LANDFILL MANUALS

LANDFILL RESTORATION AND AFTERCARE

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PREFACE

The Environmental Protection Agency was established in 1993. The functions of the Agency are set down in the Environmental Protection Agency Act 1992. They include the licensing and regulation of significant industrial activities, the monitoring of the quality of the environment, the provision of support to local authorities in respect of environmental protection activities and the promotion of environmental research. These powers were supplemented in 1996 with the passing of the Waste Management Act. The Agency is responsible for the licensing and control of the majority of Ireland's waste disposal and recovery activities which are listed in the Third and Fourth Schedule of the Waste Management Act. Some smaller waste disposal and recovery activities are now subject to a permit system as specified under the Waste Management (Permit) Regulations, 1998 (SI No. 165 of 1998).

Under Section 62 of the 1992 Act the Agency is required to specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites. These criteria and procedures are being published in a number of volumes under the general heading of "Landfill Manuals". Three manuals have already been published: *Investigations for Landfills, Landfill Monitoring and Landfill Operational Practices.*

The purpose of the present manual is to provide guidance on all aspects of landfill restoration and aftercare to afteruses such as amenity and nature conservation, woodland, agriculture and hard end uses. The manual deals with restoration design, afteruse, soils and soil handling operations, vegetation establishment and management and the production of site specific restoration and aftercare management plans. The maintenance requirements of the environmental pollution control systems and on-going monitoring requirements during the aftercare period are also outlined.

It is envisaged that further manuals will be available in due course and, at the time of writing, manuals on landfill site design, waste acceptance and landfill site selection are in preparation. Given that this *Restoration and Aftercare Manual* is one of a series, it is important that the present volume is read in conjunction with the other published documents.

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A review panel was established by the Agency to assist in the finalisation of the manual and those persons who took time to offer valuable information, advice and in many cases comments and constructive criticism on the manual in its draft form are acknowledged below. Grateful acknowledgement is made of the assistance afforded by the following persons:

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1. INTRODUCTION

1.1 GENERAL BACKGROUND

Landfill is currently the most widely used method of waste disposal in Ireland and is likely to continue to be the main disposal option for the short to medium term despite considerable efforts in recycling and waste minimisation. Reducing the present reliance on landfill is one of the most fundamental issues to be addressed in current waste management and planning. In line with standing policy and economies of scale, many of the smaller landfill sites have been closed or are in the process of closing and those which do not, or cannot, be upgraded to meet high environmental standards will have to close and be restored.

Successful restoration is one of the ways of convincing the public that landfills are an acceptable means of waste disposal. Selection of an appropriate site, good operational practice and site design are other important elements. Restoration and aftercare are both essential steps in the process of waste disposal, and must be considered at all stages of the life of the site if landfilling is to be managed in a way that minimises environmental impacts.

In the eyes of the public, successful site restoration is often considered one of the more important elements because the results endure and are visible for much longer than the period for which the site is operational. Also, many of the engineered structures which are essential in preventing environmental pollution are below ground and are therefore not visible. A well restored site returns the land to a beneficial and attractive afteruse and gives assurances that any future landfill site will also be restored to a similarly high standard, thereby promoting public confidence in the landfilling process.

1.2 STATUTORY BASIS AND USE OF THIS MANUAL

The Environmental Protection Agency is required, under section 62 of the Environmental Protection Agency Act, 1992, to specify and publish criteria and procedures for the selection, management, operation and termination of use of landfill sites for the disposal of domestic and other waste. This manual on Landfill Restoration and Aftercare is one of a series of manuals published by the Agency to fulfil this statutory function. Under section 62 (5) Local Authorities have a statutory obligation to have regard to the contents of this manual.

Under section 68 (3) of the Waste Management Act, 1996, the statutory requirements detailed in section 62 of the EPA Act do not apply where the Agency has granted a waste licence for a particular landfill facility. Therefore the requirements of this manual apply to operational and closed landfill sites not subject to waste licensing. However, the manual is intended to provide general advice and guidance to practitioners involved in the restoration of landfill sites subject to waste licensing or any other landfill sites.

1.3 EU AND NATIONAL WASTE POLICY

Ireland's waste policy is outlined in the document *Waste Management - changing our ways* published by the Department of Environment & Local Government in 1998. Irish policy in relation to waste management is founded on the EU-approved hierarchy of waste management options. These priority options include:

- the prevention and reduction of waste at source;
- reducing the quantity of non-recoverable waste;
- recycling and re-using waste to the maximum extent for raw materials and energy; and
- environmentally sustainable disposal of waste which cannot be prevented or recovered.

Legislation and best practice guidelines have been introduced to promote a more sustainable and safe approach to waste management in Ireland. These include the Environmental Protection Agency Act, 1992, and Waste Management Act, 1996. The Environmental Protection Agency Act, 1992, allowed for the introduction of Integrated Pollution Control (IPC) licensing of scheduled industrial activities by the Agency, with emphasis being placed on the use of cleaner technologies and waste minimisation.

The Waste Management Act, 1996, provides a comprehensive statutory framework for the management of waste within the agricultural, commercial and industrial sectors with particular emphasis on waste prevention, minimisation and safe disposal. This Act provides for a wide range of measures to be applied to promote and support waste recovery. It also prohibits the holding, transport, recovery or disposal of waste in a manner which causes or is likely to cause environmental pollution. The 1996 Act designates the Agency as the licensing authority for significant waste management facilities, and sets down criteria which must be adhered to for a waste licence to be issued, retained and surrendered. The Waste Management (Licensing) Regulations, 1997 (SI No. 133), and the Waste Management (Licensing) (Amendment) Regulations, 1998 (SI No. 162), provide for the commencement and operation by the Agency of a system of licensing of waste disposal and recovery activities.

1.4 LANDFILL MANUALS

The Environmental Protection Agency has published a series of manuals as required under the Environmental Protection Agency Act, 1992. These manuals deal with many aspects of landfill development and management. The present manual on *Landfill Restoration and Aftercare* should be used in conjunction with the other manuals in the landfill series. Manuals in this series which are published or currently in preparation are:

- Investigations for Landfills, 1996
- Landfill Monitoring, 1996
- Landfill Operational Practices, 1997
- Landfill Restoration and Aftercare, 1999
- Landfill Waste Acceptance (in preparation)
- Landfill Site Design (in preparation)
- Landfill Site Selection (second draft).

1.5 MANUAL ON LANDFILL RESTORATION AND AFTERCARE

The purpose of the present volume is to provide guidance on all aspects of landfill restoration. Good landfill restoration provides an opportunity for landfill operators to promote public acceptance of landfills. The manual sets down the requirements for successful restoration to afteruses such as nature conservation and amenity, woodland, agriculture and hard end uses such as built structures and car parks. Restoration is a process which will return a site to a condition suitable for its proposed afteruse whilst incorporating measures to protect human health and the environment.

Restoration includes design, initial landscaping works, soil spreading and aftercare. Aftercare is the work that is carried out after replacement of the soil and includes all operations necessary to establish and maintain the afteruse of a restored site. Aftercare includes cultivations, vegetation establishment, maintenance and an ongoing long term commitment to the restored land. Particular attention must be given to soil management and weed control if successful restoration is to be achieved.

This manual covers restoration design within the context of the overall design and management of landfill sites. An important aspect of restoration design is the successful integration of the site's environmental pollution control systems with the proposed afteruse. It also discusses the important role of soils in restoration, the choice of afteruse, the benefits of phased restoration, vegetation establishment techniques and maintenance.

An important element for successful restoration is the production of a site specific restoration plan detailing the timing, personnel, skills and materials required in restoration including the production of an aftercare management plan which details the works and responsibilities for the ongoing management of the restored land. It is essential that the restoration and aftercare management plan is a flexible working document that can respond to changing circumstances and technologies.

Figure 1.1 illustrates the linkage between the sites environmental management plan and the restoration and aftercare plan.

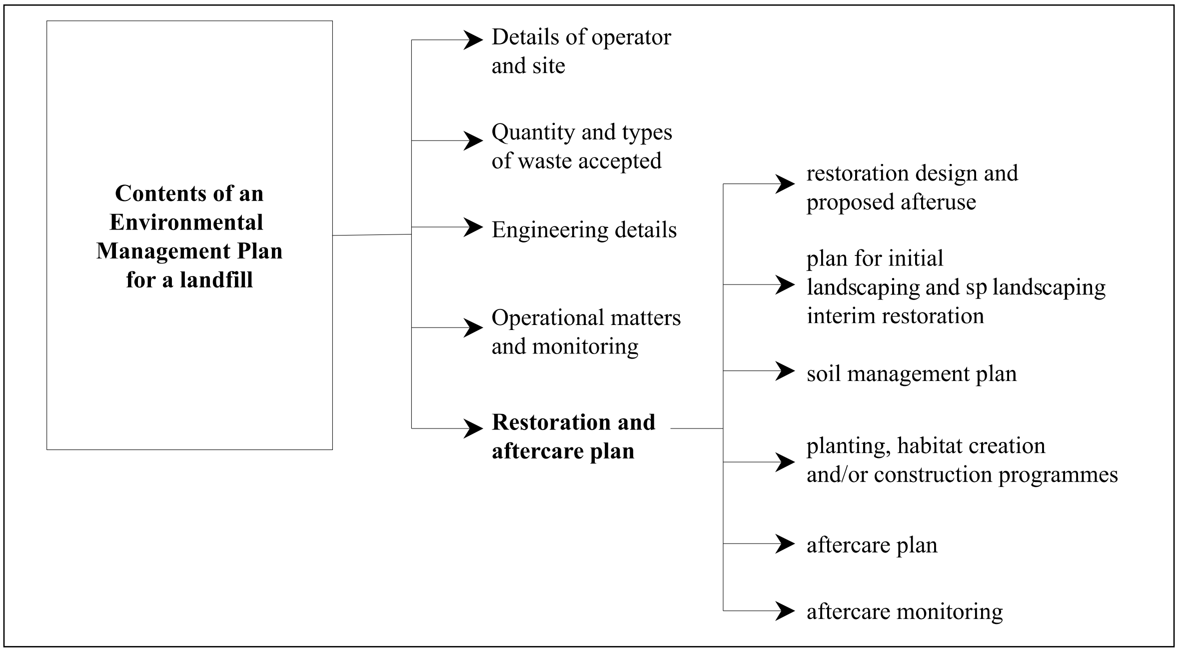


FIGURE 1.1 CONTENTS OF AN ENVIRONMENTAL MANAGEMENT PLAN FOR A LANDFILL

2. DESIGN

2.1 INTRODUCTION

For high quality restoration to be achieved it is essential that restoration requirements are considered at the outset during the design of the landfill and also throughout its operation. The objective of restoration design should be to produce integrated proposals for pollution control, restoration and aftercare whilst ensuring the protection of the environment and human health. A site specific restoration plan must be prepared early in the overall planning of the site so that the landfill can be restored on a phased basis. The plan will outline the restoration programme and detail the works, the timings, expertise and materials required for successful restoration.

The first stage in design is a detailed site investigation and an assessment of the environmental issues. For existing or closed landfill sites, the impacts of the landfill on the surrounding environment must also be assessed so that appropriate remedial measures can be designed. Further details on investigations are available in the Agency's manual on *Investigations for Landfill.*

2.2 LANDFILL RESTORATION CONSIDERATIONS

2.2.1 INTRODUCTION

Successful landfill restoration requires good silvicultural, agricultural, ecological and engineering practice. These principles apply to all types of restoration but persons specifically involved in landfill restoration must understand and be aware of the potential problems which can be encountered on landfills. Implementing restoration and aftercare works on site may require the specialist skills of:

- soil scientists;
- landscape architects;
- civil and/or geotechnical engineers;
- hydrogeologists and geochemists;
- agriculturists, horticulturists and silviculturists;
- ecologists; and
- archaeologists.

