as substitutes for acidic soils without further modification. This is unfortunate since there is great need for soil-forming materials in areas where target habitats are usually found on acid soils. For example, in Gwynedd alone there are an estimated 730 Mt of slate quarry waste, with a further 6 Mt produced every year. Natural soils in the Welsh uplands are almost exclusively acidic (pH <6) and, as heather moorland is a priority habitat in Wales, compost would seem unsuitable without modification.

Acidic materials, organic and mineral wastes can be used to reduce the pH of composts and soils. In particular, elemental sulphur (S^0) effectively lowers the pH of compost when added during maturation[45,46] or mixed with finished compost.[47] There is a considerable body of research into the effects of acidifying soil for the purposes of heathland and grassland (re)-creation[48] and a range of techniques are reviewed by Walker *et al* (2004)[49] and Marrs (1993).[50]

[44] Williamson *et al* (2003) *Restoring habitats of high conservation value after quarrying*: best practice manual. University of Wales, Bangor.

[45] Mari *et al* (2005) Use of sulphur to control pH in composts derived from olive processing by-products. Compost Science and Utilisation 13: 281-287.

[46] Roig *et al* (2004) The use of elemental sulphur as organic alternative to control pH during composting of olive mill wastes. Chemosphere 57: 1077-1105.

[47] Nason *et al* (2006) Physical and chemical characteristics of composted wastes can be altered to make them suitable for large scale habitat creation. Proceeding of Waste 2006 Conference. Copies from The Waste Conference Ltd., University of Warwick Science Park, Coventry, UK.

[48] Owen and Marrs (2001) The use of mixtures of sulphur and bracken litter to reduce the pH of former arable soils and control ruderals species. Restoration Ecology 9: 397-409.

[49] Walker *et al* (2004) The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. Biological Conservation 119: 1-18.

[50] Marrs (1993) Soil fertility and nature conservation in Europe: theoretical considerations and practical management solutions. Advances in Ecological Research 24: 241-301.

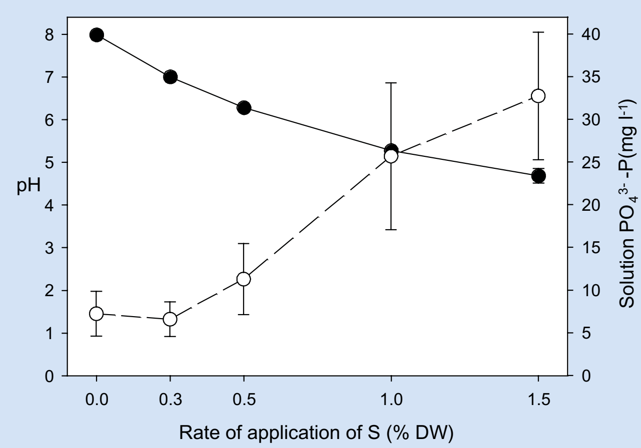
Use of acidic materials with compost is perhaps more problematic due to the high pH buffering capacity of compost and the unpredictable rate of generation of acidity, which is dependent on temperature and moisture. Nonetheless, it is possible to reduce compost pH using a variety of organic and chemical materials, some of them wastes (for example sulphurous wastes produced as by-products from refining crude oil) and some products (including S^0, iron- and aluminium-sulphate purchased from chemical companies). Bracken litter and pine chippings are of potential value as acidic feedstock wastes for composting or additives to finished compost.

When adjusting the pH of composts and soil-forming media it is essential to conduct preliminary trials to assess the likely rate and magnitude of pH change and the altered availabilities of PTEs and plant nutrients. Lowering compost pH by 1-2 units substantially increases the availability of phosphate-P (**Figure 3.2**), which may be highly desirable for establishing amenity grassland or producing compost for horticulture, but not when creating habitats of conservation value where high P availability is associated with low diversity. The availability of a range of metals is also related to pH but, provided that amounts of metals in the compost and the ameliorant are low, this should not be of concern. Where significant (but still regulatory acceptable) amounts of metals are present it is advisable to assess the change in availability and mobility, particularly of metals that form positive ions such as lead, copper, zinc and cadmium (availabilities of metals that form negative ions is lower at acid pH). The simplest way to do this is to analyse a water extract of the materials. Accredited laboratories should have the facilities to do this.

Land application of S^0 is a well established agricultural practice and there are no regulatory reasons why this technique cannot be used for creating acidic habitats. However, to do this may be a missed opportunity when considering composts. Since the rate and amount of acidity generated by adding S^0 and a range of sulphurous wastes is greater under warm, moist conditions, desired pH reductions may be achieved more quickly if additions are made during composting or immediately prior to maturation. Again, preliminary trials are recommended to assess the effectiveness of these techniques since feedstock wastes for composting are inherently variable and there have been surprisingly few studies into techniques for adjusting compost pH.

As a rough guide, a two-unit reduction in pH should be achievable during maturation by adding finely divided S^0 at a rate of 1% of the total dry weight of the compost, provided that the S^0 is thoroughly mixed with the compost and the addition is made under warm, moist conditions. Rates of application and time taken to achieve desired reductions in pH will vary considerably when using sulphurous or acidic organic and chemical waste materials. Higher rates of addition may be needed when S^0 is spread to land and it may take considerably longer for the pH reduction to occur. For example, a 0.6 unit reduction in pH of a sandy arable soil was achieved five years after addition of S^0 at 3-6 t ha^{-1}.[51]

Figure 3.2 (redrawn from Nason *et al* 2006) pH (closed circles) and phosphate-P (open circles) of compost solution sampled from pots containing composted green waste, 14 d after addition of elemental sulphur at 0, 0.25, 0.5, 1 or 1.5% total dry weight. Data are mean ± SE, n = 30.



3.5.2.2 Raising pH

At some sites it may be necessary to mitigate increasing soil acidity that can result from applications of mineral fertiliser and weathering of rocks. Lime and gypsum are traditionally used, as is pulverised fuel ash. The high pH buffering capacity of organic wastes means they are often highly effective at increasing soil pH when used at appropriate rates. Lime stabilised sewage sludge has a neutralising value of 10-20%,[52] de-inking paper fibre and construction and demolition wastes are also useful liming materials.

3.5.3 Chemical amelioration to reduce phosphorus availability

For grassland, high floristic diversity is generally associated with low levels of soil P[53] and, whilst habitats can be managed to reduce P availability (e.g. by harvesting vegetation), this approach can take decades and incurs extra management costs.

[51] Pywell *et al* (2000) Reversion of intensive arable land to grass heath and Calluna heath: vegetation aspects. Report to the Ministry of Agriculture, Fisheries and Food (BD1502), Institute of Terrestrial Ecology (now Centre for Ecology and Hydrology), Monks Wood.

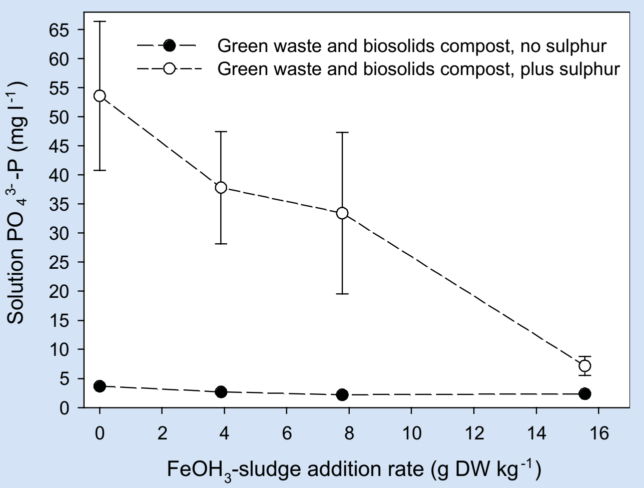
[52] MAFF (2000) Fertiliser recommendations for agricultural and horticultural crops (RB209). 7th edition. In revision. Online at http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm. Accessed August 2007.

[53] Critchley *et al* (2002) Association between lowland grassland plant communities and soil properties. Biological Conservation 105: 199-215.

In addition to the techniques detailed above, chemical amelioration can be an effective method of lowering the availability of P in soil and this approach is particularly suitable when producing soil-forming media from organic products and wastes as these can be modified, tested and trialed before use in large-scale restoration. Amongst several techniques for reducing the availability of P in soil, the addition of oxides and hydroxides of iron (Fe) and aluminium (Al) that form insoluble or slow-release P-compounds can be highly effective.[54] This is also of potential value in controlling runoff of P from sites receiving high or repeated rates of application of P-rich organic materials.

Ameliorants are available either as pure chemicals or as organic or mineral waste materials. In the case of P, Fe-hydroxide and Al-sulphate can be highly effective and are available either as pure chemicals or as components of some wastewater treatment sludges. For example in pot trials, Nason *et al* (2006)[55] found that levels of solution phosphate-P (PO_4^{3-}-P) in compost produced from green waste and sewage sludge and amended with S^0 (to reduce pH) could be reduced 10-fold by addition of a mine water treatment sludge at *ca* 16 g kg^{-1} on a dry weight basis (**Figure 3.3**). In this particular case, unacceptable levels of arsenic meant that the de-watered sludge, which originated from a coke storage site, could not be used for land restoration but other organic wastes may be more suitable and merit consideration. This is especially true for some water treatment work sludges that can be blended with quarry by-products to produce infertile 'special purpose' topsoil conforming to BS 3882 (specification for topsoils and requirement for use) under the EA's low-risk regime.

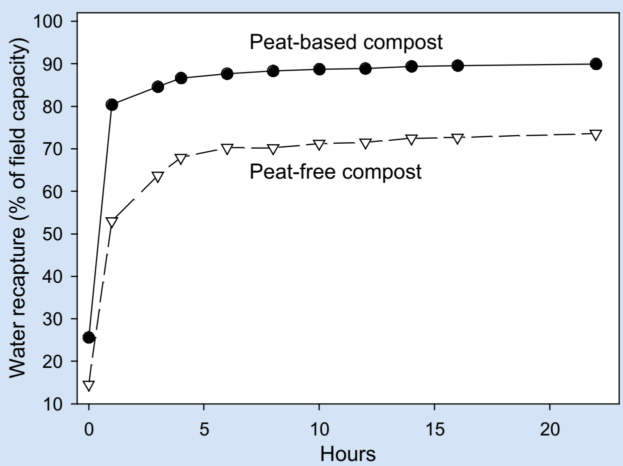
Figure 3.3 (redrawn from Nason *et al* 2006) Phosphate-P (PO_4^{3-}-P) in compost solution sampled from pots containing green waste and sewage compost with (open circles) or without (closed circles) elemental sulphur at a rate of 1% total dry weight. Solution was sampled 14 d after addition of iron hydroxide-rich mine water treatment sludge at 0, 4, 8 or 16 g kg^{-1} DW. Data are mean ± SE, n = 6.



3.5.4 Increasing water holding capacity

Drought, particularly during early establishment, is a key concern of restoration programmes even in areas of high rainfall, since soil at post-industrial sites lacks water holding organic matter. Unfortunately, poor WHC is a feature of some commercial composts formulated from organic waste materials; the problem seems to be that, although peat-based and peat-free composts hold similar amounts of water at field capacity, green waste composts do not recover well from drought (**Figure 3.4**). In soil, WHC is a function of particle size distribution and organic matter content and there is generally a positive linear correlation between WHC and organic matter content,[56] although clay-sized mineral particles are also important. There is no reason why water storage and release properties of composted waste materials cannot be improved through careful blending of different organic waste materials.

Figure 3.4 Water re-capture (rewetting potential) following drought of peat-based compost in comparison with peat-free compost. Both composts were purchased from a major UK supplier, moistened to field capacity water content (FC_W) and allowed to dry to 5% FC_W content before re-wetting. Data are mean, n = 3.



Organic wastes with a high carbon and low nutrient content (e.g. paper fibre, see **Table 3.9** and **Box 15**) can be valuable components of soil-forming materials or composts for use in land restoration since they improve WHC and reduce nutrient availability both by dilution and by biological immobilisation. De-inking paper fibre is particularly valuable since it holds approximately double its own dry weight in water and its macromolecular structure means it decays relatively slowly with long-lived benefits on soil structure and organic matter content. Paper fibre (and other high

C:N ratio materials) *may* inhibit growth of plants when used in too high proportions but this will depend on the other feedstocks present e.g. proportionately more paper fibre can be used if sewage is added in similar proportions.

The TWIRLS project demonstrated that for promoting establishment of mesotrophic (MG5b) grassland at a bare sandy site, compost produced from green waste, paper fibre and sewage sludge (35:35:30 by dry weight) performed significantly better than compost produced from just green waste, or from a mixture of green waste and sewage sludge (**Box 12**). A likely reason is the improved WHC afforded by the paper fibre, particularly since plants were establishing under drought conditions, a situation that will become more common in the UK given current models of environmental change.

Chemical additives are also available that may increase WHC of soil-forming materials, these include water-absorbing polymer gels commonly used in horticultural compost and for stabilising and vegetating motorway embankments. In the UK, polymer gels have been trialed for use in slate quarry restoration[57] and research into their effectiveness as a component of soil-forming material produced from organic wastes is ongoing. However, as a general principle of sustainable (and economical) land restoration it is better to reuse waste materials wherever possible than to synthesise and purchase chemical additives.

3.6 Applying compost and other soil-forming materials

Soil-forming materials can either be spread to land, incorporated with pre-existing soils at the site for restoration (e.g. to create infertile soils) or used in planting pockets. The choice of spreading technique and machinery depends upon terrain, the nature of pre-existing soil or substrate, volume and characteristics of soil-forming materials and fertility requirements. To a lesser extent the rooting depth requirements of target species may influence application depths. There are also a number of special considerations that may influence spreading methods and application rates, including proximity to watercourses, a desire to dilute compost fertility with pre-existing nutrient poor soils, or a desire to spread compost in patches to encourage development of a mosaic of different vegetation types.

3.6.1 Site preparation

In addition to any large-scale landforming, contouring or reshaping it is important to prepare the existing substrate prior to applying soil-forming materials. A tracked excavator is useful for 'ripping' compacted surfaces to improve drainage and improve adhesion of soil-forming materials prior to spreading (**Picture 7**). Compacted surfaces inhibit vegetation establishment by preventing root growth. Sub-surface flows of water along compacted surfaces cause significant erosion and nutrient losses by leaching.

Table 3.9 Water-holding capacities of composts produced using EcoPOD® in-vessel composters at Blaenau Ffestiniog (redrawn from Nason *et al* 2006)[55]. To reduce compost fertility, de-inking paper fibre was mixed with two different composts at a rate of 1:1 by dry weight. Adding paper fibre increased water content at field capacity (FC_W), at permanent wilting point (PWP_W), and available water content ($AWC_W = FC_W - PWP_W$) when plots were sampled two months after spreading. Compost 1 - green waste + sewage + de-inking paper fibre, Compost 2 – green waste + sewage + slate processing fines. Data are mean ± SE, $n = 4$.

Compost	FCW (g H2O g-1 DW)	PWP_W (g H2O g-1 DW)	AWC_W (g H2O g-1 DW)
Compost 1	1.1 ± 0.1	0.20 ± 0.08	0.87 ± 0.08
Compost 1 + paper fibre	1.6 ± 0.2	0.24 ± 0.20	1.3 ± 0.2
Compost 2	0.74 ± 0.02	0.14 ± 0.02	0.60 ± 0.02
Compost 2 + paper fibre	1.3 ± 0.1	0.08 ± 0.11	1.2 ± 0.1
Paper fibre	1.9 ± 0.1	0.25 ± 0.10	1.6 ± 0.1

[54] Gilbert *et al* (2003) Chemical amelioration of high phosphorus availability in soil to aid restoration of species-rich grassland. Ecological Engineering 19: 297-304.

[55] Nason *et al* (2006) Physical and chemical characteristics of composted wastes can be altered to make them suitable for large scale habitat creation. Proceeding of Waste 2006 Conference. Copies from The Waste Conference Ltd., University of Warwick Science Park, Coventry, UK.

[56] Emerson (1995) Water-retention, organic-C and soil texture. Australian Journal of Soil Research 33: 241-251.

[57] Rowe *et al* (2005) Initial tree establishment on blocky quarry waste ameliorated with hydrogel or slate processing fines. *Journal of Environmental Quality* 34: 994-1003.

Picture 7 Slate quarry waste contoured to match the adjacent hillside and ripped using the teeth of a digger bucket to improve adhesion of soil-forming materials.

3.6.2 Application depth

In general, 20 cm rooting depth is adequate for both trees and grasses and, subject to particle size, moisture retention and nutrient status, this is likely to be sufficient in most quarry[58] and brownfield site reclamations. While most trees can thrive in reasonably shallow soils provided that they have sufficient access to water and nutrients, shallow rooting greatly increases the risk of wind throw. This hazard is strongly linked to the wind exposure of the site. Therefore, a greater rooting depth will need to be provided in sites with high wind exposure if large trees are to be established either by adding a greater depth of soil-forming material or enabling tree roots to penetrate the substrate below (either by ripping compacted layers or filling voids with finer material, as appropriate to the site conditions). This may also improve the growth of tap-rooted tree species (e.g. Scots pine, *Pinus sylvestris*). Soil-forming materials and leachate travel down slopes and adhesion can be increased by ripping the substrate before application or, where access allows, creating lenses or small terraces. With careful use of available resources it is also possible to recreate a graded soil profile appropriate to the target habitat and local geology.[63]

It is important to plan for the combined effects of settling and reduction in mass, paying attention to the degree of stability/maturity of the soil-forming materials. Even mature compost may lose up to 20% of its initial mass within three years. Unstable composts will lose more mass and it is possible that mixtures of uncomposted wastes will lose 30% of their initial mass within the first year.

Where the aims of restoration include biodiversity conservation, creating a patchwork of different habitats is likely to increase the total species diversity within a site. Spreading soil-forming materials uniformly over a large area may not then be appropriate and, instead, loose tipping of soil-forming materials in patches of various depths is preferred. At quarry sites, retaining large boulders creates microclimates for plant establishment and suitable niches for a range of species. At quarry and brownfield sites, the value of existing habitats should be considered and these incorporated within the overall programme of restoration.

3.6.3 Spreading techniques and machinery

A variety of machines, not necessarily designed to spread compost, can nonetheless be used effectively provided that consideration is given to compost moisture content, density and particle size. Remade Scotland (www.remade.org.uk) have produced a factsheet detailing methods of applying compost and the pros and cons of the different spreader units included are summarised in **Table 3.10**. The key to applying compost and other soil-forming materials successfully is to make sure the machinery used is compatible with the materials and the site. Spreader units are highly effective but differ both in accuracy and their ability to spread materials of high moisture content and density. If the application site is prone to compaction, consider fitting the spreading equipment with flotation tyres.[59]

[58] Organics Factsheet (May 2006) Compost Application Techniques. Remade Scotland, Glasgow Caledonian University, Scotland. Online at www.caleyprojects.org.uk/remade/File/Reports. Accessed August 2007).

[59] Williamson *et al* (2003) Restoring habitats of high conservation value after quarrying: best practice manual. University of Wales, Bangor.

Table 3.10 Summary of techniques for applying compost and other soil-forming materials. Information on the six different spreader units is from a factsheet (Compost Application Techniques) produced by Remade Scotland (www.remade.org.uk).

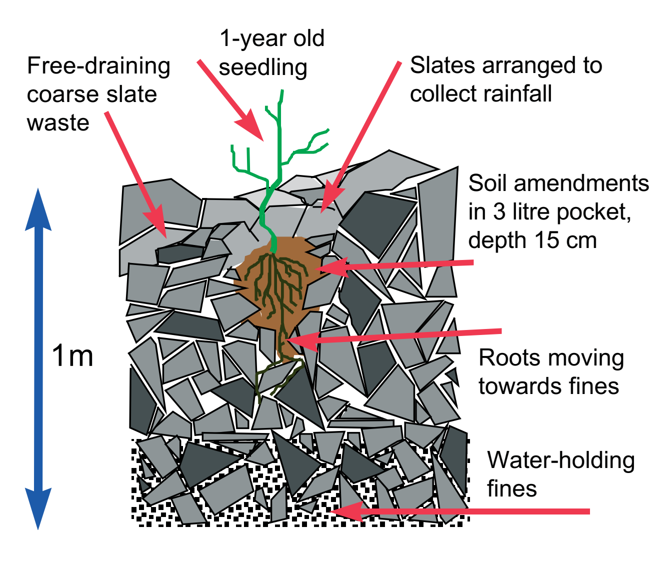
Machinery	Method	Comments
Beater drum / rotating cylinder	Projects material toward soil, finishing brushes can be used to break-up clumps of material	Large volumetric capacity. Designed to apply higher application rates (3.5 - 7.5 mm) of high bulk density materials over large open areas.
Brush	Use a rotating bristled brush to project materials toward soil surface.	Can apply materials with moisture content over 50% in 3 – 12 mm layers. Usually have small – moderate volumetric capacity but new units designed specifically for compost have large capacity.
Flail	Use paddles to project materials up and out.	Not as neat as other units but widely available (used for manure spreading). Can spread sticky materials in somewhat narrow strips. Flails can be hooded for topdressing compost.
Pneumatic / blower	New technology previously used to apply woodchips, mulches, sawdust and other wood products.	Main advantage is ability to apply materials precisely in inaccessible locations with house some 100 m in length. Works best with materials of particle size <50 mm and max moisture content 45 – 50%. Capacity of lorry and trailer mounted units 1 – 30 m^3.
Slinger	Use a rotating drum with teeth to sling materials some 50m. Most common slinger units are side discharge manure spreaders. Also large pull-behind and lorry mounted units.	Large units useful for land restoration as they can traverse steep inaccessible slopes and can spread high density materials with high moisture content, e.g. sewage sludge. Deflectors can be fitted to project material downwards.
Spinner	Use centrifugal force to project material from the rear of the unit. V-shaped hopper.	Designed for seed, lime, fertiliser etc. Work best with dry dense materials. Wet materials, e.g. sewage, have a tendency to 'bridge' onto hopper walls.

Spreader units may not be suitable for applying compost to steeply sloping sites or very rough terrain, for example blocky quarry waste. In this case a pneumatic blower can be used (**Table 3.10**) or materials can be tipped in bulk and spread using a 360° tracked excavator. An excavator or loading shovel can be used to 'superload' tips of blocky quarry waste by pushing material down them - the effect on the drainage and stability of the slope must be considered and assessed in preliminary trials where necessary. As has already been mentioned, applying soil-forming materials patchily and retaining boulders (where appropriate) can increase biodiversity by increasing the number of microhabitats available for colonisation by plants.

3.6.4 Pocket planting

Pocket planting of container grown trees or mature transplants ('wildings') can be an effective method of using limited volumes of soil-forming materials to establish vegetation over a large area and is particularly suitable for restoring blocky quarry waste (**Boxes 16** and **17**). Pocket planting allows the *in situ* substrate to be improved as a growth medium through addition of new material to provide the seedling with sufficient water and nutrients during the early years of establishment: this encourages roots to grow beyond the pocket into finer materials deeper within hard rock waste tips.[60] Williamson *et al* (2003) recommend an approximate volume of 3 litres for a planting pocket used to plant an individual tree into slate quarry waste (although larger volumes of soil-forming materials can be used where substrate and fertility requirements allow), the time taken to dig the pockets depends on the substrate and degree of compaction.

Figure 3.5 Schematic diagram from Williamson *et al* (2003). The pocket planting design is particularly suitable for using relatively small volumes of soil-forming materials to establish trees at inaccessible sites such as on tips of blocky mineral quarry waste and was used in TWIRLS project demonstration site at Kamariza, Greece to establish native pine trees.



3.7 Propagating plants and establishing vegetation

This is discussed in detail in several existing manuals listed in **Appendix I**. Many different techniques can be used to establish plants and these are summarised in Cripps *et al* (2007)[61]. Briefly, these include transplanting container grown trees and shrubs, broadcast seeding or seeding by pouring, drilling or using seed mats, hydroseeding and spreading seed rich grass cuttings or litter collected from beneath heather. It is worth reiterating that germination and growth of plants is likely to be poor on immature composts (see **3.4.6.3** for stability indicators) and germination tests are essential.

3.8 Aftercare, habitat management and monitoring

Aftercare is a key requirement of any restoration programme and a legal requirement under Section 106 of the Town and Country Planning Act 1990. Mineral Planning Guidance Note no. 7 (MPG7) requires a five-year period for mineral extraction sites but this is likely to be insufficient when restoring bare quarry or former factory sites to habitats of conservation value. Especially when trialling new or experimental techniques, it is recommended that monitoring of key soil characteristics and floristic diversity is carried out annually for at least 10 years. Ideally, diversity surveys should be carried out in the summer when experienced botanists will be able to identify plant species more effectively. Regular monitoring should be a central component of a long-term habitat management plan and allows remedial action to be taken early on should vegetation begin to diverge from the target habitat. This may occur where initial amounts of P were too high for example, in which case it may not become apparent for several years that one or a few highly competitive species are becoming increasingly dominant. Remedial measures might then focus on reducing fertility by removing biomass.

Conversely, regular monitoring of restored or created habitats will identify poor plant establishment or growth that can result from nutrient deficiency. For example, plants grown under conditions of N deficit may have pale green/yellow leaves and be stunted (these are also symptoms of S deficiency but this is less common). A good indicator of N deficiency is leaf chlorophyll status, which can be monitored quickly and cheaply using a hand-held chlorophyll (SPAD) meter (**Picture 8**). Since N deficiency is a key reason for restoration failure, it is advisable to monitor plants and soil throughout the monitoring period and apply mineral N fertiliser (this is most relevant to trees) where appropriate.

Picture 8 Monitoring leaf chlorophyll status (as an indicator of nitrogen availability) using a hand -held SPAD meter.

[60] Williamson *et al* (2003) Restoring habitats of high conservation value after quarrying: best practice manual. University of Wales, Bangor.

[61] Cripps *et al* (2007). Reclamation Planning in Hard Rock Quarries: A Guide to Good Practice. Published by the Department of Civil and Structural Engineering, University of Sheffield, UK.

The value of post-industrial sites as 'refugia' for rare invertebrates has already been mentioned and insect diversity surveys are recommended, for example using simple pitfall traps to collect ground-dwelling beetles (**Picture 9**). Insects can be difficult to identify and partnerships with universities, charitable organisations (e.g. Buglife) and nature conservancy agencies (e.g. Countryside Council for Wales) are invaluable.

Further guidance on aftercare and long term habitat management can be found in several of the manuals listed in **Appendix I**.

Picture 9 Pitfall traps are a simple and effective method of monitoring the abundance and diversity of ground dwelling invertebrates during restoration. Using this method at the site of the former Shotton steelworks, Deeside, Flintshire, the TWIRLS project collected several rare species, including the Red Data Book (RDB) weevil, *Gronops inaequalis*.

3.8.1 Grazing

Controlled grazing is beneficial for the development and management of various habitats within the EU including heather moor land, grassland and pasture-woodland. The purpose of controlled grazing is to control the trajectory of natural succession toward the target vegetation type and limit natural progress toward scrub or woodland where this is not the intended outcome of restoration. Grazing is a well established technique for increasing biodiversity by removing plant biomass, which allows less competitive species to become established as the abundance of dominant species is reduced. However, grazing must be carefully managed as too high a stocking rate will lead to excessive grazing intensity which reduces biodiversity, leaving only the most tolerant species (predominantly grasses).

In general, grazing should not commence at the outset of vegetation establishment but be introduced, where appropriate, after several years. Developing heathland benefits from fencing to exclude sheep (and, if practical, rabbits) during the first two to three years, thereafter grazing by rabbits is desired since it checks the development of grasses.[62] Grazing by sheep, rabbits and sometimes deer or goats results in poor survival of young trees and must be controlled for at least three to five years, ideally by well-maintained fencing in preference to individual tree protectors. If the conservation objective is to promote populations of species benefiting from more open and disturbed woodland conditions, after five years, some grazing or coppicing may be beneficial, but this will be at the cost of those species that thrive in less disturbed habitats.

A thorough review of conservation grazing regimes and the theory and practice of using grazing as a habitat management tool is provided in WallisDeVries *et al* (1998).[63] The website of the Grazing Animals Project (www.grazinganimalsproject.org.uk) is a useful resource providing sources of information, theory of conservation grazing and a UK network of conservation grazing sites.

3.8.2 Thinning

It is standard practice in woodland establishment to plant trees at a higher density than will survive in the mature woodland in order to accommodate early mortality and achieve early closure of the canopy (lessening the problems created by weed competition and with benefits for the form of the tree for timber production). In commercial forestry it would then be standard practice to actively thin the trees to reduce their density progressively towards the final target, thus maximising the growth rate of the eventual crop trees. However, this can be a costly operation and if the objectives of restoration are not timber production it should not be assumed that thinning must be carried out. In stands left to develop naturally, "self-thinning" (i.e. mortality of the smaller trees) will more-slowly achieve the same outcome. If access through the woodland is required this may require active thinning along planned routes, or grazing can be used to increase the general rate of "self-thinning". One situation in which active thinning may be required to ensure stability if the stand is on sites subject to high wind throw hazard, where the confined root distribution of individual trees growing at a high density may leave the stand vulnerable to being blown over.

[62] Williamson *et al* (2003) Restoring habitats of high conservation value after quarrying: best practice manual. University of Wales, Bangor.

[63] WallisDeVries *et al* (1998) Grazing and Conservation Management. Kluwer Academic Publishers, Dordrecht, The Netherlands.

3.9 Summary

- Post-industrial sites may require treatment to be restored to beneficial use but their existing conservation and heritage value must be assessed and incorporated into any programme of restoration. This involves full and proper engagement with stakeholders from the outset.
- Stakeholder engagement is essential when determining achievable target options for restoration. Some of the most successful schemes have restored bare sites to a mixture of soft (amenity green spaces, biodiversity conservation) and hard (housing, industry) end uses.
- Using raw and composted wastes for large-scale land restoration and vegetation re-establishment has the potential to mitigate low levels of soil organic matter, offset anthropogenic emissions of CO_2 and increase biodiversity.
- Organic wastes and composts contain potentially toxic elements (primarily metals, organic pollutants, pathogens and weeds) that have the potential to affect human health and the environment. Using wastes is about managing environmental and human health risks whilst recognising the specific benefits they offer. Risk assessment, testing of materials and preliminary trials are critical.
- There is considerable potential for growing bioenergy crops on post-industrial sites, key benefits of this option include:

i) the ability to supply plant nutrients in organic wastes/products to match crop demands is not constrained by the Nitrates Directive
ii) provision of an income
iii) phytoremediation of contaminated land using bioenergy crops
iv) potential for recycling ash back to land.

- A range of organic and mineral products and wastes can be used to restore land. The most widely available waste materials are:

i) green waste and green waste composts
ii) tertiary-treated sewage sludge
iii) de-inking paper fibre
iv) digestates from anaerobic digestion
v) municipal solid waste compost
vi) other water treatment sludges
vii) construction, excavation and demolition wastes
viii) mineral wastes produced as by-products of quarrying.

- Use of untreated wastes in land restoration should always be considered since monetary and environmental costs are likely to be lower and the potential for net carbon retention greater (i.e. less waste-derived carbon released to the atmosphere when considering losses during treatment and following land-application).
- There are no set rules to manage fertility. Many organic wastes and most composts contain P in excess of the requirements of biodiverse habitats but may contain relatively low amounts of plant available N. In general, it is better to add excess nutrients initially than to add too few nutrients, which may hinder early establishment of vegetation or provide insufficient organic matter to mitigate against drought.
- Where necessary, fertility can be reduced by:

i) mixing high and low nutrient materials prior to application
ii) chemically ameliorating soil-forming materials
iii) incorporating soil-forming materials with pre-existing nutrient poor soils
iv) monitoring and managing the fertility of the developing vegetation.

- Well-managed composting of organic wastes creates a stable, high quality soil-forming material and can help to reduce total amounts and availabilities of potentially toxic elements.
- Technically advanced in-vessel composting systems (although space efficient) incur higher monetary and environmental costs than windrow systems. They should be used where:

i) regulators stipulate their use
ii) real environmental and human health benefits are offered by in-vessel systems (e.g. capture and treatment of gases).

- Physical and chemical characteristics of soil-forming materials can be modified to make them more suitable for creating biodiverse habitats (e.g. raising WHC and altering pH). Preliminary trials should always be conducted to assess the effectiveness of such techniques, germination of sown species and availability of potentially toxic elements.
- The key to applying compost effectively is to ensure the machinery used is compatible with the materials and the site. Biodiversity can be increased by applying material patchily to create a mosaic of different soil conditions.
- Aftercare and monitoring of restored sites is critical for successful habitat development and is often a legal requirement. Regular monitoring of soil nutrient status and floristic composition is recommended, ideally for 10 years. Timely remedial action can then be taken should the development of the target habitat be threatened by highly competitive species or by nutrient deficiency.
- Grazing is beneficial to the development and management of many habitats but should be avoided at the outset of restoration programmes. Grazing can be introduced after plants have become established and used to reduce the abundance of dominant species and control rate of natural succession toward scrub woodland (where appropriate).

Box 3

Conservation value of derelict industrial sites – Unusual plants and insects at the TWIRLS project brownfield site in Shotton.

In July of 2006 and 2007 the TWIRLS project placed 200 insect traps as part of a biodiversity assessment of a brownfield site in Flintshire, North Wales. Steel workings at 'Area A4' (including a by-products recovery plant and tar lagoons) were decommissioned in the 1980s leaving soil and rubble contaminated with volatile organic compounds (VOCs) including benzene and toluene. As a 'remedial' measure the land was capped with several metres depth of dredgings from the Dee Estuary. Only one abortive attempt at developing the site has been made when, in 2000, an area of approximately 2 ha was cleared and compacted in preparation for construction work. In May 2005 the infertile, sandy soils were sparsely vegetated (95% bare cover) with ruderal (weedy) plants including a number of uncommon alien species such as the chenopod summer cypress (*Bassia scoparia*) and the composite Canadian fleabane (*Conyza canadensis*). Pitfall trapping produced a number of uncommon ground-dwelling beetles, most of which are associated with open, light soils and the ruderal species that grow on them. Perhaps the most significant discovery was of the rare weevil, *Gronops inaequalis*, a Red Data Book (RDB) species. Fifteen individuals were collected, this being the first record of this species for Wales. Interestingly, the first time *G. inaequalis* was sighted in the UK was in a Kentish landfill site in 1983.

By inhibiting natural succession of sparse vegetation toward grassland (as has happened over much of Area A4), the aborted development helped to maintain high quality habitat for rare insects that require bare ground. This poses a dilemma. It is arguable that efforts to create biodiverse grassland, unless highly successful, may in time reduce the conservation value of the site, at least from the perspective of the least common species. However, natural succession at the site will also reduce the suitability of the habitat for these insects, whose populations will decline as patchy, pioneer vegetation is increasingly replaced by a tight grass sward. Wholesale habitat creation at Area A4 may not be the best option for conservation – but a zero intervention approach may be equally damaging to populations of the rarest species.

The rare weevil *Gronops inaequalis* (picture by Karoliina Riika).

Patches of bare ground with ruderal plant species are favoured by a variety of invertebrates.