A good understanding of the potential problems which can be encountered on landfill sites will help the restorer to ensure that restoration is successful. In addition, modern technologies and good engineering practices can eliminate many of the potential problems, however, settlement is unavoidable on sites where biodegradable waste has been deposited.

The main considerations include:

- settlement;
- landfill gas;
- leachate;
- elevated temperature;
- shallow soils and soil compaction; and
- surface and groundwater flow patterns.

2.2.2 SETTLEMENT

Settlement is one of the most visible signs of the complex physical and biochemical processes which occur after the deposition of waste in landfill sites. The final post-settlement levels and contours of a landfill must be taken into account in developing a restoration plan. In order to achieve the required contours it is necessary to predict the amount of settlement that will occur and to ensure that this takes place as evenly as possible across the site. It is important when predicting degradation times to account for changes in waste composition that will occur over the life of the landfill. The rate and degree of settlement occurring at a landfill will always be site-specific and will be influenced by the site conditions, landfill practices, types of waste deposited, and the effects of the mechanical and biochemical processes. Settlement values of between 10 and 25% of the depth of the landfill can be expected for municipal waste landfills. The highest rates of settlement will occur within the first five years with the rates gradually slowing down over time until the waste eventually stabilises.

Three stages of settlement can usually be distinguished at landfills *(Latham, 1994; Manassero et al. 1996):*

- instantaneous settlement following the application of a new layer of waste or cover as a result of physical compression;

- delayed physical settlement due to loading and the migration of smaller particles into void spaces within the waste (lasting weeks or months); and

- long term biochemical settlement due to decomposition of the biodegradable waste and physicochemical changes such as corrosion and oxidation within the landfill (lasting decades).

Settlement has the potential to be a major impediment to successful restoration as the rate of settlement is difficult to predict. Specialist advice should be sought when assessing and calculating settlement rates for individual sites. Specialist literature on the subject should also be consulted e.g. *Environmental Geotechnics* prepared by Technical Committee TC5 of International Society of Soil Mechanics and Foundation Engineering (ISSMFE). Figure 2.1 illustrates a problem area which needs careful attention in phased landfilling. If the waste type varies between different phases then each phase may require a different amount of fill (i.e. surcharge) above final contours to allow for subsequent settlement *(Gawn, 1991).*

The problems on restored landfills caused by settlement include:

- damage to buried services including components of leachate and gas management systems;

- breach of the capping system;

- formation of low spots particularly in phased restoration, leading to ponding, infiltration, leachate generation and crop death;

- damage to land drainage including ditches and drains;

- poor landform;

- limited afteruse options; and

- extending the aftercare period.

2.2.3 LANDFILL GAS

Landfill gas is the complex mixture of gases formed during the decomposition of biodegradable waste. It is primarily composed of methane (64%), carbon dioxide (34%) plus trace concentrations of a range of organic gases and vapours. The rate of landfill gas production is influenced by a number of factors including the types of wastes deposited, the moisture content, temperature, pH and density of wastes, the infill rate and degree of compaction. Landfill gas is produced in significant quantities during the first ten years of the landfill with a typical annual

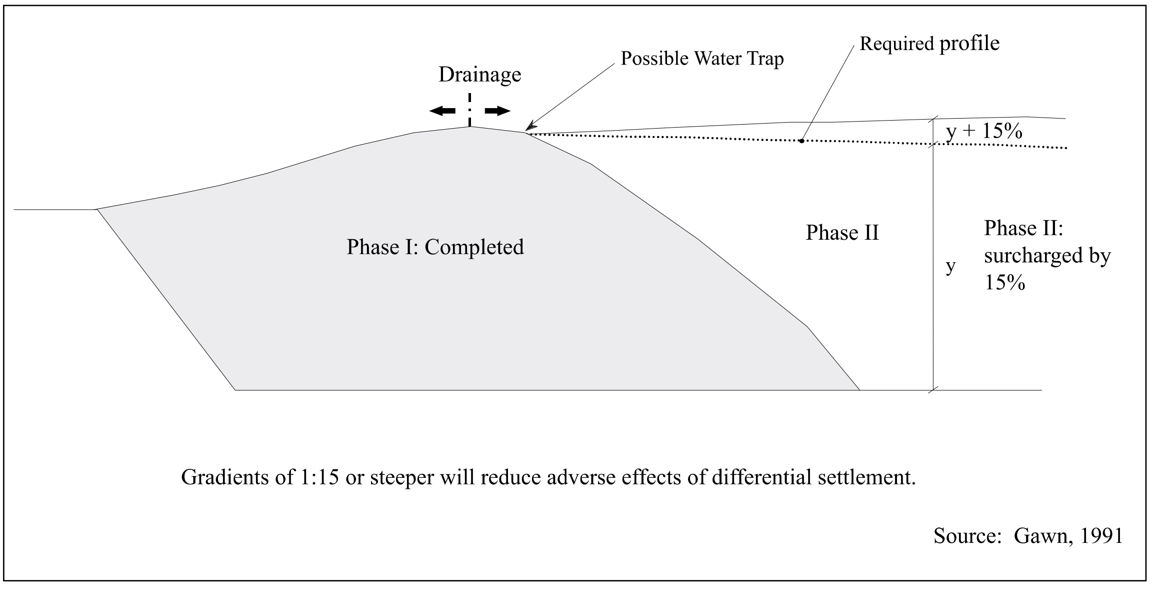


FIGURE 2. 1 ILLUSTRATION OF A PROBLEM AREA IN LANDFILLING

production rate of $10m^3$ of gas produced per tonne of deposited waste. Further details are available in the Agency's manual on *Landfill Operational Practices.*

Landfill gases escape, because of differences in pressure and density, through the top surface or through cracks that may be present in capping materials or because of diffusion through permeable strata bordering the site. Migration of these gases into the root zone of vegetation growing on top of landfills can cause plant deaths. On sites with no cap or landfill gas control system, landfill gas may vent across the whole restored surface causing widespread vegetation dieback *(Holmes, 1991).* Some localised hot spots may be identified by patches of dead or dying vegetation. Vegetation affected by landfill gas typically exhibits wilting and yellowing of leaves (chlorosis), premature leaf loss and stunted growth of roots and shoots. Severely affected vegetation will eventually die.

2.2.4 LEACHATE

The term leachate describes any liquid percolating through the deposited waste and emitted from or constrained within a landfill. The quantity of leachate produced is dependent upon the liquid fraction of wastes, rainfall, surface water inflow and groundwater intrusions. Current landfill engineering practice requires the containment, collection and treatment of leachate. Uncontrolled migration of leachate may arise at existing sites. Leachate breakout is caused by high leachate levels within the waste resulting from uncontrolled ingress of water into the site, or a perched leachate table caused by relatively impermeable layers within the waste. However, on existing sites, leachate may escape through weaknesses in the capping layer, or through the soil covering particularly around the edges of the landfill, or through defects in the lining of containment systems. There are some toxic effects from leachate *(Dobson & Moffat, 1993)* but in many cases it is the waterlogging and anaerobic soil conditions that cause dieback of vegetation. Leachate has also the potential to impact negatively on surface and groundwater thereby affecting water quality for humans and wildlife particularly salmonid and wetland sites.

2.2.5 ELEVATED TEMPERATURE

Microbial decomposition of wastes within the landfill generates energy in the form of heat. As a result, landfill sites accepting biodegradable waste may have elevated temperatures in comparison to other sites. Temperatures at the surface depend on the type and thickness of the barrier layer and the depth of the soil cover.

Root zone temperatures for optimum tree growth lie in the range of approximately 10 - 30°C, and temperatures at which root growth declines significantly lie in the range 25 - 35°C, though the effects of soil temperature on plant growth are strongly species dependent *(Ruark et al. 1983).* If elevated temperatures are experienced some alteration to roots and growth will occur. Where temperatures exceed 30°C damage is more likely to be caused by soil anaerobism induced by increasing oxygen demand of roots and stimulated soil microbial activity.

2.2.6 SHALLOW SOILS AND SOIL COMPACTION

Soil is used in the restoration of landfill sites for amenity, forestry and agricultural afteruses. Even for hard end uses, some soil will be required for landscaping purposes. The importance of soils in achieving successful restoration has often been overlooked. Poor soil management during construction, operation and decommissioning may result in soil loss and damage. As a result the quantities of soils available on site are often inadequate for successful vegetation establishment. The depth of soil overlying the cap is an important factor in determining the available water capacity. A compacted shallow soil may be prone to waterlogging in winter. Shallow soils may restrict the growth of roots and nutrient supply making trees prone to windthrow.

Poor soil structure and compaction are problems which commonly occur on many restored landfill sites leading to lack of soil aeration and anaerobic conditions throughout the year. These problems arise as a result of poor soil handling. Inappropriate soil handling techniques such as poor timing of operations and unsuitable machinery use can cause a reduction in pore space, aeration, water holding capacity, gaseous exchange and root penetration which will affect restoration success. Waterlogging in the winter and the growth of rushes, buttercups etc. are conditions that commonly occur on restored landfill sites as a result of improper soil handling practices.

2.3 RESTORATION DESIGN

2.3.1 INTRODUCTION

The objective of restoration design is to produce integrated proposals for the restoration of the landfill. It is essential that restoration is considered as an integral part of the whole landfill process which should be taken into account throughout the life of the landfill, from planning to completion. Careful integration of the pollution control systems, site operations, environmental management, landscape and restoration design will minimise conflicts during aftercare. It is important to build in some flexibility into restoration design to allow for changes in future land use priorities.

The parameters which affect restoration and aftercare design of a landfill site include:

- ecology of site and surrounding area;
- landuse and soil resources (including proximity to settlements);
- landscape;
- drainage requirements;
- gradients;
- hydrology and hydrogeology;
- archaeology;
- pollution control systems; and
- afteruse.

2.3.2 ECOLOGY

The restoration design should take account of the results of an ecology survey so that important habitats are protected during the landfilling operations and that opportunities for creation/enhancement of appropriate and site-specific ecologically valuable habitats are fully realised.

The level of detail required for an ecological assessment will vary considerably with the ecological significance of the existing environment. This assessment should extend beyond the site boundaries to obtain information on the quality/ecological characteristics of the existing environment prior to the development. The Development Plan and Waste Management Plan should also be consulted. Ecological assessment of the site and the surrounding area should include:

- identification of existing and/or pending environmental designations e.g. Natural Heritage Areas (NHAs) (proposed), Special Protection Areas (SPAs), Special Areas of Conservation (SACs) (proposed), Statutory Nature Reserves, National Parks, Salmonid Water, etc. Further details on environmental designations are given in *Evaluation of Environmental Designations in Ireland (2nd Edition, 1997)* by David Hickey;
- identification and location of any rare and/or endangered species as specified under the Wildlife Act, 1976, Flora Protection Order of 1987 and the *Irish Red Data Book I: Vascular Plants* by T.G.F. Curtis & H.N. McGough, *Irish Red Data Book 2: Vertebrates* by A. Wilde and *Red Data Books of Britain and Ireland: Stoneworts* by N.F. Stewart & J.M. Church;
- an assessment of the significance of the habitats (terrestrial and/or aquatic) and species on a local, regional, national and international scale;
- identification of land use and any management practices which have or are currently influencing relevant habitat types, relevant species abundance and diversity;
- location of any significant natural features such as streams, wooded areas, food sources, shelter, outcrops etc. upon which specific species and habitats depend;
- identification of any important seasonal factors and food chain implications which may affect habitats and/or individual species; and
- consultation with Dúchas, An Taisce, The Heritage Council, Regional Fisheries Boards, wildlife NGOs (e.g. Birdwatch Ireland, IWT etc.), local naturalists and other relevant bodies.