Box 4

Conservation value of post-industrial sites – Insect conservation value of urban brownfield sites, Canvey Wick. **Claudia Watts, Buglife.**

Canvey Wick is a 93 hectare brownfield site in the Thames estuary in Essex, and the first major brownfield site to be given SSSI status because of its invertebrate interest. To date, over 1500 different species of invertebrate have been recorded from the site, including 32 Red Data Book species, 3 proposed RDB species, 28 UKBAP species, 122 Nationally Scarce and 367 Local species. At the time it was designated, 2 species found on the site were new to Britain and 1 had previously only been recorded at one other UK site, so this was clearly a nationally important invertebrate habitat with few other sites in the country to rival it for supporting rare and threatened wildlife.

This, however, was not a pristine "unspoilt" wilderness, but a former industrial or brownfield site. Large quantities of dredged silty sand, rich in shell fragments, were dumped on an area of former grazing marsh to a depth of 2 or 3 metres before the infrastructure was put in place for an Occidental oil refinery in the 1960's and 70's. Concrete roads with rows of lamp-posts and vast oil storage tanks on large tarmac bases were built, but the refinery was never brought into service and was decommissioned and dismantled in the 1990's. In the meantime, nature had moved in, as was discovered when the site was targeted for development as a business park at the beginning of the 21st century.

Why is this site so rich in biodiversity? Several factors have contributed to its richness. The warm continental climate of the Thames gateway is favourable to invertebrates which are at the northern limit of their distribution. The area's lack of rainfall combined with the well-drained, nutrient-poor, friable sand, means that many plants suffer from drought stress, thus slowing succession, and also providing habitat niches for stem-nesting insects. Drought-stressed plants may also produce more flowers, increasing the nectar and pollen resources vital to species such as the rare Shrill carder bee *Bombus sylvarum* and Brown-banded carder bee *Bombus humilis*, two of the BAP species which thrive here.

Bombus sylvarum © Peter Harvey

Canvey Wick site

Box 4 continued

Lotus glaber at path edge © Claudia Watts

The open nature of the site has been maintained over the years not only by the lack of water and nutrients, but also by less traditional methods. The mounds of dumped sand and the unmanaged nature of the site have attracted scramble bikers and horse-riders to use it, ensuring a continuous supply of disturbed ground that could be colonised by species such as Narrow-leaved Bird's-foot trefoil *Lotus glaber* - a very important forage plant due to its long flowering period. The bare, sandy ground is also ideal for solitary bees and wasps such as the Silvery leaf-cutter bee *Megachile dorsalis*, Five-banded weevil wasp *Cerceris quinquefasciata* and Bee-wolf *Philanthus triangulum* to make their burrows, and for predatory ground beetles and wolf spiders to stalk their prey. The occasional accidental fire, perhaps caused by a burnt-out car, would also have made a useful contribution.

The lack of traditional management has been beneficial in other ways, too. Most conservation managers when faced with an area of unimproved grassland would be tempted to introduce a grazing or mowing regime – these are seen as ways to reduce competitive grasses and increase floristic diversity. However, as has been mentioned, here the competitive plants are mostly kept in check as a result of the low nutrient status, lack of water and high disturbance. As there is no grazing or mowing at Canvey Wick, plants retain their dead stems throughout the season, allowing creatures whose larvae develop in dead herbaceous stems or the flower-heads of grasses to thrive. Canvey has six types of Tumbling Flower beetles (*Mordellistena* species), 4 of them Red Data Book, all requiring a supply of dead plant stems in which to breed.

Future management of the site as a public nature reserve may prove somewhat problematic. Now that it has been saved from development, local wildlife enthusiasts are keen for it to be protected from what they view as damaging activities. Foremost of these is scramble biking. After many complaints, the site has been fenced off to prevent access to bikers and motorists, but their exclusion creates its own difficulties. Without the perceived 'antisocial' activities, the amount of regularly disturbed land is reduced considerably, so succession and scrub invasion has markedly increased. Scramble bikers still access the site illegally, but now target one small area of the site – a sandy mound well used by nesting mining bees and wasps – resulting in rapid deterioration of that habitat, while other parts of the site are becoming overgrown with taller vegetation such as Silver birch and Sea buckthorn. As Health and Safety considerations are likely to prevent the co-existence of bikers and pedestrians on the site (there have already been accidents), other approaches will be needed to ensure a continuity of disturbed ground. Fire has in the past been a useful tool, but is, again, impractical on a public nature reserve. Hand removal of birch and buckthorn saplings and seedlings is labour-intensive but quite possible with plenty of willing volunteers, but it looks likely that mechanical means may be necessary to create enough new areas of disturbed ground. However, convincing the reserve's users may not be easy!

Box 5

Conservation value of post-industrial sites – Biodiversity value of blocky slate waste in Snowdonia

Ecologically, slate waste tips are extremely interesting since their colonisation by plants mimics processes of primary succession where vegetation first establishes on bare land, for example following the retreat of glaciers or the cooling of volcanic lava. Arguably, it is worth preserving areas of blocky slate waste to study these processes. Among the first colonisers of the surface of the rocks of both natural blocky scree and free-draining slate quarry waste are slow-growing lichens and drought-tolerant mosses, such as woolly hair moss (*Racomitrium lanuginosum*). Where there is an accumulation of moisture-retaining fine material other mosses such as urn haircap (*Pogonatum urnigerum*) and ferns, most notably parsley fern (*Cryptogramme crispa*), are among the first colonisers. Wind-dispersed seeds of wood sage (*Teucrium scorodonia*), silver and downey birch (*Betula pendula* and B. *pubescens*) and grey willow (*Salix cinera*) germinate directly in pockets of moist moss. Although summer drought may mean that seedlings only survive for one or two years, during their brief life they shed leaves that will rot down amongst the slates and begin the slow process of soil formation. The colonisation of plants with bird-dispersed seeds is generally much slower but they can be found under established birches and willows, and scattered oaks are seen on many older tips. Heathland plants are generally restricted to places where the waste slate has been compacted into a less porous substrate, e.g. on the bed of old tramways.

In some cases it is desirable to intervene and try to accelerate the slow colonisation of quarry waste by plants, for example to restore connectivity between patches of heather moorland severed by quarry expansion or to reduce the visual impact of sterile, newly produced spoil. However, the wildlife value of old quarry waste should be considered within any restoration plan. Areas of naturally regenerating quarry waste can be retained and highlighted using interpretation boards placed near public rights of way. At Penrhyn Quarry near Snowdonia, a cycle route skirts the base of slate waste tips some 200 years old, providing an opportunity for local people, students and visitors to North Wales to enjoy a unique man-made habitat of conservation value.

Two pioneer species common on slate quarry waste and natural block scree in Snowdonia. Urn haircap moss (*Pogonatum urnigerum*) and, parsley fern (*Cryptogramme crispa*). Rotting leaf litter from these species kickstarts soil formation, raising the stock of nutrient and water holding organic matter within the waste tip and facilitating natural succession.

Box 6

Industrial heritage value of slate quarries in North Wales

Slate dominates the cultural and visual landscape in many parts of North Wales and quarrying drove the development of communities and culture particularly in Bethesda, Blaenau Ffestiniog and Llanberis. An estimated 98% of slate extracted from the ground is waste and although new equipment and techniques are lowering this figure, the mineral waste legacy of North Wales' 200-year industrial heritage remains. In Gwynedd alone, there are an estimated 730 Mt of slate quarry waste, with a further 6 Mt produced every year. Slate quarry waste is an integral component of the Welsh landscape and attitudes towards it differ enormously - whilst some visitors to North Wales speak of slate waste tips as a blot on the landscape, many local people feel that their environment would be 'naked without them'.

Surveys in Bethesda and Blaenau Ffestiniog reveal that the local communities value old tips and galleries formed by traditional methods and are concerned that revegetating these tips would hide this important heritage. Tips formed by modern methods and not hand-finished are not valued by the communities, who mostly want them regraded and planted.

Galleries preserved at Penrhyn Quarry

Box 7

Trialing the use of quality compost in brownfield regeneration

Paul Mathers, WRAP.

Topsoil resources on brownfield sites are often scarce and tend to be replaced by importing natural topsoils from nearby undeveloped land. One alternative to this traditional approach is to create topsoil on-site using quality BSI PAS 100:2005 compost mixed with existing materials from site, such as subsoils, quarry fines, colliery shales and steel slag. Recent trials have shown that when PAS 100 compost is mixed with other materials it can provide an excellent balance of nutrients, organic matter and water retention capacity, providing ideal conditions for plant growth and establishment.

WRAP (Waste & Resources Action Programme) has been working with a number of partners on a series of brownfield regeneration trailblazer projects around the UK to investigate the benefits of using PAS 100 compost in either topsoil creation or improvement. Pilot projects looking at the use of BSI PAS 100:2005 compost *in situ* as an organic soil-forming material have demonstrated both technical and commercial benefits, showing significant improvement in both cost efficiencies and the quality of the resulting topsoil. In some cases, costs have been reduced by 50%.[1]

One of the current trailblazer projects demonstrating the technical and commercial benefits of using PAS 100 compost in its regeneration is the former Lambton Cokeworks site in County Durham. This 60 ha site forms part of English Partnership's National Coalfield Programme and has been earmarked for the development of 350 new houses, woodland and open space. Due to its history of mining and coke manufacture, the Lambton site was left contaminated and in need of remediation.

[1]refers to published results of the regeneration of the Royal Ordnance Factory, Chorley (Restoring the land with compost report, published by WRAP on www.wrap.org.uk).

Material change for a better environment

Above and Bellow Lambton Cokeworks, County Durham restoration

Box 7 continued

Trials were undertaken to establish the best soil profiles and construction techniques for manufacturing topsoil *in-situ*. High quality PAS 100 compost was mixed with colliery shale and de-inking paper fibre in different ratios to establish the best water holding capacity and nutrient balance for plant growth. Woodland species quickly established in the new soils, providing the site regeneration partners with the reassurance they needed to regenerate the whole site using this technique. To date more than 10,000 tonnes of BSI PAS 100:2005 compost has been incorporated into these engineered soil profiles at the site.

Lafarge Cement's Dunbar Quarry Works in East Lothian Scotland is another trailblazer project which is using 2,300 tonnes of BSI PAS 100:2005 compost to restore and improve the nutrient-poor and stony topsoil – which is stockpiled and spread during the rolling process of opencast strip mining. The improved soils are already demonstrating better establishment of native plant communities and are also intended to provide greater water retention and erosion prevention capacity. Grassland areas will eventually be returned to sheep grazing.

A further trailblazer project is examining compost use in the restoration of former landfill sites at Lumley North and Coxhoe East. The intractable soil capping layers were improved with up to 1,000 tonnes of BSI PAS 100 compost per hectare, prior to the establishment of short-rotation coppice willow. In conjunction with similar trials on a range of brownfield sites in Teesside, this suite of projects is examining whether low-quality, virtually derelict soils can effectively support revenue-generating biomass crops for local generation of renewable energy.

Dunbar Quarry Works in East Lothian Scotland

Former landfill Coxhoe East

For more information on how the trials using PAS 100:2005 compost in brownfield regeneration projects are progressing please contact Paul Mathers at WRAP on 01295 817899, or visit www.wrap.org.uk/composting

Box 8

Ecological Restoration of Cronton Colliery, Merseyside using green compost. **David Evans, Land Restoration Trust.**

The land at the former Cronton Colliery, Knowsley, Merseyside, is currently undergoing a new restoration programme using PAS 100 green compost in a partnership involving English Partnerships (providing funding through the National Coalfields Programme), the Land Restoration Trust (LRT), the North West Development Agency (NWDA), Knowsley MBC, the Forestry Commission and the Waste and Resources Action Programme (WRAP). The site was partially restored in the 1990s, during which time removal of industrial infrastructure, major earthworks and tree planting were undertaken. At present the site remains in this partially restored state, with some natural colonisation of colliery spoil on two plateau areas.

Ownership of the site is expected to pass from the NWDA to the LRT in 2007/2008. The long-term intention is to develop the site as an informal country park. The first phase will undertake a semi-natural restoration of the southern plateau area, using an ecologically-informed approach. This should provide sustainable plant cover, while offering significant opportunities for improving local biodiversity. Future phases will see an existing area of hard standing converted for car parking use and the integration of the wider site into the local cycle and footpath network.

The restoration strategy was developed to maximise use of existing site resources, working with nature rather than importing soils. A 30 mm layer of compost was incorporated within the top layer of colliery spoil or used to top-dress areas where some natural colonisation had already taken place. It has been seeded with an acid grassland wildflower seed mix. Green compost is a recycled resource which fitted within this ethos whilst also offering appropriate soil nutrient and structural properties for the intended restoration. Being alkaline, it also helps to reduce the acidity of the colliery spoil.

The LRT is committed to taking an ecologically-informed, community-led approach to restoration wherever possible. They are taking a pragmatic approach to the restoration of their site, importing limited quantities of compost to encourage native plant communities, rather than higher-input/maintenance end uses. This light touch approach is innovative in the restoration sector, but should encourage biodiverse native habitat which can be enjoyed by future generations without saddling them with large on-going maintenance costs. If successful LRT are keen to roll-out this approach to other suitable sites throughout the country.

It is hoped that the compost will speed up the natural colonisation of the colliery spoil, without unduly raising soil fertility, demonstrating the value of a low-cost approach to restoration, the sustainable use of a recycled product and long-term cost and biodiversity benefits.

Land-formed colliery spoil.

Natural regeneration.

Amending spoil with compost to create a seedbed.

Box 9

Municipal-scale in-vessel composting in Greece

Dr G Arvanitis, Head of M.B.T Plants Sector, ACMAR, Attika.

The Association of Communities and Municipalities of the Attica Region (ACMAR) of GREECE is a non-profit, intermunicipal association authorised and dedicated to the planning and development of policies for the sustainable and environmentally effective management of municipal solid waste in the Attica Region through consultation. ACMAR consists of 72 municipalities (among them the cities of Athens and Piraeus) and 17 communities corresponding to 95 % of the 4,5 millions citizens of the Attica Region.

In accordance with the National Waste Management Plan and current E.U. strategic objectives and directives, and in collaboration with the Ministry of Environment, ACMAR has elaborated an Integrated Municipal Waste Management Plan. Its main objectives and goals are:

- waste reduction, with the implementation of a source separation program and the support of the recycled products market
- renovation and improvement of the solid waste collection system
- construction of municipal solid waste recycling and composting plants
- construction of modern landfills with high standards
- effective management of hazardous and health care waste
- closure and restoration of all open dumps and of "controlled" but not sanitary landfills

The in-vessel composting of organic wastes at the Recycling and Composting Plant (RCP) in Ano Liosia, Attika is the most integrated solution for waste recycling due to its exceptionally large rate of production of consistent quality compost. The composting unit consists of 48 bioreactor bays in which the organic fraction of the waste is treated using fully automated in-vessel rapid composting procedures. The material, which is 2 m deep, is aerated through 84 m long and 5 m wide channels and the procedure lasts for 9 weeks. Mixing and movement along the channel is achieved using special mixing machinery. The compost parameters are controlled automatically from the composting control centre over the whole composting period to give consistent and efficient results. The resulting compost consists of humic substances and has the characteristics of an organic soil. It is fully sterilized and free of phytotoxic substances, has high water holding properties and has the potential to contribute significantly to efforts to protect against erosion and degradation.

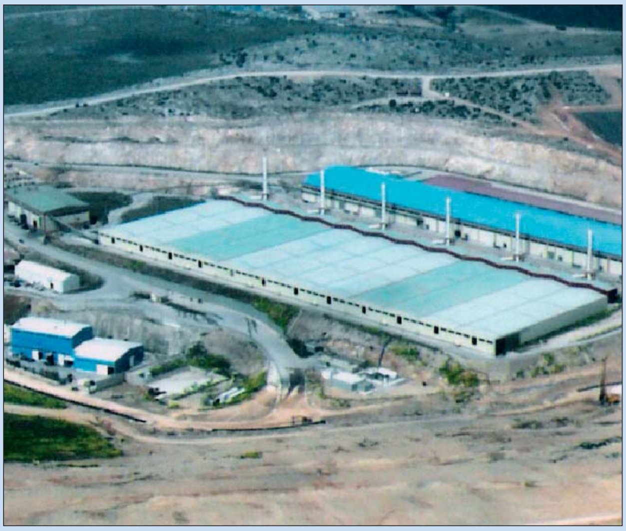


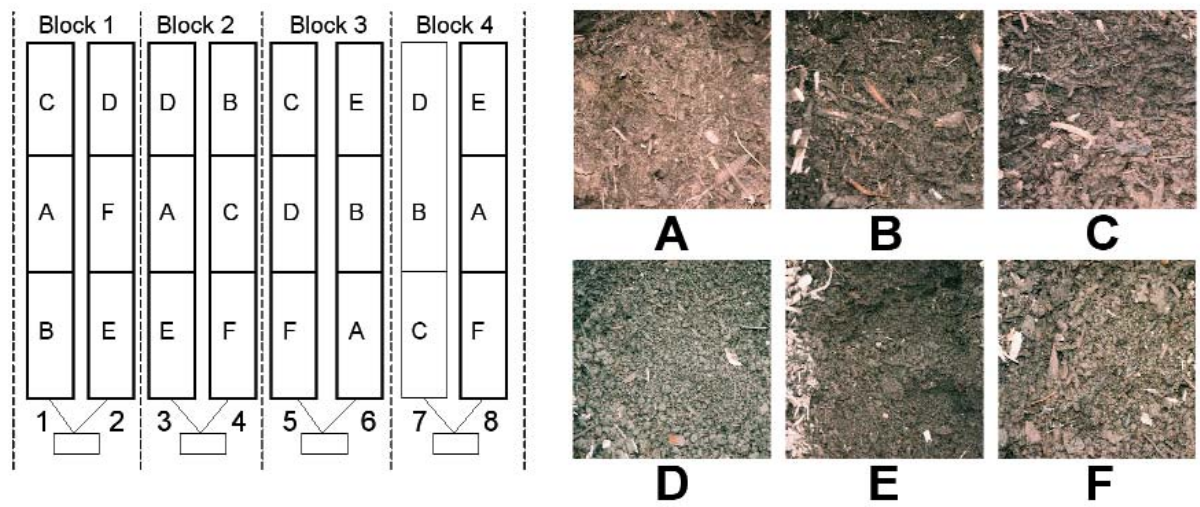
Fig. 1. A panoramic view of the Recycling and Composting Plant (RCP) in Ano Liosia, Attika

Fig. 2. Mechanical mixing of the wastes during the composting process.