2.3.3 LANDUSE AND SOIL RESOURCES

The land and soils of Ireland can be divided into three broad categories *(Lee, 1991):*

- lowland mineral soils (wet or dry);
- mountain, hill and high level peat (land over 150m above sea level); and
- low-level peat (basin or blanket).

The system of land classification adopted in Ireland evaluates the degree of suitability of each soil unit for a ranges of uses. Soil suitability depends largely on the physical properties of the soil and the environment. Landuse categories for urban and rural areas include:

- central city or town area;
- renewal area;
- industrial area;
- residential area;
- open space;
- amenity/scenic and nature conservation areas;
- agricultural area; and
- woodland area.

Development Plans and Waste Management Plans should be consulted. Further information on soil classification in Ireland is given in Appendix E.

Soils are required for restoration to softend uses such as amenity (including nature conservation), woodland and agriculture. The types and quantities available for restoration are a critical design consideration. A soil materials balance needs to be undertaken to determine the quantities of soils available on site and the quantities that will be required. Type and quantity of available soils will influence the design of the site by affecting the potential afteruses, and need to be determined on a site by site basis. In general, however, soil requirements will depend on the intensity of use i.e. extensive or intensive. Further details on soil requirements are given in Chapter 4.

A detailed soil survey will provide the information necessary to assess the quantity and quality of soils available for restoration and their location. The requirements of this survey should be taken into account during the investigation so that soil sampling and inspection can be undertaken when boreholes are drilled and logged. This information will be used to plan soil stripping, storage and replacement operations and also to determine the viability of different afteruse options. The information obtained during the soil survey should include:

- soil texture and colour;
- total soil depth including topsoil and subsoil (soil profile);
- location and extent of different soil types on site;
- stoniness; and
- any obvious physical limitation to use.

2.3.4 LANDSCAPE DESIGN

The objective of landscape design is to create a landscape suitable for the proposed afteruse, to integrate the restored site into its surroundings, to screen the operational area and to leave finally an area which is of benefit to society. High quality landscape design must recognise long term management and maintenance requirements of the proposed afteruse. The key landscape design considerations are gradient requirements for proposed afteruses and stability, integration with the surrounding topography and integration of environmental pollution control systems. The landfill gas management system is particularly important and may influence the choice of afteruse.

High quality landscape design is important in creating an attractive restored landfill site which achieves its proposed afteruse. Landscape design objectives can be divided into short term and long term. High quality landscape design will:

- enable the restored site to blend into its surroundings and make a positive contribution to landscape quality of the area;
- ensure landscape development in tandem with phasing of the landfill;
- minimise the duration of disturbance on

each part of the site;

- maximise areas for early tree planting thereby reducing initial site disturbance;
- provide a suitable landscape setting for the proposed afteruse;
- recognise long term management and maintenance requirements;
- reduce visual impacts by utilising screening mounds and tree planting throughout the lifecycle of the landfill; and
- achieve landscape integration by creating visual links with adjacent features such as continuing existing hedgerows across reclaimed sites, extending adjacent woodlands, replicating small scale features e.g. stone walls, rock outcrops and creating wildlife corridors where appropriate.

Different landuses have individual landscape characteristics which should be included in the design. The landscape design must suit the needs of the proposed afteruse in terms of slopes, contours, adjoining habitats, soil depth and drainage, planting design and access arrangements.

2.3.4.1 LANDSCAPE AND VISUAL IMPACT ASSESSMENT

A landscape and visual impact assessment should be carried out as part of restoration design proposals for new, existing and landfills not subject to waste licensing. The objective in landscape assessment is to compare the existing landscape of the site and the surrounding area with that which will be created during construction, operation and restoration of the landfill. Landscape impacts result in changes to the character of the landscape while visual impacts are concerned primarily with the direct impact of the landfill upon views. Particular attention should be focused on scenic areas, areas of conservation value, designated tourist routes and view points, residences, hotels and other amenities, monuments and archaeological sites.

Landscape assessment of the site includes identifying and mapping:

- areas of different landscape character and landuse e.g. open water, coastline, streams, rivers, lakes, upland or lowland pasture, woodland, upland moorland and settlement areas;
- the height and form of the surrounding topography and drainage patterns;
- individual landscape features e.g. hedgerows, ponds and streams, areas of mature trees, archaeological sites, monuments;
- access routes e.g. pathways, roads etc.; and
- residential and amenity areas.

The visual impact assessment will determine how many people are likely to be affected visually by the proposal and will indicate where landscaping earthworks, planting and screening should be included to mitigate any visual intrusion or obstruction. Such an assessment will be particularly important for land-raised schemes and the visual effect of the elevated landform must be clearly stated. In determining the visual impact assessment of a proposed landfill, a viewshed or visual envelope should be used to indicate visual impact, if any, on the environment. In its simplest form a viewshed map is a diagram showing all areas that can be seen from a particular point and the map illustrates the degree to which something is seen or not seen.

Visual impact assessment of the site and surrounding area includes:

- a study of the viewing typology including view elevation, view distance and view type both into and out of the site;
- quantitative measurement of the scenic quality of the environment and views which may be categorised broadly as views vivid, conspicuous, definite or eyesores;
- assessment of seasonal impacts;
- assessment of the impacts during construction, operation, termination and restoration;

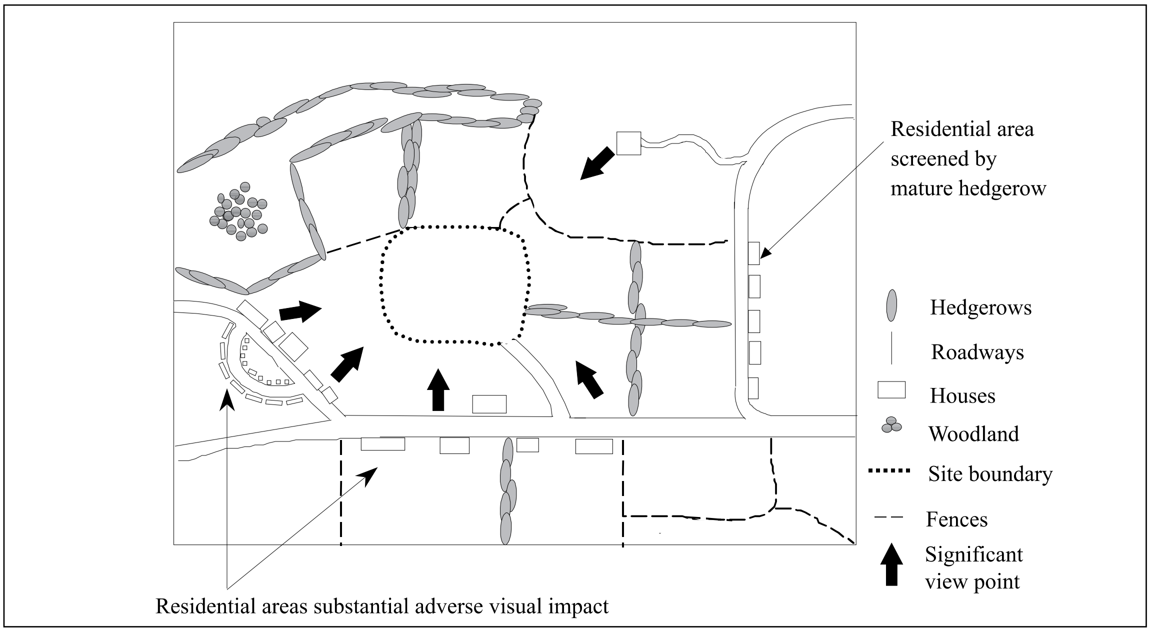


FIGURE 2.2 MAP ILLUSTRATING VISUAL IMPACT ASSESSMENT OF LANDFILL SITE

- quantifying the numbers and types of viewers affected; and
- quantifying the extent of visual intrusion/obstruction or enhancement by reference to height, mass and colour of obstruction.

The assessment should be illustrated in a site plan which should indicate the numbers and types of viewers affected using appropriate symbols to identify the major and minor visual receptors. Figure 2.2 shows an illustration of a visual impact assessment on a site plan. The landscape architect can illustrate visual effects in more detail using cross sections from key viewpoints and computer models which may be superimposed on photographs of the area.

2.3.5 DRAINAGE REQUIREMENTS

An appropriate drainage system for each landfill undergoing restoration needs to be designed on a site by site basis. Drainage layers are used below the topsoil and subsoil and above the barrier layers to provide drainage and ensure good soil conditions for plant growth. They also minimise the head of water on the underlying barrier layer and increase slope stability.

The drainage layer can consist of:

- a blanket layer of granular material of 300-500 mm thickness; or
- a geosynthetic drainage medium; or
- a herringbone drainage system using granular material.

The hydraulic conductivity should be equal to or greater than 1 x 10^{-4} metres/sec. The slope for the drainage layer in the final capping system should be no less than 4 %, i.e. 1 vertical : 25 horizontal, to assist gravity drainage. Filter layers may be required above the coarse granular material or geosynthetic drainage layer to prevent the ingress of fines and roots. In all instances where a drainage layer is placed above a clay cap and trees planting is proposed, a geotextile membrane should be placed above the granular drainage material.

Water collected by the drainage layers will need to be drained to surface water drains or similar outlets. The surface water drainage system performs the function of collecting and transporting drainage and runoff water from the landfill and surrounding area to drains at the periphery of the landfill. Perimeter surface water control systems are usually designed to accommodate both offsite and onsite runoff. It may be necessary to provide settlement ponds to remove solids from surface water. For further details on landfill drainage requirements refer to the Agency's manual on *Landfill Site Design* (being prepared).

2.3.6 GRADIENTS

Factors influencing gradient requirements of restored landfills include:

- proposed afteruse and related machinery operations;
- differential settlement;
- type of capping system;
- soil erosion and instability;
- field drainage requirements; and
- landscape requirements and local topography.

Gradients which are 1 in 15 or steeper will reduce the adverse effects of differential settlement, particularly waterlogging, in low lying areas. The visual effects of differential settlement will be less noticeable on undulating sites than on relatively flat sites. A minimum gradient of 1 in 25 is recommended for sites that will experience differential settlement. Even in flat areas the final landform should be designed to this gradient where possible to encourage natural drainage, reduce the effects of differential settlement on drainage systems and to ensure that the field drainage system on restored sites remains effective. On slopes steeper than 1 in 10, measures to control soil erosion will be required. These include the use of geotextiles, cut-off ditches and the timing of cultivation and seeding works so that grass can be established before winter.

The use of tractors in restoration works is recommended on slopes steeper than 1 in 4. However, these slopes can appear unnatural, are difficult to cultivate and seed and are also costly to maintain. The planting of trees and/or shrubs on such slopes is recommended. The maximum slope which can be safely and effectively cultivated and managed depends upon the management operations being undertaken and the type of machinery being used. Table 2.1 shows the minimum and maximum slopes related to various land uses.