Box 10

Producing compost from six different combinations of organic wastes at a brownfield former steelworks site in Shotton, Flintshire

In June 2005, the TWIRLS project began composting 1000 m^3 of wastes at Shotton, Flintshire, Wales. Wastes (green waste, de-inking paper fibre and tertiary treated sewage sludge) were delivered to site, mixed according to six different combinations designed to give a target initial C:N ratio between 20 and 35, and composted for 80 days in EcoPOD® in-vessel composters. The experiment had several aims: to demonstrate that quality assurance criteria can be satisfied using mixed wastes; to follow the changing chemistry of the composts over time; and to produce composts with a range of different physical and chemical characteristics to use in grassland establishment trials. All of the composts met criteria detailed in the BSI PAS 100 processing standards in terms of temperatures, pathogen kill and final amounts of potentially toxic elements.



Six different mixtures of feedstock wastes were composted using EcoPOD® in-vessel composters Each of the 8 EcoPOD®s was divided into 3 sections to allow replication of each mixture (x 4) in a randomised complete block experiment.

A = Green waste (100 % dry weight)
B = Green waste + paper pulp (70: 30 %)
C = Green waste + sewage (80: 20 %)
D = Paper pulp + sewage (60: 40 %)
E = Green waste + sewage + paper pulp (50: 15: 35 %)
F = Green waste + sewage + paper pulp (35: 30: 35 %)

Feedstock wastes are accurately weighed and mixed using a cattle-feed mixer wagon.

Perforated plastic aeration pipe is fed into the recyclable LDPE EcoPOD® composting bags and connected to timed aeration fans powered by a diesel generator.

Box 11

Producing compost from mixed organic and mineral wastes at Blaenau Ffestiniog using portable plant and sealed composting vessels

Inaccessible quarry sites in areas of high conservation value present particular challenges for restoration using organic wastes. At Blaenau Ffestiniog, the TWIRLS project used EcoPOD® sealed composting vessels under a Paragraph 12A exemption to the Waste Management Licensing Regulations. Sealed systems offer several advantages when used at sensitive sites. A particular concern of the Environment Agency (EA) is the production of leachate; this is contained in sealed vessels which may also allow greater process control and reduced production of odours. A major advantage of using sealed systems is one of public acceptance; we have found that community leaders, EA and Local Planning Authority officers perceive small to medium sized in-vessel systems to be safer (in terms of the environment and human health) than open-air windrows. Regulatory and planning approval for composting, particularly when considered by committee, may be swifter for in-vessel systems. Sealed systems should not be used in all situations. They are more expensive and consume extra fuel and materials when compared with windrows.

Top Right, either de-inking paper fibre, a by-product of recycling paper fibre, or slate mineral fines (a quarry by-product) are loaded into a vertical auger cattle feed mixer wagon together with tertiary-treated sewage sludge and green waste shredded at a local authority site (Conwy BC). Wastes are mixed in batches of 15 m^3 and conveyed into a CT5 EcoPOD® filling machine which uses a hydraulic ram to push the material through a filling chamber into an extending 1.5 m diameter plastic bag. At the same time as filling the EcoPOD®, a perforated plastic aeration pipe is simultaneously fed along the base of the bag to provide aeration. The aeration regime is controlled by a timed fan powered by a diesel generator. **Bottom Right**, instead of usual agricultural equipment for applying compost, we used machines available on-site (a telescopic handler and tracked excavator) to spread the composts to approximately 1000 t ha^{-1}.

Box 12

Assessing the potential of six different composts applied at three rates to promote mesotrophic grassland establishment at a brownfield site

Following three months maturation, the six composts produced at Shotton (Box 10) were applied to land using a farm spreader wagon. Composts were applied to the bare site at rates of *ca* 0, 250 or 500 t ha^{-1}. The composts were not incorporated with the sandy soil on this occasion as the dimensions of the plots (16 m^2) were too small. Half of each plot received a mixture of seeds of 24 species present in the target MG5b habitat (Emorsgate Wildflower Seeds, Norfolk) at a rate of 40 kg ha^{-1}.

Right, newly established mesotrophic grassland trial plots at Shotton showing zero, low and high rate of application of six different composts according to a randomised complete block design. **Below**, floristic surveys carried out after 18 months identified 15 of the 24 sown MG5b grassland species, some of which were already present at the site. The frequency of some species (*principally Achillea millefolium* and *Festuca rubra*) was significantly greater in sown plots. In general it was clear that biomass was greater on the highest rate of application of compost, reflecting improvements in soil water-holding capacity as well as nutrient supply.

The composts differed in their potential to support vegetation similar to the target MG5b community. In terms of the frequency of indicator species for the target vegetation type, 100% green waste compost performed worst and compost produced from 35:30:35 green waste : sewage : paper fibre performed best. Long-term monitoring is necessary to follow development of the plant communities and see how initial amounts of nutrients and compost water-holding capacity determine progress of the plots toward the target MG5b vegetation.

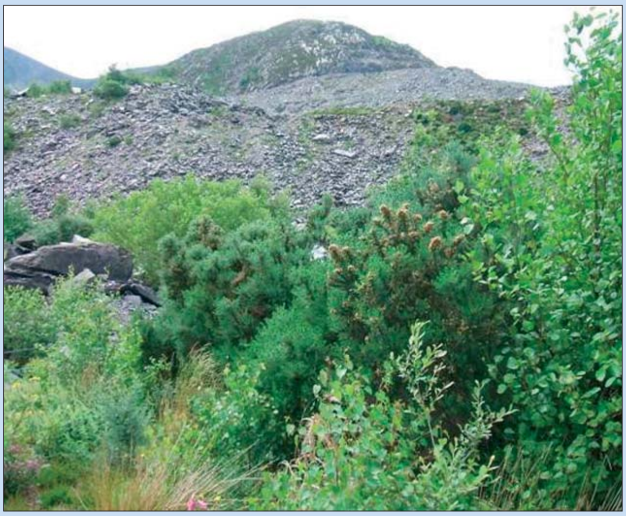
Box 13

Early establishment of native woodland on slate waste using waste soil, slate mineral fines, uncomposted sewage sludge and de-inking paper fibre

An ecological approach is being taken to the ongoing restoration of Europe's largest slate quarry, Penryhn Quarry in Bethesda, Gwynedd, N. Wales. Tips of hard rock quarry waste are inhospitable to plants because of their poor water-holding capacity (WHC) and low nutrient availability[1]. These constraints can be overcome by adding organic matter in the form of waste materials or by using fine mineral material or subsoil arising from quarrying. In contrast to mineral fertiliser, organic wastes add WHC and contain slow release nitrogen and phosphorus together with the micro-organisms necessary to recycle these nutrients to plants. Establishing functional communities of soil microbes early on is critical to the success of restored systems, which are then more diverse, self-sustaining and resilient to change.

With financial help from the European Commission under the *Life*-Environment programme and in partnership with Alfred McAlpine Slate Ltd, Bangor University has been studying how best to restore slate quarry waste to habitats of conservation value for the last seven years. The suitability of a range of organic and mineral wastes for establishing native tree species over the long-term is being assessed using a randomised complete block experiment. Results show that whilst mineral fertiliser improved tree establishment and growth, it did not increase soil microbial biomass. When used together (to control rates of N and P mineralisation), sewage and paper fibre increased soil organic matter and WHC, and stimulated and maintained soil microbial biomass. Work at Penrhyn Quarry has demonstrated how a little waste can go a long way. Low fertility subsoil (glacial till excavated to win slate) was spread to 0.75 m depth over slate waste, into which trees were pocket planted. Nutrients supplied by the organic wastes allowed tree roots to grow out of the planting pocket and access water and trace elements in the soil.

English oak, *Quercus petraea* (**below left**) and a mixture (**below right**) of oak, common alder (*Alnus glutinosa*), mountain ash (*Sorbus acuparia*), grey willow (*Salix caprea*), birch (*Betula pendula x B. pubescens*) and gorse (*Ulex europeaus*) planted in slate waste at Penrhyn Quarry, Bethesda, Gwynedd in spring 2000. The 'bonsai' oak tree was planted with Osmacote® slow-release mineral fertiliser and no organic amendments; after two years it was 20 cm tall. Trees grown in three-litre subsoil planting pockets filled with sewage sludge: paper fibre mix (1:1 ratio) had reached heights of up to 2 m.



[1] Rowe *et al* 2005 Initial tree establishment on blocky quarry waste ameliorated with hydrogel or slate processing fines. *Journal of Environmental Quality* **34**: 994-1003.

Box 14

Native woodland establishment on slate waste in Wales: Seven years on

Matthew Ling, Bangor University

In April 2000 an experiment was established at Penrhyn slate quarry, Bethesda, Gwynedd, to study the effects of water and nutrient limitations on the ecological restoration of waste slate tips. The waste slate was treated with water holding amendments (a 75 cm layer of boulder clay overburden placed over the slate, or a small quantity of polyacrylamide gel (PAM) placed into the planting pockets, and fertiliser amendments (mineral NPK controlled-release fertiliser or an organic mix comprising biosolids and de-inking paper fibre) placed into the planting pockets. Seedlings of six native woody plant species were transplanted into the pockets. Plant survival and growth were monitored regularly until 2002 **(Box 13)**. Here results are presented of longer-term plant establishment from observations carried out in April 2007.

It is clear from Fig.1 that the addition of a boulder clay layer to improve the water holding properties of the waste slate caused a large increase in plant growth. However, the addition of PAM to the planting pocket had little or no benefit. Without clay, the growth of alder, gorse and birch was notably greater than that of willow, rowan and oak. Fig.2 shows a mixed response across plant species to fertiliser addition. None of the differences between these treatments had a statistically significant effect. However, for all six species mean height was greater (by up to 34% in oak) for plants established with the organic fertiliser mix than with no amendment. The benefits of mineral NPK fertiliser addition were less uniform; it led to greater mean plant height than with no amendment in four of the six species (by up to 31% in rowan). Despite the mixed response to water and fertiliser amendments, survival rates from 2002 to 2007 were very good *viz.* ≥96 % for all species and treatments.

These results strongly indicate that increased water holding capacity provides the greatest benefit to restoration outcomes. Whilst water holding capacity was vastly improved here by the addition of a large volume of boulder clay, equivalent volumes of organic matter such as biosolids and de-inking paper fibre would be expected to achieve similarly successful results. The high rates of plant survival and sustained plant growth (at least with clay addition), offer encouraging signs for potential habitat development on waste slate over time.

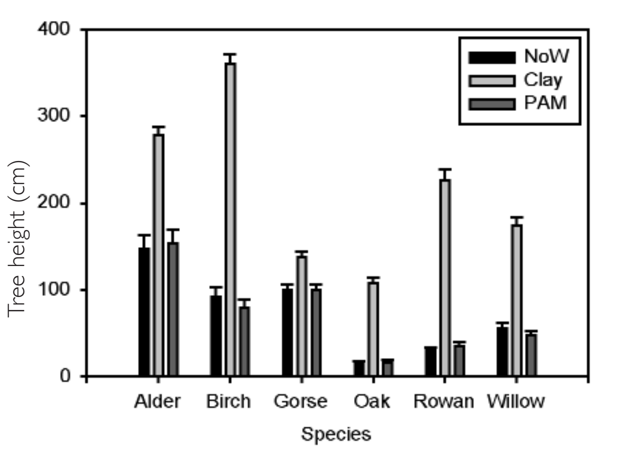


Fig.1. Effect of water–holding amendment on woody plant species growth in waste slate over seven years. Values represent means ± SE, n ≥169. NoW = no water amendment.

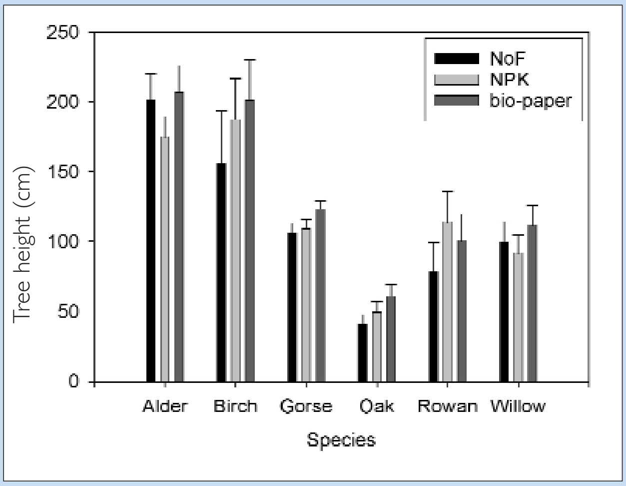


Fig.2. Effect of fertiliser amendment on woody plant species growth in waste slate over seven years. Values represent means ± SE, n ≥170. NoF = no fertiliser amendment. Bio-paper = biosolids plus de-inking paper fibre mix.

Box 14 continued

An area amended with boulder clay, showing well-developed alder, birch, gorse, oak, rowan and willow plants seven years after planting.

Severely stunted seven-year-old willow and birch trees in an area amended only with PAM gel.

Box 15

Spreading compost and managing fertility at an upland quarry restoration site in Blaenau Ffestiniog

Composts produced at Blaenau Ffestiniog were too fertile to use at the restoration trial site without further modification. For composting to proceed properly and reach the high temperatures required to kill pathogens and sterilise weed seeds it is necessary to keep the initial C:N ratio of mixed feedstocks between *ca* 25 and 35. Inevitably, composts produced from this initial C:N ratio contain amounts of nutrients in excess of the requirements of biodiverse target habitats. Whilst fertile compost may be fine for establishing amenity grassland, it contains as much as 200 times more *plant available* phosphorus per unit weight than natural soils supporting heathland, upland or biodiverse grassland. Thus, there is a real danger of creating a monoculture of a highly competitive grass species, e.g. Red fescue, *Festuca rubra*, at the expense of more diverse, early successional plant communities.

Managing compost fertility is complex and a variety of approaches can be taken. These include diluting compost with inert mineral wastes or quarry by-products, mixing with infertile organic wastes that also biologically immobilise nutrients, chemically ameliorating compost to 'lock-up' nutrients in less available forms or intensively managing the resulting grass sward to remove nutrients in biomass. At Blaenau Ffestiniog, we mixed finished compost with de-inking paper fibre at a rate of 1:1 by dry weight. This not only halved the availability of phosphorus, it also increased the water-holding capacity of the substitute soil from 0.87 to 1.34 g plant available water per g dry compost.

The finished composts passed BSI PAS 100 quality criteria and after diluting with de-inking paper fibre or slate mineral fines they were spread to approximately 0.5 ha of prepared slate quarry waste under a Paragraph 9A exemption (ecological improvement) to the Waste Management Licensing Regulations. In order to test that the composts were suitable for restoring low nutrient habitats, a vegetation establishment experiment was laid out according to a randomised block design. Plots were seeded at a rate of approximately 40 kg ha^{-1} either with a mixture of native grasses (*Agrostis capillaris* and *Festuca ovina* at a ratio of 1:4), heather (*Calluna vulgaris*), or with heather and grass together.

The vegetation establishment experiment in July 2006 (eight months after seeding). The most fertile plots already have *ca* 80% cover of sown grasses.

Floristic surveys indicate that addition of paper fibre to finished compost increases germination of heather.

Box 16

Using organic municipal waste compost to restore a degraded black schist quarry site near Athens, Greece.

Soil Science Institute of Athens, NAGREF.
Dr. Matina Christou, Dr. Elizabeth Avramides and Antonis Papadopoulos.

Surface mining and extraction activities, which are widespread in Greece, cause intense changes to the landscape with resulting destruction of vegetation, soil and the natural landscape. At the same time, the lack of a sustainable approach in the handling and disposal of waste from human activities degrades the environment. An approach to contribute to the solution of both these problems has been applied to a schist quarry located in a mountainous area near Athens, in collaboration with TITAN Cement Company S.A., which has been exploiting the quarry for cement production.

The black schist material is a very infertile substrate for plant growth, poor in organic matter and nutrients with low carbonate content and a pH of about 7.5. Many plant species as pines (*Pinus halepensis* Mill.), *Poterium spinosum* L., *Genista acanthoclados* D.C., *Polypogon monspeliensis* (L.) Desf., *Plantago weldenii* Reichenb. etc. contribute to the natural restoration of the degraded area (Photo 1). The site, at an altitude of 520 m, is exposed to cold winds and snow in winter and to the hot summer sun. Grazing in the area has also contributed to the slow rate of revegetation at the site.

Three different areas within the quarry were selected representing 3 different topographies: a compacted, flat area with seasonal water logging (untreated control); a gently sloping, land formed area and artificially created mounds of overburden rock material formed on the flat area (Photo 2). Compost, produced from mixing municipal waste, green waste and digested sewage sludge at the recycling plant of the Association of Communities and Municipalities in the Attica Region (ACMAR), near Athens **(Box 9)** was used for nutrient amendment and texture improvement. The compost had an organic matter content of 32.6%, C/N ratio of 11.9, EC of 21.7 mS cm^{-1}, pH of 7.0, carbonate content of 23.0% and a high concentration of plant available nutrients. Pine trees were pocket planted in 3 L of schist or compost mixed with schist at the rates of 1:2 and 2:1 by volume, in order to examine the effect of the addition of organic matter in the establishment of suitable vegetation on the infertile material.

Tree establishment and survival were better on the mounds and sloping site, compared with the flat site (Photo 3). In order to assess tree health and development, height, main stem diameter and the number of secondary branches were measured every six months (Figure 1). Results for the 18^{th} month period since the start of the experiment generally showed a markedly greater increase in these parameters for the trees with compost addition at planting. Although the rate of tree growth appeared to be greater with the lower rate of compost addition compared to the higher one, differences between the compost application rates were not significant.

The company will continue the experiment and assessment of the results after the end of the project. To date it has been demonstrated that the application of compost at pine seedlings planting has enhanced seedling development on the sloping and mound sites and that pocket planting with compost to schist ratio of 1:2 provides conditions in which the seedlings can develop with a higher growth rate. The formation of mounds gives a solution to the problem of establishing tree growth in the compacted and waterlogged areas.

As a consequence of the encouraging results from this experiment, TITAN Cement Company S.A. plans to use a significant quantity of compost from the unit of ACMAR in its current environment rehabilitation program.

Photo 1 *Poterium spinosum* L.

Photo 3 Pine development in the mounds site

Photo 2 The experimental sites

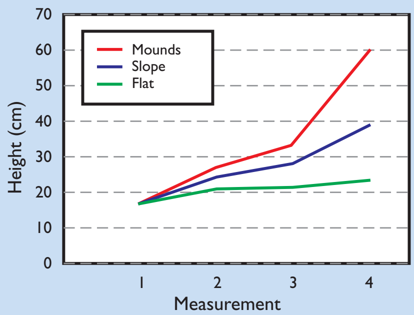


Fig 1 Mean values of pine height

Box 17

Restoration of degraded land in Greece and ISO 14001

Dr Symeonidis Kostas and Menidiatis Christos, Titan Cement Company. symk@titan.gr

The activities of the Titan Cement Co. in Greece are centered on four cement factories and 23 quarries from which inactive materials and starting materials for cement are obtained. Within the framework of Titan's policy for sustainable development, environmental remediation activities began 30 or more years ago and, within this time, 1,100,000 trees and shrubs have been planted, in large majority from Titan's nurseries. From 1996, Titan's factories in Greece and the 10 quarries from which starting materials are obtained are operated according to ISO 14001.

With the aim of improving the results and effectiveness of remediation, Titan has cooperated with many Greek Research Institutions in various research programmes. The company's participation in the LIFE-Environment project TWIRLS **(Box 16)** has arisen within this framework and the desire of the company's administration to support initiatives for the extension of recycling in our country. The success of the programme has led the company to develop a plan for environmental remediation in its quarries using a significant quantity of compost (5,000-7,500 m^3 annually) from the Recycling and Composting Plant (RCP) in Ano Liosia, Attika **(Box 9)**.

Degraded land restoration by TITAN Cement Company in Greece

Section 4

Remediating contaminated sites using organic wastes and composts

Section 4

Remediating contaminated sites using organic wastes and composts

4.1 Introduction

In any area of land classified as in need of remediation there will be zones of contamination to be identified by means of a thorough soil (or groundwater) survey. Sampling must be sufficient to provide an accurate picture of how much surface area needs to be treated. Previous surveys, photographs or old records all provide valuable evidence upon which to decide a sampling strategy that may be either targeted or non-targeted, depending on the extent and type of contamination expected. Non-targeted sampling should adhere to a pattern of sampling, the most commonly used being a 'herringbone' pattern[1]. Soil, water and vegetation samples should be analysed in a laboratory operating within certified standards of quality control, the most stringent in the UK being MCERTS (European and International Standard BS EN ISO/IEC 17025:2000) accreditation. If the level of contamination is then considered hazardous a risk assessment will be required. Published UK Soil Guideline Values (SGVs) exist for a limited, though being expanded, suite of contaminants (mainly heavy metals). However, SGVs or similar data published by other countries are not intended to replace the site-specific risk assessment required, generally involving computer models such as the Environment Agency's Contaminated Land Exposure Assessment[2].

The UK's vast areas of derelict and unused 'brownfield' spaces have been targeted by the Government for housing development[3]. However, much of the unused brownfield land is contaminated from previous industrial activities and developers are reluctant to take on the necessary (and expensive) remediation measures. The option of removing contaminated or hazardous soil to landfill is no longer viable in most cases since new EU legislation has drastically reduced the number of landfills licensed to take hazardous material.

On-site remediation options are broadly divided into engineering solutions, e.g. soil washing and thermal desorption, and biological solutions such as bioremediation or phytoremediation. Engineering solutions are quicker to enact but destroy the soil profile and biota, whereas biological solutions may require years to take effect but preserve the integrity of soil system function.

Bioremediation refers to the harnessing of beneficial microbial communities to break-down or 'metabolise' hazardous compounds in the environment. Often, bioremediation can be accelerated by optimising conditions under which these beneficial microbes work best; this generally entails providing an adequate supply of nutrients (fertiliser), water and aeration. Bioremediation works best on organic compounds like petroleum, tar or oil that can be degraded to less toxic, smaller compounds by micro-organisms which, in turn, derive energy from the process, allowing them to grow in size and number. Phytoremediation occurs when plants make a contribution to pollutant removal either by direct uptake into the plant biomass or indirectly by providing nutrients that in turn enhance microbial metabolism of pollutants.

Polluting agents such as metals cannot be broken down and to remediate metal-contaminated land it is necessary to lock-up metals so that they are rendered immobile and not 'bioavailable', i.e. less transferable within an ecosystem. Both plants and micro-organisms can take up metals but these can still enter the food chain and accumulate in higher organisms. Metal compounds can be chemically locked-up (adsorbed) in soil organic matter away from natural mechanical and chemical weathering processes.

Given that different pollutants need to be remediated in different ways and that contaminated land frequently has a mix of organic and metal compounds that need to be remediated, the challenge, then, is to develop a generic remediation strategy with sufficient in-built flexibility to deal with site-specific cocktails of pollutants.

4.2 Applying organic wastes and composts

Adding organic matter to soil has long been recognised as beneficial in terms of fertility, structure, water retention and buffering capacity. Organic matter is a

[1] Hutchings, T. *et al* (2006). Note 1 Soil sampling derelict, underused and neglected land prior to greenspace establishment. *Best Practice Guidance for Land Regeneration*. Forest Research, Alice Holt, Surrey.

[2] www.environment-agency.gov.uk/subjects/landquality/113813/672771/?lang=_e#

[3] http://news.bbc.co.uk/1/hi/uk_politics/6947138.stm Accessed August 2007.

complex material: physically, it is characterised by having large pore spaces to facilitate water, gas and nutrient flows whilst chemically it has a large, highly charged surface area with the capacity for 'attracting' or adsorbing nutrients and trace elements. The term 'organic' here refers to matter that contains hydrocarbons (C-H) in its chemical make-up.

Fresh or composted additions of organic matter to contaminated land, either to promote biodegradation of pollutants or to render them 'unavailable' to the wider environment, has received theoretical attention for over 30 years[4] with some reported success in small-scale trials, usually laboratory or greenhouse based. It is much harder to find published work that refers to the use of such remediation approaches in the field whilst adhering to existing legislative frameworks.

Organic matter is particularly beneficial to micro-organisms as it supplies both nutrients like nitrogen, phosphorus and sulphur and, importantly, carbon. Organic C, N, P and S metabolised by microbes allow the microbial population or 'biomass' to increase in size and diversity. The broader the spectrum of organic compounds available to microbes, the more functionally diverse the population is likely to become and the greater the functional diversity of a microbial population, the greater its capacity to break-down pollutants.

It is also relevant to note that by adding organic matter, there is a potential to inadvertently add to existing pollutant levels, e.g. pathogens in manure, heavy metals in sewage, persistent organic pollutants (POPs) in compost. Before recommending large or repeated applications of organic materials to remediate land, they must be considered safe and fit for use in the environment. Further, the mixing of 'clean' material with contaminated soil results in a greater quantity of contaminated material if the attempted bioremediation is unsuccessful and, so to avoid this, pilot scale pot experiments must be carried out as 'proof of concept'.

4.3 Effect of the composting process on pollutants

Compost is a stabilised form of organic matter, i.e. it has become humified and is more slowly degradable. Compared with uncomposted materials this has the advantage of reducing gaseous and leaching losses of nutrients off-site and, hence, with less environmental effect after compost application. Also, the process of composting adds value to mixes of organic wastes which, if applied individually, may not impart agricultural or ecological benefit to land. Composting is a practical way of returning organic wastes to land; but is it safe? Understanding how the composting process affects potentially polluting substances carried in organic materials and wastes is essential to gaining acceptance of the practice and defining boundaries for best practice.

4.3.1 Human pathogens

Since its pumping out to sea from our coastlines was banished at the end of 1998 under the Urban Waste Water Directive, there are now massive quantities of sewage requiring treatment. Sewage is rich in nutrients and carries a high fertiliser value and land application is an obvious outlet. While treated sewage sludge (or, biosolids) is applied directly to agricultural land throughout Europe and worldwide, it is not permitted as a component of compost in England and Wales, apparently reflecting public perception and governmental priority in gaining public acceptance of compost quality by strictly controlling permitted feedstocks (see **Section 2**). The principal pollutants of concern are human pathogens and heavy metals, though levels of the latter depend on the industrial footprint in the area. Defined treatment processes and standards ensure at least 99% of pathogens in biosolids have been destroyed; enhanced treatment processes are capable of virtually eliminating any pathogens (99.9999%) which may be present in the original sludge.[5]

The TWIRLS project examined the survival patterns of human pathogens during composting and maturation phases where a range of feedstock mixes were used, with both treated and enhanced treated biosolids from two utilities outlets – one rural and one industrial/peri-urban source. The experiment conformed to a randomised block, fully replicated design for statistical rigour. Human pathogens *E. coli* and *Salmonella* species were counted using quality compost methodology and benchmarked against industry acceptance levels (PAS 100: 2005). Mixed waste composts containing biosolids were compared with green waste compost. All composts containing biosolids met the critical limits for human pathogen content when tested using PAS 100 specified methods[6] (**Box 18**).

4.3.2 Persistent Organic Pollutants

Organic pollutants range greatly in chemical make-up and molecular weight, from the small molecules that are easily broken down in the environment to the recalcitrant POPs that are largely resistant to

[4] Semple *et al*. (2001). Impact of composting strategies on the treatment of soils contaminated with organic pollutants. *Environmental Pollution*, **112**, 269-283.

[5] www.defra.gov.uk/farm/waste/sludge/index.htm Accessed August 2007.

[6] Williamson *et al* (2006) Pathogen survival patterns in waste-derived composts destined for land restoration. *Proceedings of Waste 2006 Conference*. Copies from The Waste Conference Ltd., University of Warwick Science Park, Coventry, UK.

degradative processes. The most commonly occurring POPs in contaminated brownfield sites are dioxins, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). Of these, the urban and industrial footprint of PAHs is the most marked[7] being widely found in soil, groundwater, air and plants, while some are known carcinogens. They occur naturally in fossil fuels and are produced from both natural and anthropogenic forms of combustion, e.g. natural fires and road traffic, respectively.

Composting soils contaminated with hazardous materials is still an emerging *ex situ* biotreatment[8]. There are potentially two options involving compost to remediate land contaminated with PAHs: the most common is to incorporate compost into contaminated soil, while the less frequently practiced/reported is the co-composting of contaminated soil with organic feedstocks. The perceived advantage of the second route is that intimate contact with contaminants from the start may result in a microbial community with greater capacity to degrade pollutants by the formation of something akin to a 'starter culture' which, when spread onto contaminated land, would serve to prime a more effective soil microbial 'degrader' population. However, there are problems that could arise from co-composting: firstly, with high concentrations of available carbon in the organic feedstocks, this may actually reduce the rate at which microbes metabolise more complex or unusual substrates like PAHs; secondly, high organic matter content may result in surface adsorption of PAHs, rendering the compounds less accessible to micro-organisms.

Investigations into the behaviour of PAHs in the TWIRLS project were designed to establish what happened when contaminated soil was co-composted with organic feedstocks - see **Box 19**. Later, we will look at what happens when co-composted contaminated soil plus organic wastes is returned to land (**Box 22**).

4.3.3 Metal pollutants

Several potential feedstocks for compost may contain varying concentrations of metals. To reduce the risk of the build-up of metals in soils where it is regularly applied, the BSI PAS 100 compost standard sets limits for total metals in mature compost[9]. As feedstocks break down during composting, mass is lost and metals concentration increases. Total metal concentrations, however, do not tell the whole story. More important is the fraction of metals that is 'bioavailable', that is to say available to plants and soil organisms. High plant available concentrations can lead to toxicity and plant death, while lower concentrations may lead to bioaccumulation up the food chain. The composting process stabilises organic matter by humifying it. It could therefore be assumed that metals present in feedstocks would be 'locked' up in mature compost as organic matter is known to bind metals. This was investigated by looking at three different types of compost produced from a range of feedstocks (municipal solid waste fines (MSW), greenwaste, biosolids and de-inking paper fibre). MSW, biosolids and de-inking paper fibre all have a high potential for contamination with heavy metals. The composts were examined at the start and end of composting to establish the availability of the individual metals (**Box 20**).

4.3.4 Biochemical pollutants

Endocrine disrupting compounds (EDCs) are examples of biochemically-active pollutants present in organic wastes and it is necessary to establish best practice guidelines to minimise the potential harm to aquatic ecosystems, particularly where EDCs leach into water courses, in which case established recommendations for avoiding eutrophication caused by leaching of nitrate and phosphate are relevant. The following steps are recommended to reduce potential for movement of EDCs from restoration sites to water courses. It also worth consulting DEFRA guidance on spreading organic wastes in Nitrate Vulnerable Zones (NVZs) found at www.defra.gov.uk/environment/water/quality/nitrate.

- Assess the risk of EDCs leaching from restoration sites to water courses. Avoid spreading organic wastes (particularly sewage sludge) when the ground is frozen, waterlogged or snow-covered or during periods of heavy rain.

- Avoid spreading organic wastes on steep slopes adjacent to surface or coastal waters or with surface water flows.

- Do not spread organic wastes within 10m of water courses.

- (Outside of the EU) ask the paper mill providing de-inking paper fibre about the nature of the surfactants used in the de-inking process. Were environmentally benign alternatives to APEs used? Ask the operators of water treatment works whether they monitor levels of EDCs (particularly APEs) and if any technology is in place to reduce levels in treated sewage sludge.

---

[7] Environment Agency (2007) Report 9: Environmental concentrations of polycyclic aromatic hydrocarbons in UK soil and herbage. *UK Soil & Herbage Pollutant Survey*. http://publications.environment-agency.gov.uk/pdf/SCHO0607BMTC-e-e.pdf?lang=_e Accessed August 2007.

[8] Antizar-Ladislao B. *et al*. (2006). Degradation of polycyclic aromatic hydrocarbons (PAHs) in an aged coal tar contaminated soil under in-vessel composting conditions. *Environmental Pollution*, **141**, 459-468.

[9] http://www.wrap.org.uk/downloads/Introduction_to_BSI_PAS_100-20052.abab7d36.pdf

- Evidence suggests that levels of EDCs in organic wastes are reduced more by aerobic composting[10] (**Box 21**) than by anaerobic biodigestion. Consider this at the outset of any restoration programme where the intention is to use significant quantities of wastes containing EDCs, or where movement to surface or ground waters is of concern. For example, levels of EDCs in sewage sludge are likely to reduce substantially if the sludge is co-composted with other wastes (i.e. green waste or de-inking paper fibre).

4.4 Effect of amending contaminated land with composted organic wastes

4.4.1 Persistent Organic Pollutants

Here, we look at examples of compost being applied to contaminated land to promote bioremediation. This practice is becoming more frequently used by environmental engineers to clean up contaminated zones of brownfield land prior to development and is hailed as green technology, which helps gain public acceptance. One well disseminated example highlights the use of a composted 'mulch' to clean-up in *ca.* eight weeks 8,500 m3 of soil contaminated with petroleum hydrocarbon compounds (including PAHs).[11]

The TWIRLS project demonstrated the use of organic wastes co-composted with contaminated soil added to PAH-contaminated soil as a remediation option at a former steelworks site in N.Wales. Records of tar lagoons existing on site by 1958 indicate the potential for site contamination spanning nearly fifty years, which presents a challenge to bioremediation because organic pollutants such as PAHs become more strongly adsorbed onto the soil organic matrix over time and, consequently, are increasingly inaccessible to micro-organisms. In these circumstances, we refer to the PAHs as aged. In this sense, adding compost has both advantages and disadvantages – microbial metabolism of pollutants is likely to be stimulated but pollutants may be locked-up and inaccessible to the micro-organisms. However, this locking-up, whilst not remediation *per se*, offers the advantage of avoiding pollution of the wider environment – at least, in the medium-term.

Box 22 describes the fate of PAHs in contaminated soil previously co-composted with organic wastes after land application and vegetation establishment.

4.4.2 Metals

A major problem with metal polluted soil is that it prevents vegetation cover (e.g. Parys Mountain, former copper mine in North Wales), allowing wind and water erosion to spread the contamination. As the removal of polluted soil to landfill in no longer a viable option, there are limited choices for treatment. Chemical extraction procedures (soil washing) may remove metals but they also destroy the soil structure and biota. It is known that organic matter binds metals making them less available and mature compost is high in organic matter. An investigation to see if compost would render metals present in the soil less available to plants by either co-composting soil or mixing mature compost with soil compared to soil diluted with an inert material achieved successful results (**Box 23**).

4.5 Phytoremediation

One *in situ* decontamination approach showing promise for addressing both organic and metal pollutants is phytoremediation, a field of study that has grown considerably over the last decade. Still in development, the technology is not yet widely accepted by regulatory agencies and, therefore, not commonly used by practitioners. It may also take considerably longer to attain clean-up targets than through more traditional approaches.

4.5.1 Persistent Organic Pollutants

Plants remediate organic pollutants either by direct uptake or by stimulating soil microbial activity. Plant root exudates improve the nutrient status of soils and produce a rich micro-environment capable of promoting microbial biomass and improving the biodegradation capabilities of the micro-organisms inhabiting the soil closely associated with plant roots (i.e. the rhizosphere). **Box 22** refers to TWIRLS case study where the application of compost was used to enhance vegetation establishment and, in turn, phytoremediation of PAH-contaminated soil.