TABLE 2.1 SLOPE RELATED TO VARIOUS AFTERUSES

Gradient		Significance for land use
Fraction	Degrees (to horizontal)	
1 in 2	27°	maximum for downhill use of most forestry machinery
1 in 2 approx.	25°	maximum for pasture land to avoid soil creep and formation of paths by animals across the slope
1 in 3	18°	limit for 2 wheel drive tractors with fully mounted equipment
1 in 4	14°	limit for most machinery used in cereal and grass production including combine harvesters and 2-wheel drive tractors with trailed equipment. Maximum slope for 2-way ploughing
1 in 8	7°	maximum slope for arable agriculture. Suitable for most agricultural machinery but the limit for precision seeding and harvesting machinery
1 in 10	6°	maximum longitudinal gradient for forest roads
1 in 40	1° 25’	optimum gradient for drainage channel
1 in 300	0° 11’	minimum practical fall for piped land drainage

Source: After Environment Agency, UK 1996

2.3.7 HYDROLOGY AND HYDROGEOLOGY

Landfill design includes provisions for both surface and ground water management. The Agency's manual on *Investigations for Landfills* details the extent of the investigations required.

Information of particular importance in restoration design includes:

- status of surface water bodies including amenity, nature conservation and recreational use;
- surface water drainage patterns;
- details of on-site ponding and streams;
- flow regime in watercourses;
- temporal variations in flow and quality, including flooding data and low flow;
- location of springs, sink and swallow holes or other groundwater features;
- distribution, thickness and depth of subsoils and bedrock;
- groundwater vulnerability and aquifer category;
- groundwater usage in the area;
- groundwater table level; and
- occurrence of wetland sites of nature conservation value.

Groundwater protection plans adopted by local authorities should be examined and the groundwater section of the Geological Survey of Ireland should be consulted. Investigations may be required to confirm any information gathered on the groundwater in the area. The nature and extent of the geological materials underlying the site will need to be examined and an assessment made of their suitability for use as cover, capping material and in restoration.

2.3.8 ARCHAEOLOGY AND CULTURAL HERITAGE

Archaeological sites should be identified from a desk study and during the walk-over survey of a site which is being developed. The National Monuments Section of Dúchas, The Heritage Service should be consulted regarding the occurrence of sites included in their list of recorded Monuments and Places (formally known as Sites and Monuments Records (SMR)). The National Museum should also be contacted to determine whether any significant finds of artefacts have been found in the area. A professional archaeologist will be required to identify and assess the importance, both locally and at a regional level, of any find. In addition, it is important to ensure that any finds unearthed during construction and/or operation are assessed and monitored. The archaeologist, in conjunction with the Dúchas should establish a plan for the protection of any significant archaeological finds within the boundaries of the site. This information needs to be incorporated into the environmental management plan of the site and included as part of the restoration design.

2.3.9 POLLUTION CONTROL SYSTEMS

The impact of in-situ pollution control systems on the proposed afteruse and access requirements for monitoring purposes needs to be considered in restoration and aftercare design. Integration of the pollution control systems and their protection must be a central feature of any restoration design. When a system is selected, the proposed afteruse needs to be carefully considered so as to minimise the impact of the system on aftercare. Agricultural areas generally require larger areas for cropping and machinery operations, and above ground equipment such as gas well heads and monitoring boreholes may severely reduce productivity and result in damage to machinery. If possible, wellheads and the like should be located along field boundaries. Amenity and nature conservation afteruses allow for greater flexibility in design and generally require less maintenance. This reduces the potential for damage and allows for greater use of shrubs and trees in screening. Earth mounds can be designed for both noise and visual screening. The height of the mounding, the gradient and the choice of vegetation cover will be determined by which component of the pollution control system is being screened.

The main pollution control systems that require integration and protection include:

- capping system;
- landfill gas management system;
- leachate management system;

- surface water collection and storage system; and
- fixed monitoring points for settlement, groundwater quality, surface water quality, leachate and gas sampling.

The design considerations for the pollution control systems are summarised in Appendix F.

2.3.10 AFTERUSE

Afteruse refers to the intended use of the restored site on completion of the restoration process. Important factors in determining the afteruse of a specific site include:

- site specific characteristics;
- topography and character of the surrounding area;
- Development Plan and Waste Management Plan;
- local authority consultation; and
- consultation process involving all other relevant bodies e.g. Teagasc, Coillte, Dúchas, An Taisce, The Heritage Council, Fisheries Boards, Planning Authorities, landowners and local communities.

The range of afteruse options includes amenity which covers nature conservation and recreation, woodland, agriculture and hard end uses. Afteruse options need to be specified in a sites restoration plan. The time frame for cessation of landfilling and restoration needs to be considered.

3. AFTERUSE OPTIONS

3.1 INTRODUCTION

Choosing an appropriate afteruse for a landfill is critical to ensure successful restoration. For new landfills, the proposed afteruse should be determined during the planning process with some degree of flexibility built-in, in order to accommodate changes that will occur during the lifespan of the landfill. For existing landfills, the afteruse must be determined as early as possible prior to restoration plans being developed. Phased restoration enables the proposed restoration plan to be assessed, modified and improved throughout the operational life of the landfill. Initial landscaping works such as tree and hedge planting should take place during the operational phase even where the final end use has still to be determined. A sensitive planting regime which uses species appropriate to the area will blend in with any future afteruse option. On many sites a combination of different afteruses may be more beneficial to the area in which the site is located.

The range of afteruse options include:

- amenity afteruses ranging from nature conservation to informal recreation and formal sports, both water and land based;
- woodland afteruses include the planting of hedgerows, shelterbelts, amenity and commercial woodland;
- agriculture afteruses; and
- hard end uses e.g. roadways, buildings, car parks, yards etc.

3.2 FACTORS AFFECTING THE CHOICE OF AFTERUSE

Selecting the afteruse of a landfill is basically a consultative process involving all relevant parties. Successful restoration to the proposed afteruse may help promote public acceptance of landfills, offer educational opportunities and in many cases can enhance the visual appearance of the surrounding landscape.

The initial choice of afteruse may be based on the landowners' requirements or on land use zoning as specified in the development plan. This choice may however, be amended following evaluation of all site specific characteristics. The proposed afteruse should be realistically achievable in terms of site topography, geology, soil types and particularly the quantity of soils available for restoration. The long term requirement of the environmental pollution control systems on the landfill and the need to provide access for use and monitoring purposes must be built into the chosen afteruse. The financial costs involved in restoration need to be considered and provision needs to be made during the lifetime of the landfill to ensure adequate funding is available for restoration, aftercare and post closure management.

3.2.1 CONSULTATION WITH INTERESTED PARTIES

Effective consultation with interested parties is essential in selecting an appropriate afteruse. The landfill operator and landfill designer should consult with:

- local community and end users - local community involvement during the lifecycle of new or existing sites will help identify local requirements and future potential uses for a restored landfill. This type of consultation will give landfill operators the opportunity to demonstrate that they are environmentally conscious and concerned and are proactive in the conversion of what may be a negatively perceived land use to a valuable local asset. On many existing and closed landfills, mitigation measures will be required initially to deal with environmental pollution and opportunities to enhance degraded habitats and landscapes may also arise;
- the local authority and the planning authority should be consulted in proposals for afteruse options of landfill sites in their functional areas. The development plan should also be considered as it may influence the proposed afteruse or impose certain conditions on the site such as dimensions of final landform, shape, slope, screening etc.;
- the landowner(s) - the owner(s) of the site may have a preference for a specific afteruse to maintain current landuse

patterns and practices; and

- relevant organisations, local and/or national which may be future end users of the landfill or who may provide useful guidance on restoration to specific end uses should be consulted. Teagasc, Coillte, Dúchas, An Taisce, The Heritage Council, Fisheries Board, farming organisations, nature conservation organisations, NGOs (Birdwatch, IWT, IPCC etc.) sports and youth clubs, etc. where appropriate.

3.2.2 SITE CHARACTERISTICS

Many of the site characteristics and the character of the surrounding areas are critical factors in determining the choice of afteruse of the landfill. These include:

- topography and landscape including current landuse, land quality, landform and drainage particularly slope requirements and hydrology;
- occurrence of ecologically valuable habitats, archaeological sites and geological features of interest in the surrounding area;
- soil resources - the quantity and type of soils available for restoration, which is one of the most critical factors in the choice of an afteruse. On new landfill sites careful management of the existing soil resources during the construction, operation and closure will allow greater flexibility in the choice of after-uses. On existing or closed sites where soil resources have been lost or contaminated, the choice of afteruses may be limited;
- size, location and access - each will influence the choice of afteruse. Small sites may not be attractive for an agricultural afteruse due to machinery size whereas a similar size site close to an urban area may be more suitable for amenity purposes;
- historical use of the site;
- type of waste - which will influence the choice of afteruse as the type of waste will influence gas and leachate production and settlement rates. A site which takes largely inert waste is capable of a wide range of afteruses including hard development, while sites accepting biodegradable wastes will have fewer options;
- phasing of restoration - landfills are generally developed on a phased basis and are restored progressively over their lifetime. The phasing of restoration will have to be considered when choosing an afteruse;
- engineering design of the landfill; and
- environmental pollution control systems.

3.2.3 ENVIRONMENTAL POLLUTION CONTROL SYSTEMS

The long term maintenance of the pollution control system and access requirements will influence the choice of afteruse. The pollution control systems will require integration and protection and their potential impacts on the various afteruses will need to be evaluated.

The pollution control systems which require integration and protection are:

- capping system;
- landfill gas management system;
- leachate management system; and
- fixed monitoring points for settlement, groundwater quality, leachate and gas sampling.

The landfill gas management system has the greatest potential to impact on the afteruse and the design of this system will be site specific and is influenced by many factors including the size of landfill, the type of waste accepted and the gas control system that is chosen (active or passive) and the age of landfill deposit. A gas system should be selected with design features which take into account in so far as possible the proposed afteruse.

3.2.4 FINANCIAL PROVISION

The restoration, aftercare and annual maintenance costs for the restored landfill site need to be calculated for the various afteruse options. These are dependent upon:

- costs of the land, site development and environmental protection;
- costs of restoration, aftercare and maintenance costs;
- income from incoming waste and gas utilisation (if applicable); and
- income from afteruse.

The landfill operator should consider the cost of restoration, aftercare and annual maintenance costs and provisions should be made to ensure adequate finances are available for restoration.

3.3 SPECIFIC AFTERUSES

Factors which need to be considered for specific afteruses are detailed in Table 3.1.

TABLE 3.1 IMPORTANT ISSUES TO BE CONSIDERED FOR SPECIFIC AFTERUSES

Afteruse	Considerations for specific afteruses
• Amenity	– long term management needs of conserved and created habitats – ongoing consultation with appropriate nature conservation specialists – consultations with local communities which use site – how areas of existing nature conservation interest should be incorporated into the overall restoration scheme – options for including attractive areas of natural vegetation which are located close to the site – the influence of site size on the types of habitat which can be established – the potential benefits of multi-purpose use – methods for dealing with hazards and mitigation methods for existing damaged areas – opportunities for public access and the safety and legal liability of allowing public access – county development plan – existing and pending environmental designations – habitat creation and reconstruction – landscape integration – local community needs and aspirations – nature conservation organisations – soil requirements – cost of restoration to recreational uses such as golf courses, playing pitches etc.
• Woodland	– tree and shrub planting is commonly combined with other afteruses – landscape design and diversity issues – site location with respect to wind hazard – haulage routes for timber extraction – potential conflicts between maintenance requirements and pollution control system – potential benefits of multi-purpose use – provision of screening and opportunity for advance planting prior to site development
• Agriculture	– landowner requirements – acceptability of agriculture as an afteruse – successfully restored agricultural land is easily managed – preservation of good quality agricultural land – set-aside and the need to reduce agricultural subsidies – cost of restoration – soil requirements – location and access problems – impact of pollution control systems
• Hard End Uses	– hazards associated with hard end use development on landfills include flammable and explosive gases, instability and settlement and corrosive substances – geotechnical investigation of the site is required prior to the design of foundations or other structures – landscape design considerations – screening

4. THE ROLE OF SOILS IN RESTORATION

4.1 INTRODUCTION TO SOILS

Soil is the basic material for all restoration to soft afteruse. Detailed information on soil resources available on site, the quantity required for proposed afteruse, and soil handling operations required need to be assessed as early as possible. In all situations the restorer of landfills should aim to loose tip soils and strip and place soils in a one phased operation. This will reduce the number of soil handling operations, eliminate the need for stockpiling and help minimise compaction of soils. Successful restoration depends on:

- identifying all soils available on site or soils which are likely to become available by importation;
- conserving and making the best use of these resources;
- organised and careful handling of soils during stripping, storage and respreading; and
- careful planning and supervision of all soil handling operations.

The key soil properties of importance in landfill restoration include those listed below. Further details on soil properties are given in Appendix G.

- soil texture;
- soil structure;
- soil profile and depth;
- soil consistency;
- bulk density and porosity; and
- soil chemical properties including nutrient status.

4.1.1 SOIL TEXTURE

Soil texture refers to the feel of the soil as defined by the particle size distribution of the solid inorganic constituents of the soil. It is determined by the relative proportion of clay, silt and sand in the mineral fraction which is less than 2 mm in diameter. Larger particles such as gravel and stones and organic matter are recognised by qualifying textural terms. The particle size classes are given in Table 4.1

Texture, which is one of the more important physical characteristics of a soil, influences properties such as moisture retention, drainage, tilling properties of the soil and their resistance to damage by stock and machinery, and earliness of crop growth. Classes of texture are based on different combinations of sand, silt and clay. The term loam is used by soil scientists and agriculturists when classifying soil texture. A loamy textured soil is a soil composed of a mixture of sand, silt and clay such that the properties of no one group dominates its characteristics. Further details on soil texture is given in Appendix G.

4.1.2 STRUCTURE

The term soil structure refers to the shape, size and degree of aggregation or clustering, if any, of the primary soil particles into naturally or artificially formed structural units (peds, clods and fragments). The productivity of a soil and its response to management depends to a large extent on its structure. Soil structure influences pore space, aeration, drainage conditions, root development and ease of working.

4.1.3 SOIL PROFILE AND DEPTH

In relation to plant and animal production, the soil profile refers to a vertical section of the soil down to and including the geological parent material. The nature of the profile is important in many

TABLE 4.1 SOIL PARTICLE SIZE CLASSES

boulders	cobbles	gravel			sand			silt			clay
		coarse	medium	fine	coarse	medium	fine	coarse	medium	fine	
		20	6		0.6	0.2		0.02	0.006		
200	60			2.0			0.06			0.002	

Particle size diameter (mm) BS 5930

aspects of plant growth including root development, moisture storage, aeration and nutrient supply. The profile displays a succession of layers that may differ in properties such as colour, texture, structure, porosity, chemical composition, organic matter content and biological composition. These layers known as soil horizons occur approximately parallel to the land surface. Figure 4.1 illustrates a soil profile and compares terminology use.

4.2 SOIL SURVEY

The soil survey should identify, map and produce a soil resource schedule detailing the location, type and an estimation of the quantity of soils located on the site. On existing landfill sites where soils have been disturbed the soil survey should estimate the quantity of indigenous soils remaining and the potential to accumulate and save soil and/or soil forming materials coming through the gate. Detailed analysis should be carried out on both indigenous and imported soils to establish their suitability for the proposed afteruse.

The personnel involved in soil handling operations must be able to interpret and understand the information presented in the soil survey. It should describe the soil profile and depth of each horizon and should conform to BS 5930 (revised) from an engineering/geotechnical perspective. Soil scientists and agriculturists in Ireland use a modification of the system established by the United States Department of Agriculture, 1938 to classify soils. Reference should be made to Table G.1, Appendix G for a soil/subsoil classification chart. For further details on soil investigation refer to the Agency's manual on *Investigations for Landfills* and The Institution of Engineers of Ireland and Geotechnical Society of Ireland. (Draft) *New Specification for Ground Investigations.*

The distribution of the various soil types (as identified by texture, structure, colour, organic matter content) in and around the site needs to be mapped and marked on the site plan. Figure 4.2 shows an example of a site plan indicating soil type distribution.

A soil survey will describe and establish:

- soil profile and soil volume estimates
  the characteristics of the soil profiles need to be described and the depth of each horizon specified (topsoil, subsoil and geological parent material or A, B and C horizons respectively). The areas covered by the different soil types need to be measured and marked on the site plan. From this information the volume of the

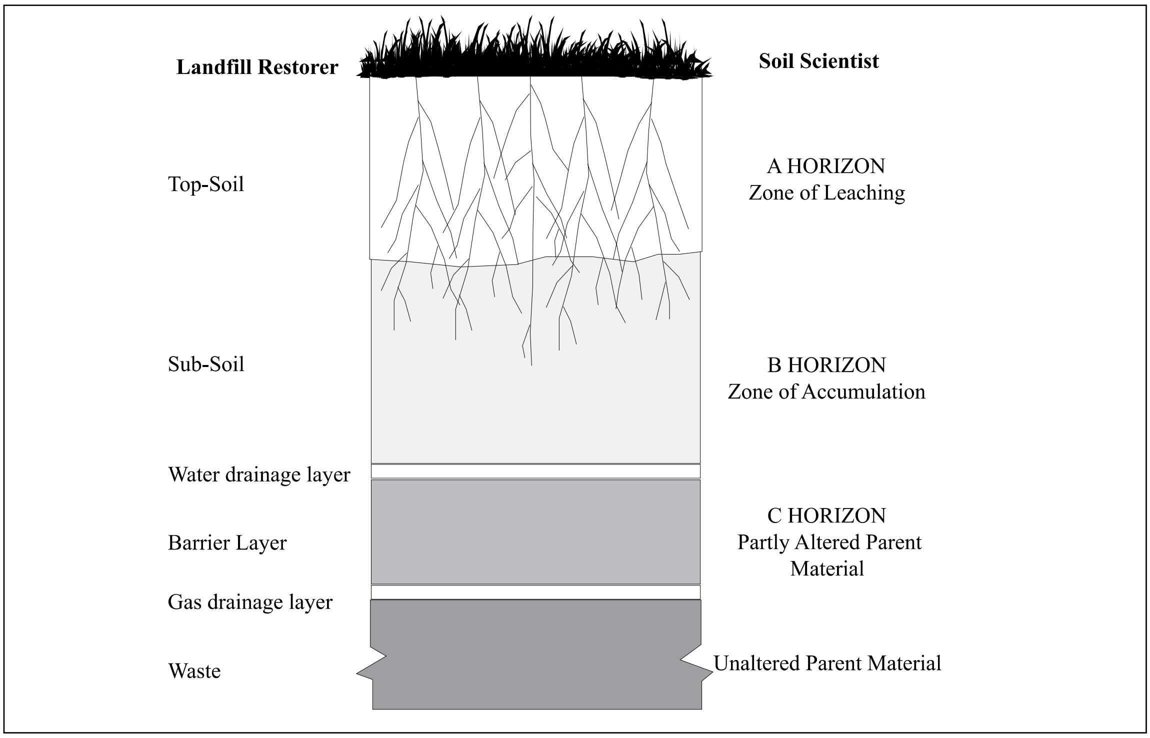


FIGURE 4.1 ILLUSTRATION OF SOIL PROFILE FROM TWO PERSPECTIVES

various soil types can be estimated. As variations in soil type can take place over relatively short distances it is important that the different kinds of soils are characterised, mapped and volumes estimated during the soil survey;

- soil type
  classified according to texture, structure, colour, organic matter content and permeability; and

- soil chemical analysis
  details on soil pH, lime requirements, fertility (N, P and K) and identification of contaminants (inorganic and/or organic) where applicable.

The best soils for restoration are the natural soils which exist on site. The landfill design and restoration plan must take account of the need to strip, carefully store, when necessary, and reuse all onsite soil. It is likely on some sites that several contrasting soil types will occur and that each will need a different form of management during restoration. A knowledge of the soils physical properties is important to the satisfactory stripping, storage and replacement of soils in the restoration process.

Most soil surveying consists of using soil augers and pits to inspect the soil profile in vertical section and linking descriptions of the soils from the boreholes and trial pits in order to identify areas of similar soil type. The complexity of the soil pattern will determine the numbers of observations per unit area. Soil surveying is a skilled job and requires the use of professional soil consultants. Skilled surveyors can assess soil resources using a combination of direct observations at sites chosen subjectively, and interpretation using the topography, vegetation and landuse to indicate where soil types change from one to another in the landscape. The results from the soil survey should be presented on factual and interpretative reports. On disturbed sites, interpretation in this way is much more difficult and will require more intensive investigations. On such sites, a grid survey approach should be used, based on regularly spaced, predetermined sampling points. This method ensures that the site is covered equally and that reliable estimates of the different soil types and quantities are determined *(Moffat & McNeill, 1994).* The soil survey should identify, map and produce a soil resource schedule detailing the location, type and quantity of the soils on the proposed or existing site. An example soil map for a 20 hectare landfill site prior to landfilling is shown in Figure 4.2 and the results of the survey are summarised in Table 4.2

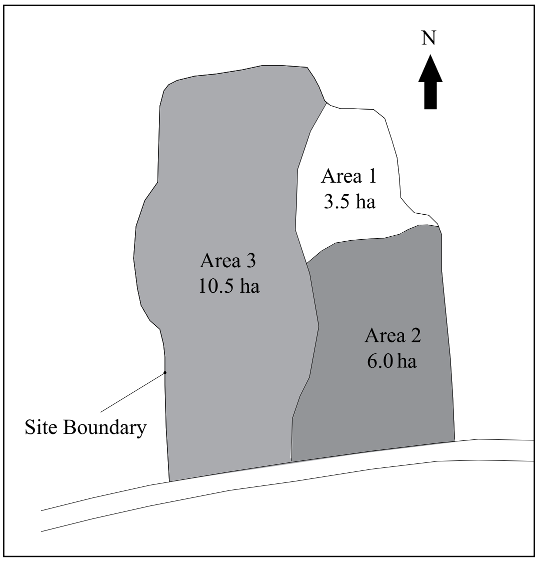


FIGURE 4.2 ILLUSTRATION OF SITE PLAN INDICATING SOIL TEXTURAL CLASS DISTRIBUTION

TABLE 4.2 EXAMPLE OF SOIL SURVEY RESULTS TO FORMATION LEVEL

Area	Description	Depth mm	Area ha	Volume m^3
Area 1	Silty clay loam topsoil	350	3.5	12,250
	Silty clay subsoil	3250	3.5	113,750
Area 2	Sandy clay loam topsoil	250	6.0	15,000
	Clay loam subsoil	3450	6.0	207,000
Area 3	Sandy clay topsoil	300	10.5	31,500
	Clay subsoil	3850	10.5	404,250

4.3 DEPTH OF SOILS REQUIRED IN RESTORATION

The restoration profile and the depth of the restoration material will depend on the type of landfill and the proposed afteruse. The depth of soil, both topsoil and subsoil required to restore landfills to softend uses such as amenity, woodland and agriculture must be determined on a site by site basis. Protecting the integrity of the barrier layer and ensuring successful plant establishment are of paramount importance when deciding on the depth of soils required. In some cases, this thickness of soil can include geological material which is neither topsoil nor subsoil e.g. glacial till, recovered aggregates etc. However, as the thickness of topsoil and subsoil decreases, vegetation establishment will be poor and growth rates will suffer. The minimum soil requirements for various landfills and afteruses are listed in Table 4.3.