4.5.2 Metals

Phytoremediation is only applicable to sites containing low to moderate levels of metals at shallow depths because plant growth is affected in heavily polluted soils and remediation can only occur in the root zone. It is also a slow process, one factor that often makes it less attractive to site owners. Phytoremediation of metals in soil can take one of two forms, phytoextraction or phytovolatilization. Only arsenic, mercury and selenium exist as gaseous species in the environment, so these

[10] Hakk *et al* (2005) Decrease in water-soluble 17b estradiol and testosterone in composted poultry manure with time. *Journal of Environmental Quality* **34**: 943-950.

[11] www.remadeessex.org.uk/pageDetail.asp?articleID=84 Accessed August 2007.

metals (or metalloids) alone are susceptible to phytovolatilization. The phytovolatilization of selenium is the one form of phytoremediation that is already being used in the field. Phytoextraction requires the uptake of large quantities of metals (in general more than 1% dry weight) into a large above-ground biomass. Hyperaccumulator (plants that can accumulate large concentrations of metals naturally) exist but their biomass is usually small. Work recently has concentrated on the search for plants with a large biomass that can be induced to take up larger quantities of metals than normal. This is usually done by changing the solubility of metals in the soil by addition of complexing agents or other chemicals.

Phytoremediation of metals is mainly still in the research and development phase, the processes that affect metal availability, uptake, translocation and chelation need to be investigated in detail[12].

4.6 Summary

- The first phase of remediating a contaminated site is to delineate the areas that are contaminated using an appropriate soil (vegetation, water) sampling strategy to determine the level of hazard. A risk assessment-based approach is necessary that takes into account the nature of the contaminant, its behaviour in soil, soil type, and intended end-use of the remediated land.

- Engineering remediation strategies tend to be invasive, destroy soil function but achieve end-results quickly. Biological solutions are more sustainable, less invasive but slower to achieve desired outcomes.

- Composting as a biological strategy for remediation of contaminated land is gaining favour as a green technology and enjoys public acceptance.

- There are scientifically proven reasons for using organic material to address both metal and organic pollutants in soil.

- Tertiary-treated biosolids is a valuable and plentiful resource and trials have demonstrated that it may be safely included as a compost feedstock material.

- TWIRLS found that mixing PAH-contaminated soil with organic wastes dissipated PAHs during composting but aerating contaminated soil on its own worked just as well. The availability of heavy metals in compost feedstocks changed during the compost process but depended on metal species and compost type: metal availability did not always decrease (i.e. stabilise).

- Mixing contaminated soil with compost enhanced PAH degradation once the mix was applied to land and vegetation had established. Mixing metal-contaminated soil with compost lead to a reduction in plant shoot uptake of copper, lead and arsenic.

- Composting was found to reduce the concentration of endocrine disruptor compounds contained in feedstocks such as sewage.

- The process of composting and application of organic wastes, particularly as compost, to remediate contaminated land appears to be a viable approach for PAHs and some metals. However, proof-of-concept trials should always be conducted before field-scale work begins.

[12] Padmavathiamma P. K. (2007). Phytoremediation technology: Hyper-accumulation metals in plants. *Water Air and Soil Pollution,* **184**, 105-126.

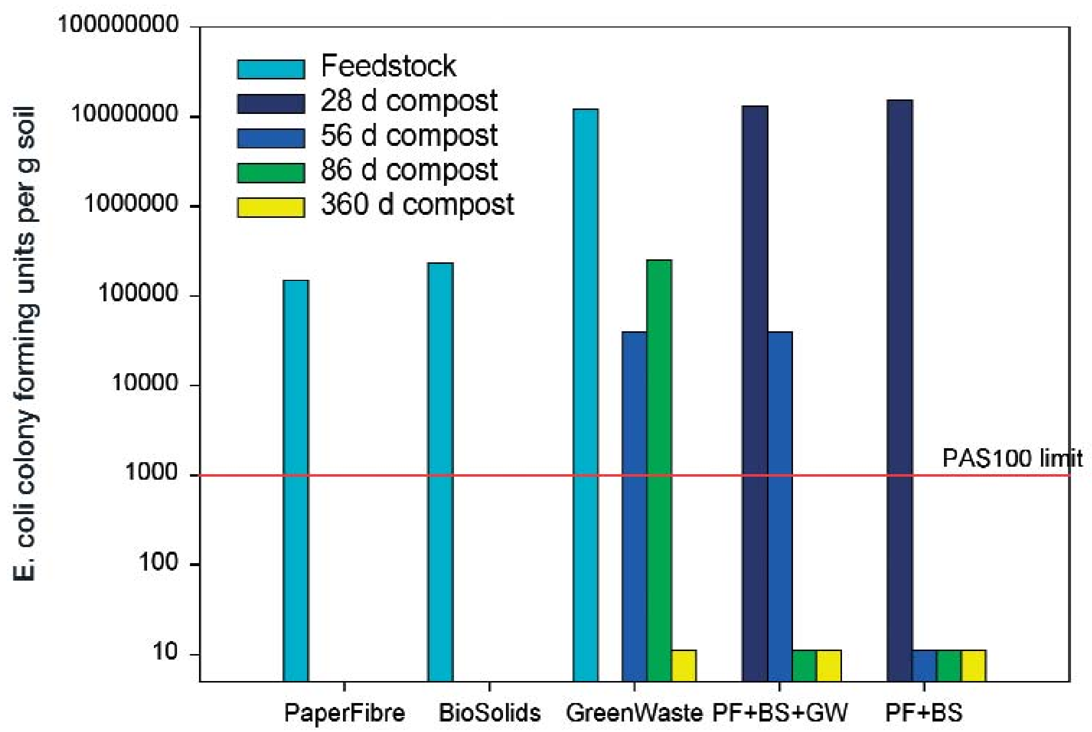
Box 18

Effect of the composting process on human pathogen survival

Organic wastes (de-inking paper fibre biological sludge*, biosolids and green waste) were co-composted in combination and tested for human pathogens to assess the suitability of the end-product for land restoration purposes. Composting was undertaken using an in-vessel system in which feedstocks were encapsulated in low density polyethylene bags (**right**) and received controlled forced aeration over a two-month period, followed by one month maturation in the bag and a further nine months in the open. *Escherichia coli* and *Salmonella* species were enumerated by a commercial laboratory using BSI PAS100-specified methods. All feedstocks contained significant numbers of *E. coli* bacteria, which decreased during the composting process and maturation. All mixes of TWIRLS compost met industry standards at maturation for *E. coli* (**below**) and *Salmonella* spp. (data not shown). *E. coli* colonies declined more slowly in green waste compost than in composts containing biosolids.

Conclusion: using biosolids as a feedstock in compost does not lead to an increase in human pathogens in mature compost and does meet the specification of quality compost.

* biological sludge refers to the mixed wastestream of de-inking paper fibre and factory wastewater sludges



Box 19

Co-composting PAH-contaminated soil with organic wastes to improve the dissipation of PAHs

A former steelworks site in NorthWales was found to contain zones of PAH contamination.The whole site had been previously capped with estuarine dredgings to remove the source-pathway-receptor linkage and hence, potential hazard. However, relatively small quantities of contaminated soil were found on the surface as a result of the arisings from the construction of a bentonite wall in 2000: these soil arisings had been formed into static piles placed on top of impermeable plastic sheeting on the surface of the field and provided a source of contaminated soil to use in the composting trial.

Contaminated soil was either composted on its own or with organic wastes (Table 1) after checking that the level of contamination was below threshold concentration limits that would classify the soil as 'hazardous', using Appendix C of WM2 (Section 2.5.1). Compost was produced using EcoPOD® in-vessel aerobic composting vessels (Ag-Bag International Ltd, Warrenton, OR, USA) with forced aeration and the fate of PAHs followed over time. EcoPOD®s are ideal for on-site remediation work, avoiding the necessity of carrying contaminated material offsite - all components of the system are mobile and suitable for 1000 m^3 compost production on an 80-day cycle. Activities were carried out under Exemption to Paragraph 12 of the Waste Management License Act (1994) and in addition, planning consent was required for composting. PAHs were measured in contaminated soil taken from the static pile and prior to mixing with organic feedstocks (Jun. 2005), immediately after mixing and placement in the EcoPOD®s (Jun. 2005) and at pod-opening after compost maturation (Jan. 2006). Analysis of PAHs was conducted under MCERTS (European and International Standard BS EN ISO/IEC 17025:2000) accreditation.

Composting resulted in some reduction in total PAH concentration in all mixes (Fig. 1) but aerating just contaminated soil on its own was one of the most successful treatments. Those treatments that included paper fibre were more variable and, on average, showed less percentage PAH removal. Figure 2 looks at the behaviour of individual PAH compounds during composting, with the molecular weights of the compounds increasing from left to right on the x-axis. In all composted mixes, the low molecular weight PAHs like naphthalene decrease in their relative contribution to total PAH-load during composting and the highest molecular weight compounds did not change much. The 3- and 4-ring compounds (middle of x-axis) mostly increased in relative contribution, notably benzo(b)fluoranthene, presumably reflecting the reduction in low molecular weight compounds.

Conclusion: composting contaminated soil using forced-aeration removed PAHs with or without added organic wastes. Low molecular weight PAHs were reduced the most during composting.

Table 1. Feedstock composition of co-composting experiment.

Code	Composition	% by dry wt
CS	Contaminated soil	100
GW+BS	Green waste + Biosolids	80+20
PP+BS	Paper fibre + Biosolids	40+60
CS+GW+BS	Contaminated soil + Green waste + Biosolids	20+64+16
CS+PP+BS	Contaminated soil + Paper fibre + Biosolids	20+32+48
CS+GW+PP+BS	Contaminated soil + Green waste + Paper fibre + Biosolids	20+28+28+24

(PAH-contaminated soil CS; de-inking paper fibre PP; green waste GW; biosolids BS)

Box 19 continued

Collecting soil contaminated with polycyclic aromatic hydrocarbons (PAHs) from former steelworks activities that had been stored at the site on impermeable plastic to monitor natural attenuation (degradation under ambient conditions) of PAHs with time. The TWIRLS project used this soil to demonstrate the effect of composting on PAHs.

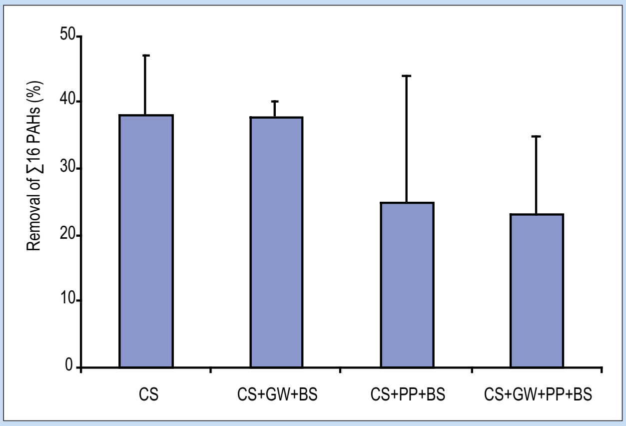


Figure 1. Percentage removal of total PAHs (i.e. USEPA priority 16 PAHs) as a result of in-vessel co-composting PAH-contaminated soil (CS) with organic wastes (paper fibre PP, green waste GW, biosolids BS) for seven months.

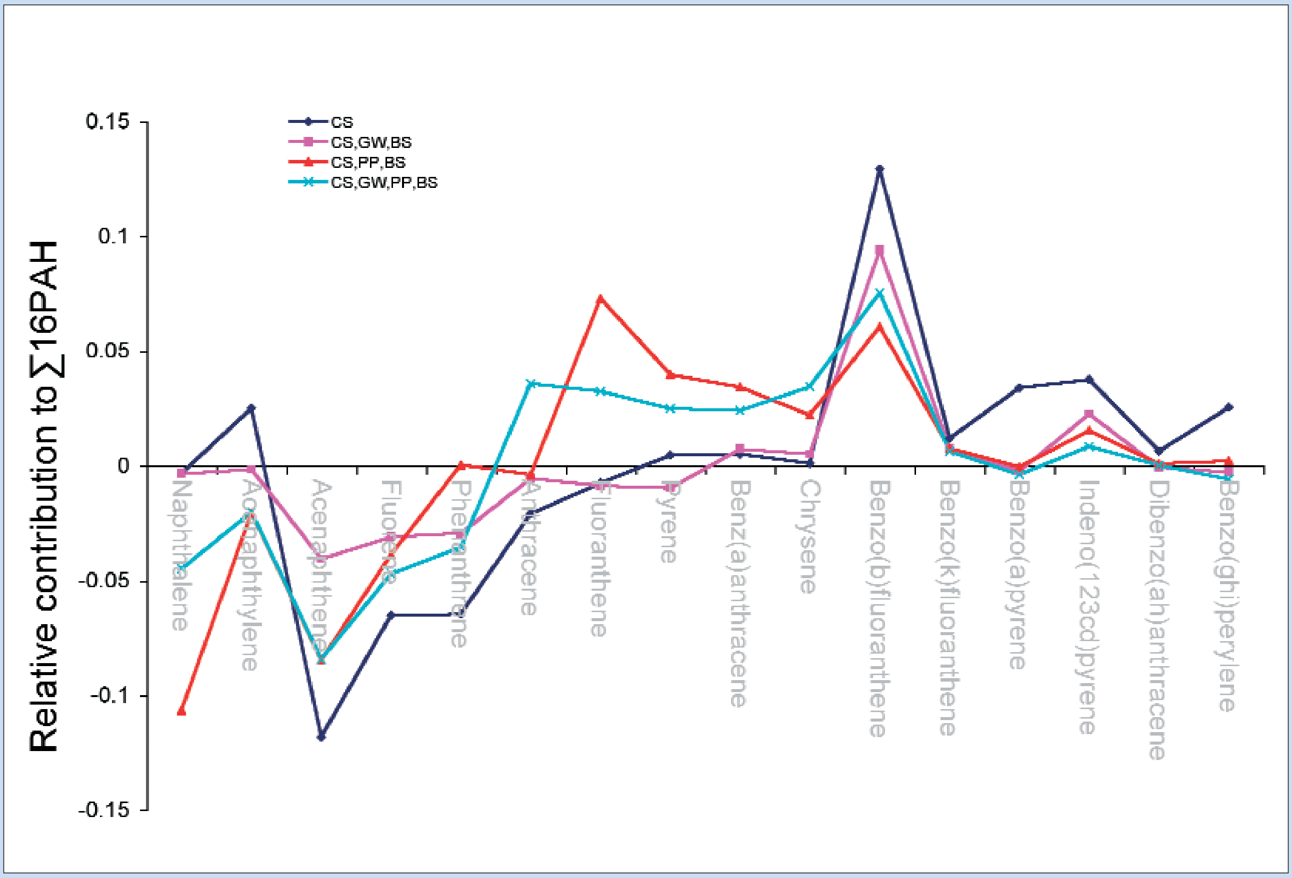


Figure 2. Change in the relative contribution of individual PAH compounds to total PAH concentration (i.e. USEPA priority 16 PAHs) as a result of in-vessel co-composting PAH-contaminated soil (CS) with organic wastes (paper fibre PP, green waste GW, biosolids BS) for seven months. A negative value denotes a reduction in relative contribution. PAHs are organised by increasing size or complexity (left to right) on the x-axis.

Box 20

The effect of the composting process on metal stabilisation

Three different types of compost were followed from the mixing of the initial feedstocks to maturation to investigate how the availability of metals present in the feedstocks changed over the process.


MSW Fines


Green Waste


De-inking Paper Fibre


Biosolids

Compost composition can be seen in Table 1. The MSW and GM composts were prepared using EcoPOD® in-vessel aerobic composting vessels (Ag-Bag International Ltd, Warrenton, OR, USA) with forced aeration and the GPB compost was made in 1 m^3 bags which were turned frequently to aerate the compost.

Total concentrations of copper, lead, zinc and nickel increased over the time of composting due to mass loss of the compost as the feedstocks were broken down. GPB compost had total copper and nickel concentrations over PAS 100 limits[1] by the end of the process, as did MSW compost for lead.

Table 1. Feedstock composition of the three composts

Code	Composition	% w/w (DW)
GPB	Green Waste + Paper Fibre + Biosolids	35 + 35 + 30
MSW	MSW	100
GM	Green Waste + MSW	55 + 45

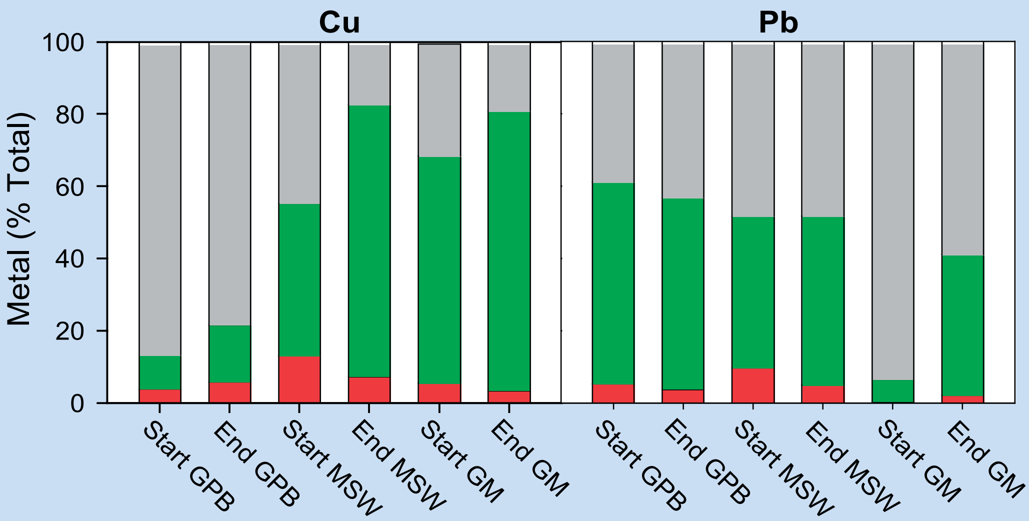


Figure 1 Change in percentage Cu and Pb over time found in different forms, recalcitrant (grey), organically bound (green) and available (red) in three composts.