Factors which need to be considered in determining the depth of subsoil and/or topsoil required include:

- protection for drainage and barrier layers;
- need to accommodate land drainage, gas and leachate management systems; and
- the choice of afteruse:
  - higher usage will require greater depth of soils e.g. intensive grazing versus wildflower meadows;
  - need to encourage good anchorage and to ensure adequate supply of plant available water in summer months. Establishment of vegetation is generally easier and more successful if both topsoil and subsoil are used;
  - topsoil is necessary where the afteruse needs high fertility, vigorous plant growth, infiltration, drainage and soil with rebound. It is good practice to replace 20% above the minimum soil requirements so as to accommodate any variations in grades across the whole site;
  - better results are often achieved in nature conservation restoration with the use of less fertile soils;
  - trees in general do not need topsoil but the likelihood of restoration success is much improved if it is used. Deciduous trees in particular benefit from the use of topsoil;
  - agriculture needs both topsoil (minimum of 150 mm to 300 mm after placement) and subsoil as there is a need for good plant growth and productivity;
  - for agricultural or forestry restoration the soil profile should be easily exploited by roots and be freely draining yet provide adequate moisture retention; and
  - vegetation will establish on 300 mm of soil depth after placement but a greater thickness is usually needed.
- where trees are planted above landfill areas the following recommendations should be followed:
  - a synthetic barrier layer should be used to augment the effects of the clay cap on areas intended for woodland planting, unless it can be shown by physical analyses in the field and laboratory that the recommended requirements for clay density and permeability have been met;
  - in all cases where a water drainage layer is employed above a clay cap, a water permeable geotextile membrane should be placed above the permeable fill beneath the area to be planted; and
  - consideration should only be given to tree species that can be grown without threatening the integrity of the cap. Poplars should be avoided *(Populus sp.)* as should some willow species *(Salix alba - white willow, Salix fragalis - crack willow).*

4.4 SOIL HANDLING

4.4.1 INTRODUCTION

Soil handling primarily refers to the lifting, transport, storage and placement of soils by earthmoving equipment. On landfill sites a soil movement plan needs to be drawn up which integrates the soil handling operations within the site restoration working plan. This plan will include a schedule of the soil requirements for restoration and details of the available soils on site as identified from the detailed soil survey. All

TABLE 4.3 RECOMMENDED MINIMUM SOIL DEPTH (AFTER PLACEMENT) REQUIRED FOR RESTORATION FOR VARIOUS LANDFILL TYPES

Type of Landfill	Afteruse	Subsoil minimum depth (mm)	Topsoil minimum depth (mm)	Total combined depth (mm)
Non-inert with a piped gas control system and drainage system installed	Trees - where 1.0 m clay barrier layer is used and compacted to a dry bulk density of 1.8 to 1.9 tonnes/m^3 achieving hydraulic conductivity of 1 x10^{-9}m/s across the filled area	1200-1350	150-300 (not essential but preferable)	1500
	Trees - where a synthetic barrier is incorporated into capping system e.g. geomembrane	700-850	150-300 (not essential but preferable)	1000
	Intensive grazing and high maintenance amenity sward	700-850	150-300	1000
	Low maintenance amenity sward	1000	not essential but possible problems of soil erosion on steep slopes	1000
	Other uses e.g. car parks, hard standing, commercial and industrial areas etc.	Non-soil material such as granular fill, glacial till, recovered aggregates etc.	not required	
Inert with no capping layer or gas control system	Trees	700-850	150-300 (not essential but preferable)	1000
	Intensive grazing and high maintenance amenity sward	500	150-300	650-800
	Low maintenance/use amenity sward	500	not essential but possible problems of soil erosion on steep slopes	500
	Other uses e.g. car parks	Non-soil material such as granular fill, glacial till, recovered aggregates	not required	

identified soil resources must be conserved for restoration purposes. It is essential that good quality baseline information is used as the basis for all soil handling operations. Any additional soils or soil like materials that become available during the operation of the landfill should be set aside, stored and recorded for future use. Prevention of soil loss or damage during landfill operations is essential. Machinery with low ground bearing pressure should be selected to deploy restoration layers thereby minimising damage to soils and environmental pollution control systems. Careless losses of valuable soil resources include:

- soil losses into hedges, water courses, erosion of storage mounds by rain and wind;
- inappropriate uses such as for daily or intermediate cover;
- mixing of soils with rubble and contamination of soils by fuel oils, waste etc.; and
- mixing of topsoils with subsoils and mixing soils of different textural classes.

Wherever possible, soils should be moved directly from the phase being stripped to the phase being restored as this will avoid the need for storage, and minimise soil handling operations, thereby reducing damage. Progressive restoration will also help reduce the risk of soil loss and reduce the costs of soil handling operations. A soil movement plan must be related to site phasing and take account as far as possible the distribution of different soil types on site. This plan should include a map indicating the soil type within each landfill phase and the location of the soil storage bunds. Figure 4.3 illustrates landfill phasing and soil storage bunds and Table 4.4 gives an example of the soil storage and location details that should be recorded on site. Sites which have a complex mixture of soils should be restored into more uniform blocks of single soil types which are easier to manage. However, account must also be taken of the proposed afteruse of the site.

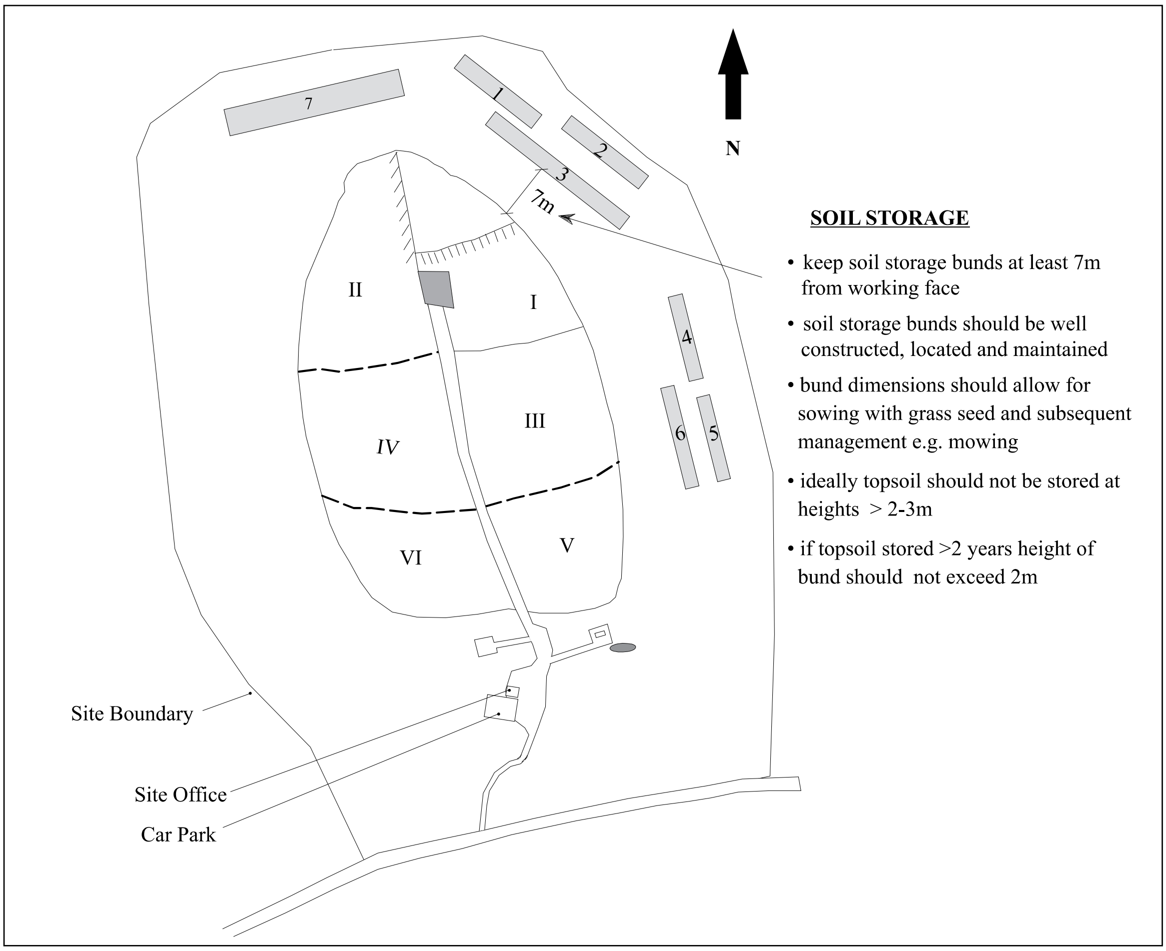


FIGURE 4.3 ILLUSTRATION OF LANDFILL PHASING AND SOIL STORAGE

TABLE 4.4 EXAMPLE OF SOIL STORAGE AND LOCATION DETAILS THAT SHOULD BE RECORDED

Soil bund location number	Soil classification	Landfill Phase	Width m	Length m	Height m	Volume m^3
1	silty clay loam topsoil	Phase I				
2	silty clay loam topsoil	Phase I				
3	silty clay subsoil	Phase I				
4	sandy clay loam topsoil	Phase II				
5	sandy clay loam topsoil	Phase II				
6	clay loam subsoil	Phase II				
7	Overburden	Phase I & II				

An understanding of the likely impacts of soil handling operations on soil properties is necessary for successful restoration. Factors which need to be considered in drawing up a soil movement plan include:

- avoidance or minimisation of soil compaction and loss of structure;
- timing of soil movement works;
- supervision of handling operations;
- contractors knowledge of soil classification, its physical properties and value;
- choice of soil handling equipment;
- soil stripping, storage and replacement operations;
- requirement for placement in lifts;
- alleviation of soil compaction; and
- requirement for stone picking.

4.4.2 SOIL STRUCTURE AND COMPACTION

The effects of soil handling on soil properties are primarily physical, but indirectly there are effects on the biological, microbiological and chemical status of soils. Soil compaction and loss of structure are the major effects caused during the movement of soil. Some of the properties affected by soil handling include:

- structure;
- soil profile, depth and distribution;
- texture, bulk density and porosity;
- permeability and drainage;
- liquid limit; and
- redox potential.

The potential impacts of soil handling operations on soil properties include those summarised in Table 4.5.

The information gathered from the soil survey and analysis will specify the total volume and location of the materials requiring sensitive treatment. The different soil types identified during the survey will require separate handling with topsoil, subsoil and parent material being handled separately.
Central to the process of successful restoration is the preservation and reuse of all the original soils on the site. Soils vary in their response to disturbance and some are easily damaged, especially when treated as engineering material rather than a natural biologically active resource. The principal forms of damage to soils when

TABLE 4.5 SUMMARY OF THE EFFECTS OF SOIL HANDLING OPERATIONS ON SOIL PROPERTIES

Soil Properties	Effects of disturbance	Actions to minimise damage
• Soil structure	– damaged by soil movement operations – extent of damage dependent on structure type and site conditions at movement – compaction with increased bulk density and impeded drainage – available water capacity is altered	• strip and place in one phase operation if possible • aim to loose tip soil and avoid stockpiles • use appropriate machinery for soil handling operations • avoid movement in wet conditions as this causes remoulding • ripping of subsoil to alleviate soil compaction.
• Soil profile and depth	– possible mixing of different soil horizons – loss of material – possible bulking during soil movement and resettlement	• careful separation of soil horizons during stripping, storage and replacement • respreading of soil horizons should be done in accordance with the quantities identified in the soil survey • grassing of storage mounds will minimise soil erosion and reduce leaching of nutrients
• Soil texture	– not usually altered if soil movement is done carefully avoiding the mixing of different textural classes – texture influences moisture retention, tilling properties and resistance to damage – available water capacity is altered	• careful soil handling operations should avoid any alterations of soil texture • remixing in the case of segregation of granular soils e.g. gravelly, stony, bouldery and sandy soils
• Bulk density	– possible loosening during stripping – increased bulk density (i.e. compaction) by passage of earth moving machinery – impeded drainage and poor root penetration	• as for soil structure
• Soil drainage	– disrupted by soil movement which alters soil structure and porosity – poor soil aeration leading to anaerobic conditions – poor crop establishment – perched watertables and waterlogging	• install drainage system • careful separation, storage and respreading of soils • attention paid to soil movement operations particularly type of machinery used

Soil Properties	Effects of disturbance	Actions to minimise damage
		• avoid wet conditions which can cause remoulding and compaction • alleviate soil compaction by ripping • attention to gradients of capping layer and soils
• Nutrient status and chemical characteristics	– soluble compounds leached during storage of soils – pH may be lowered – anaerobic conditions in wet or compacted soils	• soil analysis for major and macro-nutrients and soil pH will identify corrective action required to improve fertility and reduce acidity • avoid compaction • attention to topsoil mound height during storage • grassing of storage mounds which will increase evapotranspiration, reduce recharge and minimise nitrate leaching • regular soil analysis during aftercare will indicate the need for fertilising and liming depending on crop requirements

Source: After Environment Agency, UK 1996

moved are due to traffic movement which can result in compaction, loss of structure, reduced permeability and increased bulk density. The simplest and most widely used measure of soil compaction and soil structure in general is dry bulk density (mass of oven dry soil per unit undisturbed volume).

4.4.3 TIMING OF SOIL MOVEMENT WORKS

Seasonality, weather conditions and forecasts, evidence of waterlogging and soil moisture content and plasticity all need to be considered for soil handling operations Soils should be handled under dry conditions to minimise compaction. The more limited opportunities of dry conditions on sites in high rainfall areas and heavy textured soils which are poorly drained (such as clays) must be availed of. Ideally, soils should not be left bare over the winter months. To accommodate this, all soil replacement activities should be completed by the autumn so that crop cover can be established before the winter rains. Topsoil replacement should be finished early enough to complete cultivations and crop establishment during dry weather. The operator should balance the need to carry out soil handling operations with the need to safeguard the soil. The key criterion for mechanised soil handling is that the soil is not plastic or wet. In general the movement of soil under the following conditions should be avoided:

- wet or waterlogged soils with pools of standing water;
- winter months when soil moisture levels are high or ground is frozen; and
- when the lower plastic limit of the soil has been reached. A simple field test, which is reasonably accurate, can be used to establish the lower plastic limit. The plastic limit in a soil is reached when a pre-moulded ball of soil just fails to be capable of being rolled into a 3 mm diameter thread on a glass surface.

Neither medium textured soils in moderate to high rainfall areas, nor clay soils dry out to their full depth for any significant period. However, when soil is stripped and placed in loose piles in dry weather, it tends to dry out. Except for one year in every ten, ample opportunity is available to strip and work soils. In wet years, every opportunity to work during dry spells must be taken.

4.4.4 SUPERVISION OF HANDLING OPERATIONS

All soil handling operations, particularly soil stripping, storage and replacement, must be carefully supervised. Skilled staff, particularly machinery operators, should be employed. Such people should have appropriate skills and understand the need to minimise soil damage. Staff should have the authority to be able to respond to changing conditions at the site and stop operations when necessary. The soil handling operations which require supervision are listed in Table 4.6.

4.4.5 CHOICE OF SOIL HANDLING EQUIPMENT

Equipment for soil handling must be able to lift, transport, deposit and spread soils in their new location. Topsoils in particular should be handled as a living material. Appendix H lists the range of machinery available for soil handling and the advantages and/or disadvantages of the various methods. These various types of equipment differ in their economics, output, and effects on the soil. Successful soil handling operations in restoration should aim to minimise soil compaction caused by traffic movement by earth moving equipment and remoulding caused by rutting and scraper blades. It is generally recognised that earthscrapers probably cause the most damage to soils, while in contrast, soil removed by excavators (backactor diggers) and dumptrucks usually suffers little compaction and remoulding *(Moffat & McNeill, 1994)*. In general, if soil conditions are properly specified, then qualified contractors can put an assembly of machinery together to achieve the specified results. Soil checks in the form of structure assessment and measurements of bulk density, soil moisture and permeability are

TABLE 4.6 LIST OF SOIL HANDLING OPERATIONS WHICH SHOULD BE SUPERVISED

Operation	Key factors
• Soil Stripping	– all available topsoil, subsoil and other soil resource materials are separately stripped – materials from different soil types are stored separately – soils are stripped only in suitable conditions – soil handling machinery is operated to minimise compaction
• Soil Storage	– soils, including imported soils or soil substitutes, are stored in pre-determined and prepared locations – storage heaps are constructed to the correct dimensions and sown with grass seed after construction
• Soil Placement	– soil types should be placed in correct locations and in correct sequence to the specified depths – soils should be replaced in lifts only when conditions are suitable – soil handling equipment should be operated to minimise compaction – compaction should be aleviated by ripping – control measures should be put in place to deal with run-off and erosion

essential clauses in contract documents. Nuclear gauges and simple permeability tests are available for such measurements.

4.4.6 SOIL STRIPPING

Soil stripping operations need to be planned well in advance. They need to be integrated into the site phasing plans to ensure that the area which is stripped corresponds to the next phase in the landfilling operations. It should be large enough to accommodate the operational phase, site development and access routes. For further details on the phasing plan refer to the Agency's manual on *Landfill Operational Practices.*

Site operators must be given very clear instructions on soil stripping operations and be able to identify and locate the soil types identified in the soil survey. These instructions should include details on:

- stripping all available soil resources without cross contamination of soil types and soil horizons;
- depths of soils to be stripped and stored separately with emphasis on the need to avoid mixing topsoils, subsoils and parent material;
- which soil resources must be stripped and stored separately;
- which machinery to use;
- the sequence of stripping and the planned haul routes; and
- weather and ground conditions under which stripping operations are prohibited.

4.4.7 SOIL STORAGE

In phased restoration, where a cycle of progressive filling occurs with one phase being restored, a second being filled and a third being prepared for filling, soil storage is not required. The soil which is stripped from the preparation area is transported and deposited onto the area being restored. Ideally, on all sites phased restoration should be practised; however, on many existing sites some storage of soils will be required.

All soils, but particularly topsoil, alter during storage, because the bulk of the mound becomes anaerobic. In general, stored soils have higher bulk densities and lower porosity than undisturbed soils, and have lower organic matter contents, altered and/or reduced microbial and soil fauna populations, particularly earthworms *(Ramsey, 1986).* Seed viability is also reduced when soil is stored in mounds *(Rimmer, 1991).* Most of the changes quickly reverse when the soil is dug out and respread although the populations of micro-organisms and structural stability will take longer to recover *(Environment Agency, UK, 1996).*

Factors which should be considered to help minimise changes to soils and reduce soil losses during storage include:

- soil storage heaps should be built as loosely as possible to minimise compaction;
- the location, height and dimensions of the soil storage heaps for the different soil types should be based on estimations of the volumes of soils on site. These may be extensive depending on the size of the landfill and these must be clearly indicated in the soil movement plan;
- subsoils can be stored in higher mounds than topsoils and can also be used for screening. When constructing the storage bunds consideration needs to be given to their future management requirements e.g. sowing with grass, control of noxious weeds, mowing etc.;
- ideally, topsoils should stored in mounds 2-3 metres in height. If the storage period is greater than two years the height of the mound should not exceed 2 metres;
- large mounds of subsoil may require slope stability assessment;
- storage areas should be stripped of valuable topsoils before construction of the storage mounds;
- only machinery which is used to construct the storage mounds and remove soil from them, should be allowed to run over the mounds;
- soil storage areas should be fenced to prevent inappropriate use and/or contamination;

- storage mounds should be sown with grass to stabilise the mounds, prevent soil erosion and a build up of weeds which could invade restored areas, and to help them fit into the surrounding landscape; and

- the early establishment of a grass sward on stored soil forming materials will help promote the development of a soil structure with fine roots binding the soil and promoting the stability of soil aggregates. The build up of organic matter combined with the development of soil structure will prevent damage from erosion by wind and rain.

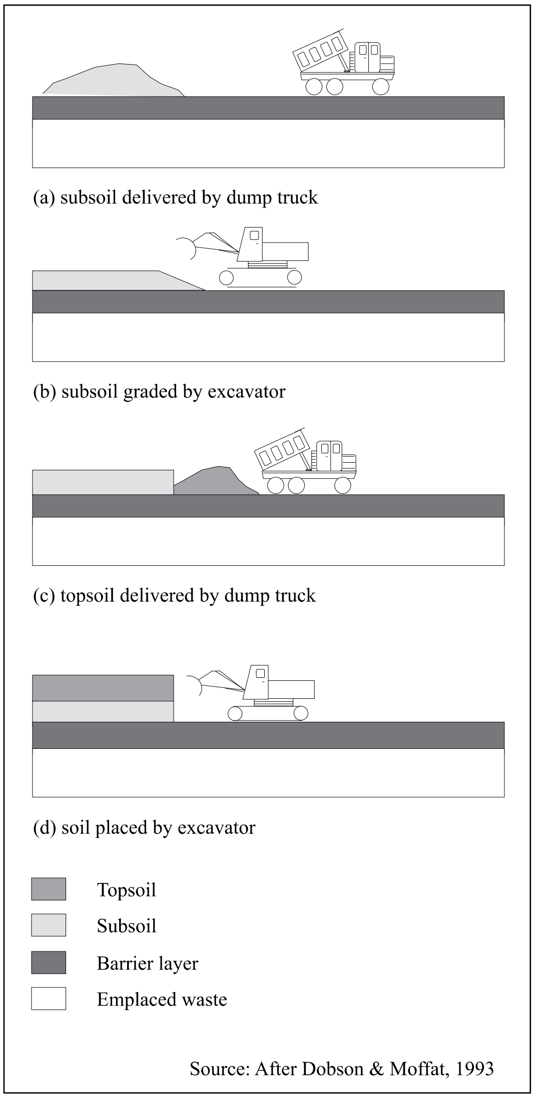


FIGURE 4.4 SEQUENCE OF SOIL PLACEMENT OPERATIONS MINIMISING DAMAGE TO SOILS

4.4.8 SOIL PLACEMENT

Soil placement should follow the same guidelines as soil stripping operations. The sequence of soil placement operations using dump trucks and excavators to directly place soils over the landfill cap is illustrated in Figure 4.4. For successful restoration to be achieved it is essential that soil placement be undertaken under ideal weather conditions. Important considerations include:

- specified soil types are removed from storage mounds and are replaced in the correct sequence, to specified depths in the correct location;

- soils are placed in lifts over the drainage layer and loosened after each placement by rippers. Each lift should not exceed 300 mm in thickness and ripping should take place to a minimum depth of 600 mm using a ripper blade at least 50 mm wide and an appropriate shoe. Checks are necessary to verify that the soil slab is fractured and fissured and permeability tests should be used to confirm that the soil is permeable;

- works are organised to cause minimum compaction to replaced soils;

- the restored soil profile must be capable of supporting the proposed afteruse; and

- soil placement must be completed early enough to enable cultivation, fertiliser (organic/chemical) application and vegetation establishment to take place before the onset of the winter.