[1] WRAP website accessed August 2007 http://www.wrap.org.uk/downloads/Introduction_to_BSI_PAS_100-20052.abab7d36.pdf

Box 20 continued

The percentage of total copper bound to organic matter increased during composting for all composts. However, that was at the expense of the percentage in the most recalcitrant (least available) fraction (**Figure 1**). The percentage of copper in the most available fraction did not always decrease over time. It can also be seen that the percentage of copper in the organic fraction varied greatly depending on the feedstocks. For lead again it can be seen (Figure 1) that the picture varies between different composts. The percentage of lead bound to organic matter remains fairly stable for GPB and MSW compost but increases greatly for GM compost. This is mirrored by stability in the percentage in the recalcitrant fraction in the former but this decreases greatly in GM.

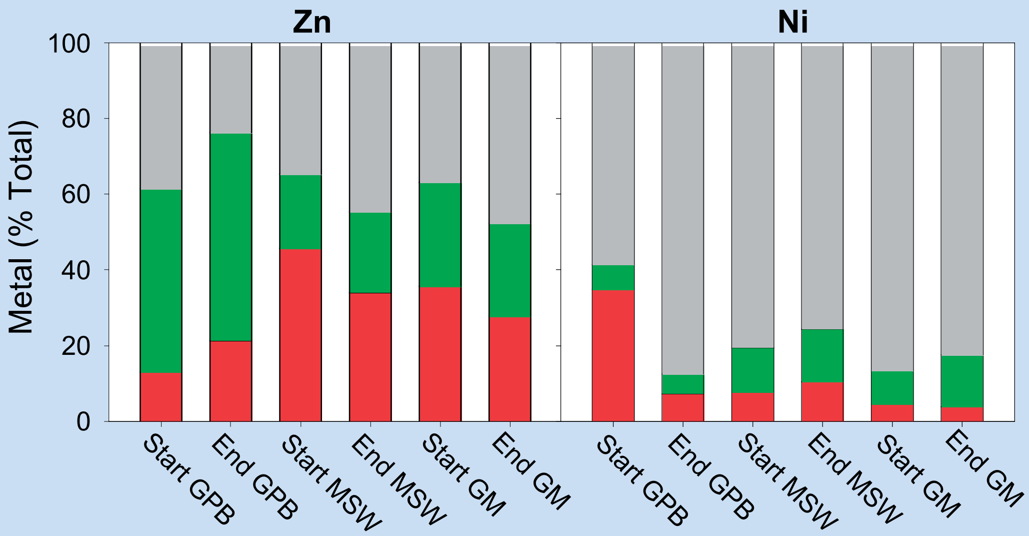


Figure 2. Change in percentage Zn and Ni over time found in different forms, recalcitrant (grey), organically bound (green) and available (red) in three composts.

The distribution of zinc and nickel between the fractions are just as variable between the different composts (Figure 2) although nickel seems to have the highest percentage in the recalcitrant fraction of all metals.

Conclusion: Total concentrations of metals increase over the time of composting. The percentage of metal found in different availability fractions depends on the feedstocks used and the particular metal. Composting does not necessarily stabilise metals found in the feedstock material and sometimes leads to them becoming more available for plants and soil organisms.

Box 21

Fate of endocrine disrupting compounds during in-vessel aerobic composting

Endocrine disruptors interfere with hormone signaling in animals and can alter sexual differentiation, reducing reproductive success and precipitating decline of sensitive populations. Although there is no compelling evidence that they are a threat to human health, endocrine disruptors have altered a range of ecosystems, with aquatic organisms most susceptible. In many rivers in the UK, a high proportion of male fish exhibit female sexual characteristics as a result of exposure to endocrine disruptors.

Most organic wastes contain natural compounds with estrogenic potential (i.e. phytoestrogens) and a range of endocrine disruptors are found at contaminated industrial sites. The risk of harm depends on amounts, rates of decay and potential for movement to water courses. For land restoration, sewage sludge is of concern since sewage contains both natural and synthetic endocrine disruptors, including human hormones, potent hormones used in contraceptive tablets and industrial surfactants. Use of sludge in land restoration is an excellent opportunity to recycle nutrients and increase soil organic matter and provided that best practice spreading guidelines are observed the risk is low.

Anaerobic biodigestion of sewage is not an efficient method of lowering amounts of some well known endocrine disruptors; research suggests that aerobic composting is.[1] The TWIRLS project followed the fate of endocrine disruptors during EcoPOD® in-vessel aerobic composting of various mixtures of green waste, tertiary-treated sewage sludge, de-inking paper fibre and contaminated soil. Compost extracts are difficult to analyse as they contain a large number of compounds and it is difficult to distinguish between them. Using high performance liquid chromatography, TWIRLS identified several endocrine disruptors, most notably small but significant amounts of nonyl-phenol (a decay product from certain industrial surfactants) present in sewage.

Whilst further research is required, aerobic composting reduced amounts of nonyl-phenol by as much as 90%. The significance of this finding is that in addition to being a useful method of creating stable soil-forming materials for land restoration, aerobic composting of mixed organic wastes also lowers the risk of waste-derived endocrine disruptors causing harm to sensitive ecosystems.

[1] Hakk *et al* (2005) Decrease in water-soluble 17b estradiol and testosterone in composted poultry manure with time. *Journal of Environmental Quality* **34**: 943-950.

Box 22

The fate of PAHs in contaminated soil previously co-composted with organic wastes after land application and vegetation establishment

Following on from Box 19, four composted mixes containing PAH-contaminated soil with or without organic wastes (Box 19, Table 1) were applied to contaminated land and spread to a depth of 7.5 cm over an approximate total area of 6000 m^2. Composts were then incorporated into the top 7.5 cm of *in situ* sandy substrate, to give 50:50 sand-compost mixes, to a depth of 15 cm, using a power harrow. The land was then seeded with meadow grassland species (NVC MG5b) and young Poplar trees were planted. PAHs were measured immediately after incorporation (February 2006) and 16 months later (June 2007).

The benefits after the landspreading of co-composted contaminated soil plus organic wastes depended on the composition of the mixes used. Composted contaminated soil, on its own, failed to show further dissipation of PAHs after landspreading; however, when composted with organic wastes, further dissipation of PAHs was observed (Fig.1). Composted mixes of contaminated soil with greenwaste plus biosolids and with paper fibre plus biosolids both showed dissipation of 3- and 4-ringed PAHs (Fig. 2). **Conclusion**: composting PAH-contaminated soil with organic wastes increases the potential for improved dissipation of higher molecular weight PAHs once applied to land and vegetated.

The contaminated soil-compost mixes planted with Poplar trees and grassland species.

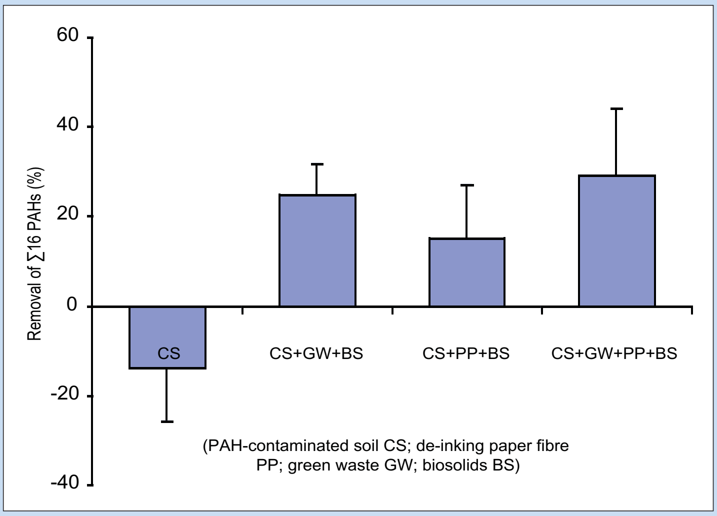


Figure 1. Percentage removal of total PAHs over a 16-month period as a result of spreading co-composted contaminated soil and organic wastes onto land and establishing vegetation.

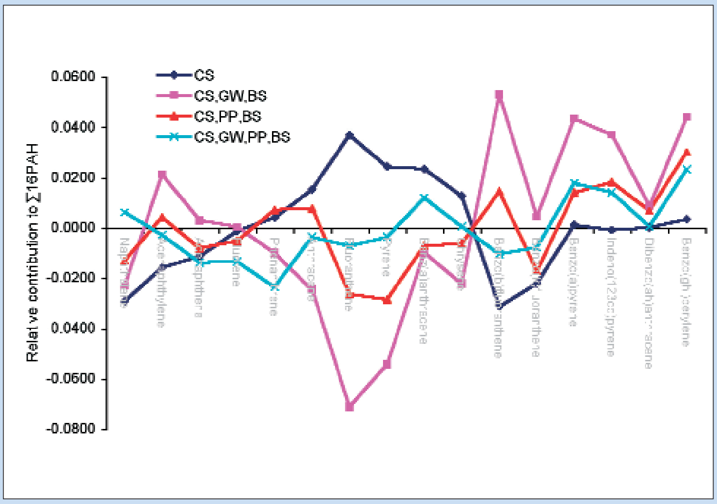


Figure 2. Change in the relative contribution of individual PAH compounds to total PAH concentration as a result of landspreading PAH-contaminated soil with organic wastes for 16 months. A negative value denotes a reduction in relative contribution. PAHs are organised by increasing size or complexity (left to right) on the x-axis.

Box 23

The effect of amending metal-contaminated land with composted organic wastes

Compost composed of green waste, de-inking paper fibre and biosolids (35:35:30 DW) was prepared in 1 m^3 bags over a period of 26 weeks. Aeration was achieved through regular turning and mixing. At the same time contaminated soil was co-composted with the same feedstocks on a 50:50 dry weight basis and the same procedure followed. The contaminated soil came from Parys Mountain on Anglesey in North Wales, a former copper mine. The soil was heavily contaminated with copper, lead and arsenic (Table 1).

Table 1. Heavy metal content of Parys Mountain soil

	mg kg^{-1} DW						
	Cu	Pb	As	Zn	Ni	Cd	Hg
Parys Mountain Soil	2834	5041	101	214	5.7	<3.8	<3.8

Soil mixed with compost

Soil mixed with inert material

The mature compost was mixed with an equal amount of the soil to that present in the co-composted mixture and both were placed in 5 L pots. A control treatment was set up by diluting the soil with an inert material (polystyrene balls) to the same degree as the compost diluted the soil. See Table 2 for treatment descriptions. After one month wheat (*Triticum aestivum* L.) was germinated and six sprouted seeds planted in each pot. The plants were allowed to grow for one month before they were harvested, the biomass measured and the metal content of the shoots extracted and measured by ICP-MS.

Table 2. Treatments and treatment codes

Treatment Code	Treatment
C	Soil + mature compost
CS	Co-composted soil
S	Soil mixed with inert material

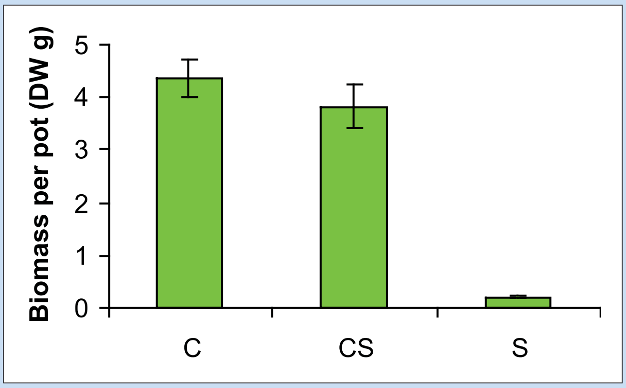


Figure 1. Wheat biomass after one month. Soil + compost (C), co-composted soil (CS), diluted soil (S). Mean ±SE

Plant biomass was greatly enhanced after one month of growth in both the soil + compost (C) treatment and the co-composted soil treatment (CS) compared with the diluted soil (S) (**Figure 1**). This is probably due to two factors: nutrition and reduction in heavy metal availability. Compost has a much higher nitrogen and plant-available phosphorus content compared with the Parys Mountain soil, which is low in all nutrients.

Box 23 continued

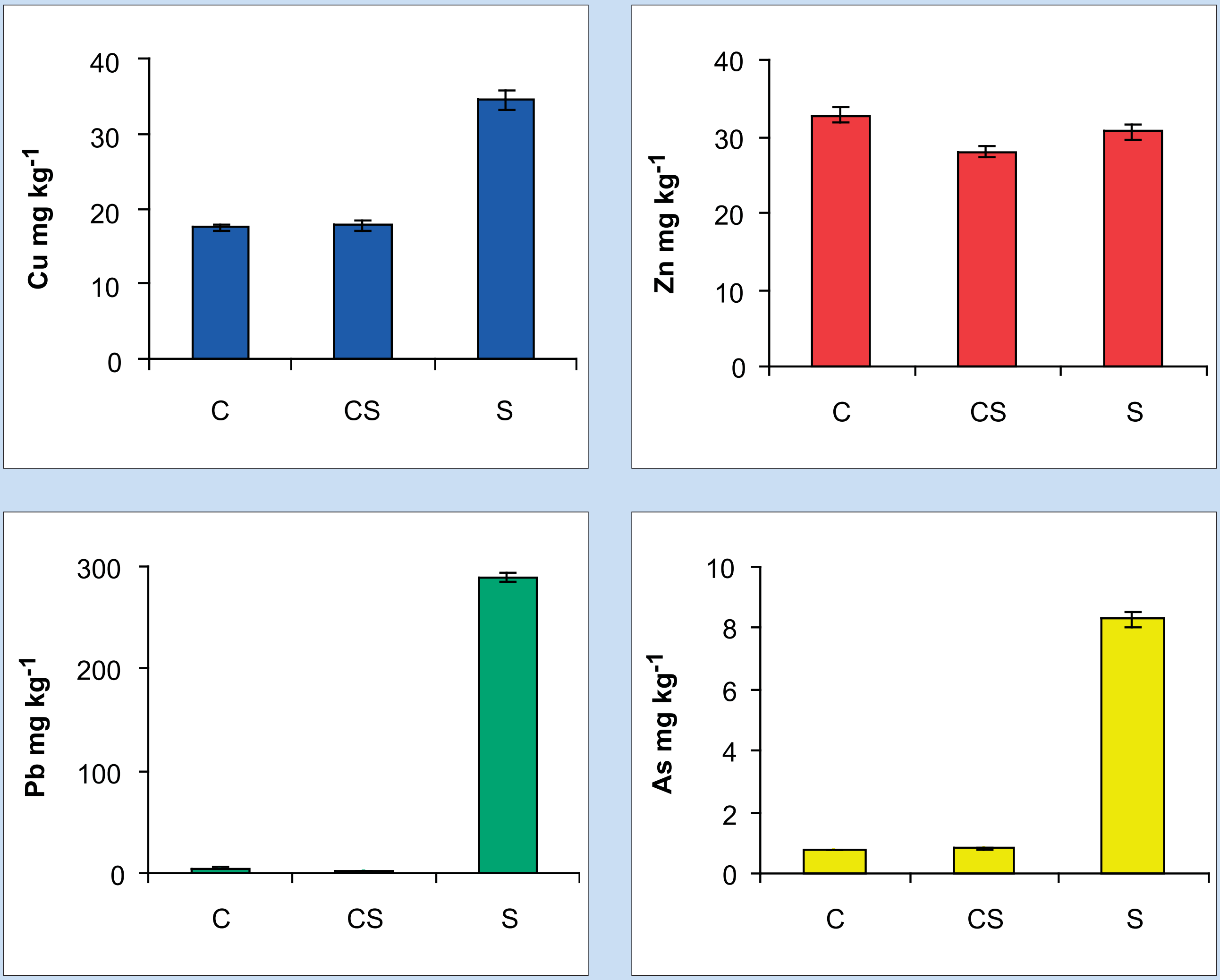


Figure 2. Wheat shoot metal concentrations at harvest.
Top left copper, top right zinc, bottom left lead and bottom right arsenic.

Both the soil + compost (C) and the co-composted soil (CS) led to a lower concentration of copper, lead and arsenic being taken up by the wheat, showing it was less available to plants (Figure 2). The concentration of zinc taken up was quite similar in all treatments. Zinc levels in the growth substrates were not greatly elevated as the soil did not contain high levels of zinc. As zinc is essential for plant growth, plants have active uptake mechanisms.

Conclusions: Mixing compost on site with the metal-polluted soil can help re-establish vegetation on these contaminated sites. It provides nutrients for plant growth and reduces the uptake of potentially toxic metals by the plants. There was found to be no difference between mixing mature compost with soil and co-composting the soil with the initial feedstocks as long as the one month was left after mixing prior to sowing.

Appendix I Sources of information

Table 1: Selected manuals detailing best practice for producing compost (green background), bioremediation, restoring land and creating habitats. Redrawn and expanded from Williamson *et al.* (2003).[1]

Publication	Emphasis
JC Cripps *et al* (2007) Reclamation planning in hard rock quarries: a guide to best practice. Dept. of Civil and Structural Engineering, University of Sheffield.	Hard-rock quarry reclamation. Constraints, regulatory framework, planning, site investigations and aftercare.
A Singh and OP Ward (2007) Applied bioremediation and phytoremediation. Springer-Verlag.	In depth consideration of major contaminants and their bioremediation. Includes addition of organic materials to soil. Brief consideration of composting.
English Partnerships (2006) The brownfield guide. A practitioners guide to land reuse in England. English Partnerships, London. Online or free CD ROM: www.englishpartnerships.co.uk/publications	Brownfield restoration. Regulatory framework and participatory appraisal, restoration options, case studies, techniques for remediating soil and water.
Enviros Consulting & CL:AIRE (2006) Use of compost in regeneration and remediation of brownfield sites in the UK. The Waste and Resources Action programme (WRAP). Online at: www.wrap.org.uk	Assesses the potential for using compost for land restoration in the UK. Includes case studies and cost comparisons.
The Composting Industry Code of Practice (2005). The Composting Association (TCA). Online (members only) at: www.compost.org.uk	Guide to establishing and running composting sites including regulation, risk assessment, process and quality control.
Enviros Consulting (2004) Managing garden waste at civic amenity sites. Good practice guide. The Waste and Resources Action programme (WRAP), Oxon, UK. Online at: www.wrap.org.uk	Guide dealing specifically with garden waste and aimed at local authority officers and their contractors. Includes labelling and marketing of compost, layout and management of civic amenity sites.
MH Wong & AD Bradshaw eds. (2003) The restoration and management of derelict land: modern approaches. World Scientific Publishing.	Emphasis on work in Asia together with universally applicable theory and practical advice i.e. soil handling and fertility management.
JC Williamson *et al* (2003) Restoring habitats of high conservation value after quarrying. Best practice manual. University of Wales, Bangor. Online at: www.bangor.ac.uk/ies/life/life.htm	Hard-rock quarry restoration. Site assessment, restoration planning and stakeholder engagement, evaluating success and practical techniques including use of sewage and de-inking paper pulp.
G White & J Gilbert (2003) Habitat creation handbook for the minerals industry. RSPB.	Practical techniques for creating BAP habitats on redundant mineral workings including hard and soft rock quarries and coal spoil.

[1] Williamson *et al* (2003) Restoring habitats of high conservation value after quarrying: best practice manual. University of Wales, Bangor.

Publication	Emphasis
ML Morrison (2002) The science and practice of ecological restoration. Techniques for habitat analysis and animal monitoring. Island Press. 209 pp.	Ecological restoration and wildlife management. Techniques for assessing wildlife populations, captive breeding, reintroduction / translocation of animals
RE Hester and RM Harrison (2001) Assessment and reclamation of contaminated land. Royal Society of Chemistry. Purchase online at: www.rsc.org	UK regulatory regime, site survey, human and ecological risk assessment methodology. Specific techniques for remediation.
D Watson (2000) Wildlife management and habitat creation on landfill sites: A manual of best practice. Ecoscope Applied Ecologists.	Techniques for creating a broad range of habitats on landfill sites; operational and engineering constraints, case studies.
MJ Oxford (2000) Developing naturally: a handbook for incorporating the natural environment into planning and development. ALGE.	Relevant planning guidance, codes of practice and British standards are listed against activities associated with habitat creation or restoration.
J Mitchley *et al*. (2000) Habitat restoration monitoring handbook. English Nature (now Natural England) Research Report no. 378. English Nature.	Implementation of monitoring methods and prescriptions, with check lists.
NAD Bending *et al* (1999) Soil-forming materials: their use in land reclamation. HMSO, London.	Preparing substrates capable of sustaining plant development on land with a range of end-uses. Suitability of wastes. Trial design.
OL Gilbert & P Anderson (1998) Habitat creation and repair. Oxford University Press.	Comprehensive guide covering ethics and theory of habitat creation. Considers all major UK habitats with examples of good and bad practice.
Land Use Consultants (1996) Reclamation of damaged land for nature conservation. HMSO, London.	All-encompassing: strategies for nature conservation, planning, management and case studies for decision-makers; technical fact sheets on establishing a range of habitats for practitioners. 3 volumes.
DM Parker (1995) Habitat creation – a critical guide. English Nature (now Natural England) Science Report no. 21. English Nature.	Project management for habitat creation including techniques for creating a range of habitats. Based on review of > 100 projects.
Welsh Development Agency (1994) Working with nature: low cost land reclamation techniques. WDA.	Design, plant establishment and management using low intervention principles. Case studies.
WE Sopper (1993) Municipal sludge use in land reclamation. Lewis Publishers.	Use of municipal sludge (sewage) on USA surface mine reclamation. Detailed assessment of the effects of sludge on plants, soil, water quality and animal health.
Environmental Advisory Unit (1988) heathland restoration: a handbook of techniques. British Gas.	Techniques for heathland restoration and aftercare.

Websites

www.adas.co.uk
ADAS are the UK's largest environmental consultancy and produce a variety of publications relevant to land restoration and use of organic waste materials, including the Safe Sludge Matrix.

www.ccw.gov.uk
The Countryside Council for Wales is the Government's statutory advisor on sustaining natural beauty, wildlife and the opportunity for outdoor enjoyment in Wales and its inshore waters. CCW champions the environment and landscapes of Wales and its coastal waters as sources of natural and cultural riches, as a foundation for economic and social activity, and as a place for leisure and learning opportunities. We aim to make the environment a valued part of everyone's life in Wales.

www.compostireland.ie
Cré – Composting Association of Ireland TEO. Cré – The Composting Association of Ireland Teo was established in 2001. Cré is the Irish word for 'Earth'. It promotes composting and compost utilisation in Ireland. The Association's function is to infuse best practices into the development of an industry. They promote public awareness and research and development of an information storehouse on composting and compost utilisation.

www.claire.co.uk
Contaminated Land: Applications in Real Environments (CL:AIRE). Independent not-for-profit organisation promoting practical and sustainable remediation technologies.

www.defra.gov.uk
UK Department for the Environment, Food and Rural Affairs (DEFRA). Regulation and policy for agriculture and the environment.

www.ec.europa.eu/environment
European Commission Directorate General (DG) for the Environment. Legislation including framework directives, definition of waste, thematic strategy on soil protection. Also funding opportunities.

www.environment-agency.gov.uk
UK Environment Agency (EA)"We are the leading public body for protecting and improving the environment in England and Wales. It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world."

www.compost.org.uk
The Composting Association (TCA) The Composting Association is committed to the sustainable management of biodegradable resources. It promotes the benefits of composting and other biological treatment techniques and the use of biologically treated materials for the enhancement of the environment, business and society.

www.hse.gov.uk
UK Health and Safety Executive (HSE). Regulatory guidance and practical health and safety advice including working with sewage sludge.

www.wrap.org.uk
The Waste and Resources Action Programme (WRAP). WRAP works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment

www.buglife.org.uk
Buglife-The Invertebrate Conservation Trust is the first organisation in Europe devoted to the conservation of all invertebrates, and we are actively engaged in saving Britain's rarest bugs, slugs, snails, bees, wasps, ants, spiders, beetles and many more fascinating little animals. Our aim is to halt the extinction of invertebrate species and to achieve sustainable populations of invertebrates.

www.compostnetwork.info
European Compost Network (ECN). The Network is a collaboration of partners, promoting sustainable practices in composting, anaerobic digestion and other treatment procedures for organic residues across Europe. It aims to address the needs of both practical operators and decision makers.

www.landrestorationtrust.org
Land Restoration Trust. Created by a partnership comprising English Partnerships, Groundwork, the Forestry Commission and the Environment Agency, the Land Restoration Trust is tackling enduring dereliction across England.

www.englishpartnerships.co.uk
English Partnerships (EP). Our overall aim is to achieve high-quality, well-designed, sustainable places for people to live, work and enjoy.

www.ieem.org.uk
Institute of Ecology and Environmental Management (IEEM). Professional membership organisation. Includes directory of members searchable by area of expertise (i.e. for providing consultancy services / expert witnesses).

www.eic-uk.co.uk
The EIC was launched in 1995 to provide environmental technology equipment and services suppliers with a strong and effective voice to influence the debate on the future of the industry among policymakers in Westminster, Whitehall and Brussels. It aims to promote constructive co-operation between the regulated, the regulators and the UK's environmental technology suppliers who serve them

www.eic-yearbook.co.uk
Land remediation yearbook published by the EIC. The Environmental Industries Commission (EIC) was launched in 1995 to provide the environmental technology and services industry with a strong and effective voice with Government in the debate about to how to ensure that British companies succeed in the growing worldwide market.

www.naturalengland.org.uk
Natural England has been formed by bringing together English Nature, the landscape, access and recreation elements of the Countryside Agency and the environmental land management functions of the Rural Development Service.

www.sepa.org.uk
Scottish Environment Protection Agency (SEPA). We are Scotland's environmental regulator and adviser, responsible to the Scottish Parliament through Ministers. As well as our role in controlling pollution, we work with others to protect and improve our environment. These pages tell you more about what we do and how we work.

www.ehsni.gov.uk
Environment and Heritage Service (EHS) Northern Ireland. EHS takes the lead in advising on, and in implementing, the Government's environmental policy and strategy in Northern Ireland. The Agency carries out a range of activities, which promote the Government's key themes of sustainable development, biodiversity and climate change. Our overall aims are to protect and conserve Northern Ireland's natural heritage and built environment, to control pollution and to promote the wider appreciation of the environment and best environmental practices.

www.netregs.gov.uk
Netregs. Legislation online hosted by the Environment Agency. NetRegs is a partnership between the UK environmental regulators – the Environment Agency in England and Wales, SEPA in Scotland and the Environment and Heritage Service in Northern Ireland. They provide free environmental guidance for small and medium-sized businesses throughout the UK.

www.grazinganimalsproject.org.uk
GAP was formed in 1997 to aid the development of conservation grazing throughout the UK; it is a partnership project drawing representatives from the nature conservation, agricultural and livestock sectors. GAP exists to help land managers achieve appropriate grazing on wildlife sites. We provide practical support to graziers, wildlife site managers and conservation advisors through 3 main work areas.

www.remade.org.uk
Remade Scotland. An initiative seeking to promote recycling (including composting) and strengthen markets for recyclates in Scotland.

Appendix II Glossary

Anaerobic Digestion

Anaerobic digestion is the biological treatment of organic wastes (usually food waste or manure in combination with green waste) in the absence of oxygen to yield methane (biogas) that can be used for heat and electricity generation or upgraded for use as vehicle fuel. A variety of different technologies exist, most produce liquid and solid outputs. Liquid outputs are valuable fertilizers, solid digestates are suitable for use as soil forming materials for land restoration and bioremediation.

Bioaerosols

Potentially harmful airborne micro-organisms (i.e. fungal spores, bacteria, viruses) or compounds produced by micro-organisms (i.e. endotoxins). Bioaerosols are a particular concern of regulators, composting, materials recovery and waste water treatment plants since they are the most likely route of exposure to harmful pathogens. Peak bioaerosol production occurs when wastes are agitated (shredded, turned, screened, spread to land) and although improved models of bioaerosol dispersion are needed it is true to say that workers are at greatest risk since levels of bioaerosols decrease rapidly with distance from source and are usually not above background > 250 m from source.

Bioremediation

Bioremediation refers to the harnessing of beneficial microbial communities to break-down or 'metabolise' hazardous compounds in the environment. Often, bioremediation can be accelerated by optimising conditions under which these beneficial microbes work best; this generally entails providing an adequate supply of nutrients (fertiliser), water and aeration.
Bioremediation works best on organic compounds like petroleum, tar or oil that can be degraded to less toxic, smaller compounds by micro-organisms which, in turn, derive energy from the process, allowing them to grow in size and number.

Brownfield land

The simplest definition of brownfield land most often used in land-use inventories is 'land that has previously been developed'.

Composting

Composting describes the aerobic (with oxygen) breakdown of organic matter by micro-organisms under managed conditions. Several key stages are defined including an initial thermophilic phase where high temperatures are generated by exothermic (energy yielding) biological oxidation of organic matter by thermophilic micro-organisms, a cooling phase where mesophilic micro-organisms decompose more complex organic molecules and a maturing phase where rates of biological activity decline and stabilise.

Compost Like Outputs (CLOs)

Solid organic output from the treatment of Municipal Solid Waste (MSW) fines (recovered by Mechanical Biological Treatment; MBT) by aerobic composting or anaerobic digestion. Depending on the efficiency of post-treatment screening and cleaning, CLOs may be suitable for land restoration and bioremediation but are more likely to contain metals, glass, plastic and sharps contamination than composts or digestates produced from separated organic waste materials.

De-inking paper fibre

De-inking paper fibre is a by-product of recycling paper with a long history of disposal to agricultural land and use in land restoration. De-inking paper has a higher dry matter (> 60 %) and C content than most other organic wastes. Since it is mostly composed of short wood fibres (lignin, cellulose and hemicellulose) that decompose slowly, it is ideal for increasing soil organic matter and water holding capacity or mixing with fertile wastes (i.e. sewage) to create soil forming materials. Paper pulp may contain some nitrogen, copper and trace elements depending on factory processes.

Derelict land

Derelict land is 'incapable of beneficial use without treatment'.

Endocrine Disrupting Chemicals (EDCs)

Endocrine disruptors are substances (including natural and synthetic hormones, certain industrial chemicals and certain agrochemicals), or mixtures of substances that have the potential to affect processes of hormone signalling within animals. Several organic wastes (particularly sewage sludge and historically de-inking paper pulp) contain appreciable amounts of EDCs and best practice land spreading guidelines should be followed to avoid harm occurring to sensitive ecosystems. Aquatic organisms are most susceptible.

Mechanical Biological Treatment (MBT)

A generic term for an integration of several processes designed to recover recyclable materials and sometimes energy from Municipal Solid Waste (MSW) and reduce the volume of residual material sent to landfill. The biodegradable fraction of MSW is recovered by screening and these 'MSW fines' are treated by several different methods including aerobic composting or anaerobic digestion. Treatment of MSW fines by either of these methods produces Compost Like Outputs (CLOs).

Micro-organism

Organisms < 0.1 mm. For example composting and soil bacteria, actinomycetes, fungi, algae and protozoa.

Municipal Solid Waste (MSW)

Non-source segregated household waste.

Phytoremediation

The use of plants to remediate polluted land or water.

Potentially Toxic Element (PTE)

(Definition taken from the compost Quality Protocol). Chemical element that has the potential to cause toxicity to humans, flora and/or fauna. The majority are also known as 'heavy metals' or 'transition metals' (e.g. lead, chromium, cadmium, mercury, copper, zinc, nickel).

Tertiary treated sewage sludge

Also known as 'biosolids', 'municipal sludge' or 'cake'. Tertiary treated sewage sludge is a dewatered output from anaerobic treatment of waste water in water treatment plants. Sewage sludge has a long history of use in agriculture, land restoration and bioremediation and is an excellent source of organic matter and plant nutrients, containing large amounts of N and P but only trace amounts of potassium. Sewage also contains Potentially Toxic Elements (PTEs), including zinc, copper, chromium, lead and organic pollutants including Endocrine Disrupting Compounds (EDCs). As with all other organic waste materials, beneficial use of sewage sludge is a question of balancing environmental and human health benefits and risks.

Water Holding Capacity (WHC)

Water storage capacity of organic or mineral materials. Field capacity water content (FCW) describes maximum WHC, water content at permanent wilting point (PWPW) describes the amount of 'extreme' reserve water held in soil with a water potential of -1.5 MPa. Available water content (AWCW) is calculated by subtracting PWPW from FCW and represents the range at which most plants can access water. WHC is a function of particle size distribution and organic matter content and is roughly correlated with C content.

Appendix III Abbreviations

ABP	Animal By-Products (ABP Directive 1774/2002/EC)
APE	Alkylphenol Ethoxylate (surfactant)
BAP	Biodiversity Action Plan
BSI	British Standards Institute
CCW	Countryside Council for Wales
CLO	Compost Like Output
DEFRA	Department of the Environment Food and Rural Affairs
DoC	Duty of Care
EA	Environment Agency
EDC	Endocrine Disrupting Compound
ECN	European Compost Network
EHS	Environment and Heritage Service (Northern Ireland)
EWC	European Waste Catalogue (code)
FC_W	Field Capacity Water Content
HACCP	Hazard Analysis and Critical Control Point
HWD	Hazardous Waste Directive (Council Directive 91/689/EC)
LPA	Local Planning Authority
LOW	List Of Wastes
MBT	Mechanical Biological Treatment
MCERTS	Monitoring Certification Scheme
MSW	Municipal Solid Waste
MTL / MPL	Mobile Treatment License / Mobile Plant License
NVC	Nitrate Vulnerable Zone (Nitrates Directive 91/676/EC)
BS 3882: 2007	Specification for topsoil and requirements for use
BSI PAS 100	Publicly Available Standard 100
PAHs	Polycyclic Aromatic Hydrocarbons
POP	Persistent Organic Pollutant
PPC	Pollution Prevention and Control (permit)
PTE	Potentially Toxic Element
RDB	Red Data Book
TCA	The Composting Association (UK)
TWIRLS	Treating Waste for Restoring Land Sustainability
WAG	Welsh Assembly Government
WFD	Waste Framework Directive (75/442/EEC)
WHC	Water Holding Capacity
WML	Waste Management License
WMLR	Waste Management Licensing Regulations
WRAP	the Waste and Resources Action Programme
S^0	Elemental sulphur
SEPA	Scottish Environment Protection Agency
SER	Society of Ecological Restoration
SGVs	Soil Guideline Values
SOM	Soil Organic Matter
SSIA	Soil Science Institute of Athens
VOCs	Volatile Organic Compounds

Citation:
Nason, M., Williamson, J., Tandy, S., Christou, M., Jones, D. and Healey, J. (2007).
Using organic wastes and composts to remediate and restore land: best practice manual.
School of the Environment and Natural Resources, Bangor University.

Further copies:
School of the Environment and Natural Resources, Bangor University, Bangor, Gwynedd LL57 2UW. WALES.
+44 (0)1248 382281 senr@bangor.ac.uk

Free download:
www.bangor.ac.uk/ies/TWIRLS/TWIRLS_home.htm