4.4.9 ALLEVIATION OF SOIL COMPACTION

In earthworks, such as cutting, filling and spreading, compaction is unavoidable to avoid uneven settlement. To restore permeability, the placed soil must be ripped in layers, viz. the layer that is placed and the underlying layer. Therefore filling and placing must be carried out in lifts. It is necessary to carry out permeability checks to verify success. Subsoiling mechanically bursts the soil and artificially creates the cracks and fissures which enable the free movement of water and air and allows the root system to fully develop. Figure 4.5 illustrates the lifting and shattering action of a winged tine ripper.

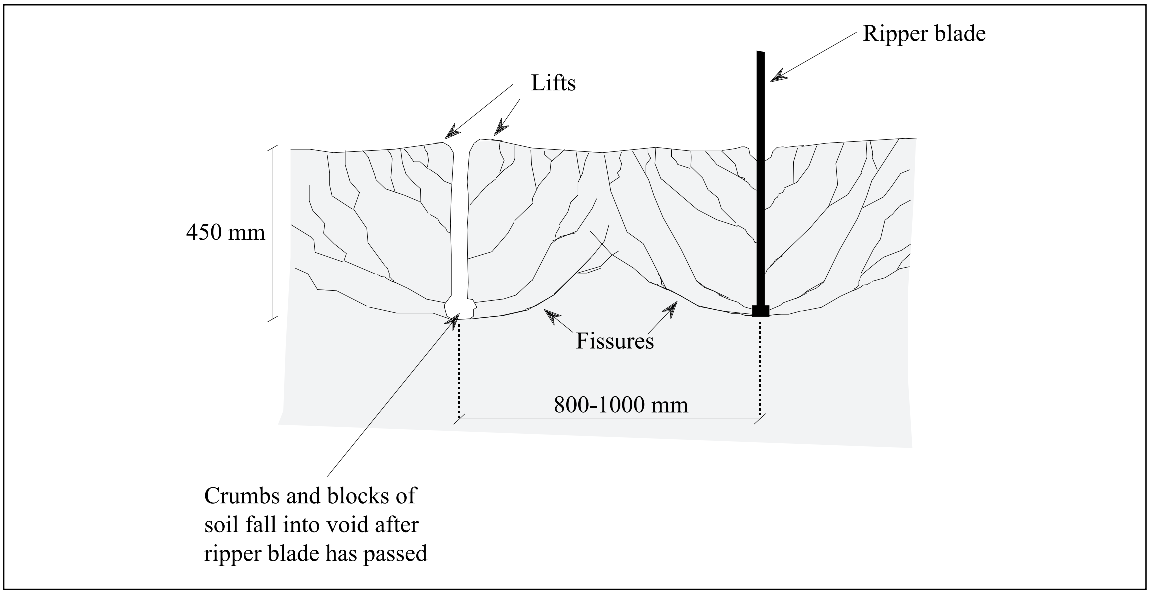


FIGURE 4.5 ILLUSTRATION OF LIFTING AND SHATTERING ACTION OF A WINGED RIPPER

Technical requirements for subsoil ripping include:

- subsoil ripping should be carried out only when the surface of the land is dry enough for efficient traction and the subsoil conditions are dry enough to obtain an adequate shattering and fissuring of the surrounding soil without damage to the soil structure. Subsoil ripping in wet conditions may cause further remoulding and compaction;

- shallow compaction (within the top 200 mm) can normally be broken by normal cultivation equipment such as ploughs (mould-board or chisel), harrows or tine cultivators. The type of equipment required will depend on the soil texture and depth of the compacted layer;

- deeper compaction and poorly structured soils will require ripping. For a 25 mm wide ripper tine the critical working depth is 350 mm, for a wide ripper tine the critical depth is up to 600 mm working depth. No loosening of the soil occurs below this critical depth;

- soils should be placed in lifts over the drainage and filter layer and ripped after each placement. Each lift should not exceed 300 mm in thickness and ripping should take place to a minimum depth of 600 mm using a ripper blade at least 50 mm wide and with an appropriate shoe. Checks are necessary to verify that the soil slab is fractured and fissured and permeability tests should be used to confirm that the soil is permeable;

- a spacing of about 1.5 times the depth of working is normally recommended with the interval between rips not exceeding 1000mm; and

- subsoil ripping should be carried out at a clearance of at least 75 mm above the drainage and filter layer.

4.4.10 SOIL CULTIVATION

Choice of cultivation will depend on method of placement, degree of soil consolidation and site characteristics such as presence of large boulders, stones or buried debris, slope, soil texture, soil depth, and proposed afteruse. The two main objectives of soil cultivations are to bury weeds and vegetation residues and to break the soil down to a sufficiently fine tilth for the germination of seeds and root growth. The soil should be cultivated enough to produce a reasonably fine tilth. Excessive cultivations however, can cause severe damage to soil structure and should be avoided. Factors which need to be considered in cultivations include:

- heavy duty agricultural machinery is generally used for cultivations;

- mould-board ploughs should be set correctly and operated at such a depth so as to avoid burying topsoil below subsoil;

- chisel ploughs and heavy rigid tined harrows loosen the surface soil; they do not invert the soils or bury weeds, therefore weed control may be necessary and surface trash may be a problem;

- spring or coil tine harrows, spike harrows or discs can also be used to cultivate soils;

- chain harrows are used to incorporate the seed and fertiliser into the seed bed;

- powered rotary cultivators are not recommended as their pulverising action makes them unsuitable for recently restored land; and

- rollers can be used to firm the soil around recently sown seed to promote germination.

4.5 TESTING METHODS AND QUALITY CRITERIA FOR SOIL IMPROVERS AND SOIL FORMING MATERIALS

The use of soil improvers or soil-forming materials in landfill restoration should not cause environmental pollution. Therefore, depending on the origin and type of material or wastes used, physical, chemical or microbiological tests may be required to determine their suitability for use in landfill restoration. Characteristics which may require determination include, *inter alia,* moisture content, pH, nutrient content, heavy metals content, presence of organic contaminants, presence of pathogens etc.

- for contaminated soils, sludges and sediments, an extraction procedure which creates a leachate which is subsequently tested could be used. An example of such a procedure is the German method DIN-38414 (S4) - *Determination of leachability by water.* The resultant eluate (leachate) from this extraction procedure is then tested to estimate the leachate characteristics. Using relevant standards it will then be possible to determine their suitability for use. Further testing methods which may be appropriate include those recommended by CEN/TC 292 (characterisation of waste) and also ISO/TC 190 (soil quality) technical committees. Further information on leaching and extraction tests are detailed in *Harmonization of leaching/extraction tests* by Van der Sloot, Heasman & Quevauviller, 1997.

- for soil improvers where the organic matter content is provided by constituents derived from the processing and/or reuse of waste materials e.g. composting of vegetable, fruit and green waste, the EU Ecolabel for Soil Improvers (Commission Decision (94/923/EC - OJ L 364/21, 31 December 1994) is the only pan-European quality standard that currently exists. Compliance is voluntary and the label is awarded for high quality products that impart a low environmental impact over their whole life cycle.

- for sewage sludge use, statutory guidelines on application rates, crop restrictions, maximum values for concentrations of heavy metals and soil testing are outlined in Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 (SI No. 148 of 1998). Maximum values for heavy metals in soil and sludge are given in Table 4.7

4.6 FERTILISERS AND SOIL IMPROVERS

A soil analysis carried out as part of the soil survey will determine whether the soil will require the addition of fertilisers (chemical or organic), lime or organic matter. Fertilisers should only be used where analysis indicates deficiencies. Codes of good practice in relation to application of organic or chemical fertilisers should be followed to avoid causing environmental pollution. Where fertilisers and soil improvers are used it is essential that good management practices are adopted to prevent the pollution of surface waters or groundwater by nitrates or phosphates. With regard to phosphate reference should be made to Local Government (Water Pollution) Act, 1977 (Water Quality Standards for Phosphorus) Regulations, 1998 (SI No. 258 of 1998) which specifies targets for improvements in water quality conditions in rivers and lakes based on phosphorus concentrations or related water quality classifications. Nutrient management planning should be practised particularly on restored sites where fertilisers or soil improvers are applied on a regular basis.

Guidance on application rates, type of fertilisers and timings of applications in relation to soil index and crops can be found in the Teagasc publication *Soil analysis & fertiliser, lime, animal manure & trace element recommendations (1994).*

TABLE 4.7 MAXIMUM VALUES FOR CONCENTRATIONS OF HEAVY METALS IN SOIL AND SEWAGE SLUDGE FOR USE IN AGRICULTURE

Parameter	[1] Maximum Values for soil (mg/kg of dry matter in a representative sample)	Maximum Values for sludge (mg/kg of dry matter)
Cadmium	1.0	20.0
Copper	50.0	1,000
Nickel	30.0	300
Lead	50.0	750
Zinc	150.0	2,500
Mercury	1.0	16.0

[1] where the pH of the soil is consistently higher than 7, the values set may be exceeded by not more than 50%, provided that there is no resulting hazard to human health, the environment or, in particular, groundwater.

Revised phosphorous recommendations should be adopted *(Teagasc, 1998).* With regard to sewage sludge, reference should be made to Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 (SI No. 148 of 1998). All relevant Codes of Good Practice should be consulted. e.g. *Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates, DAFF 1996.*

The types of plants to be grown during restoration will also be an important factor in determining the fertility levels required for good productivity. The mineral elements which are considered essential for plant growth are macronutrients (N, P, K, Ca, Mg and S) and micronutrients or trace elements (Fe, Mn, Cu, Zn, B, Mo, Cl and Co).

The availability of macro and micronutrients to plants varies with the soil pH. Soil pH is a measure of the acidity or alkalinity of a soil. It usually varies from pH 5.0 (acid), where plant growth may be suppressed due to high levels of aluminium and /or manganese around the roots, to about pH 8.0 for calcareous soils. Plants differ in their sensitivity to soil pH. In addition, the optimum use of fertilisers containing N and P is obtained when soil pH is between 6.2 and 7.2. A high soil pH reduces the availability of Mn, B and Zn and increases the availability of Mo and Se. *(Teagasc, 1996).*

4.6.1 ARTIFICIAL FERTILISERS AND ORGANIC MANURES

Chemical fertilisers are widely used to increase soil fertility levels, particularly in agriculture and to a lesser extent in forestry. These fertilisers can contain single nutrients or contain mixtures of nutrients. Mixed fertilisers can be either blended or compounded and usually contain N, P and K.

Lime is used to raise the pH of the soil and the quantity required is dependent on the proposed afteruse e.g. optimum pH for agricultural grassland is 6.3.

Organic manures include slurry, dungstead and farm yard manure and they provide both nutrients and organic matter. These manures vary in their dry matter content, are bulky and expensive to transport. However, if there is a source close to the restored site their use is recommended especially on subsoils or where topsoil is scarce. Manures should be analysed for their nutrient and dry matter content prior to application.

4.6.2 COMPOSTED WASTE (VEGETABLE, FRUIT AND GREEN WASTE)

Composting is the term used to describe the natural degradation of plant and putrescible waste by the action of bacteria, fungi, insects and animals in the presence of an adequate air supply. This process, which occurs naturally, reduces the material to a stable state and the resulting compost improves the fertility of the soil with which it comes into contact. Any material which is biological in nature could be subjected to composting, but some materials are more suitable than others. Composting of bulky plant and putrescible waste, has advantages in that it reduces the amount of methane gas produced from landfills, reduces settlement problems and leaves

TABLE 4. 8 TYPICAL ANALYSIS OF COMPOSTS MADE FROM SOURCE SEPARATED ORGANIC WASTES IN THE UK

	Unit	Typical Value (median) [1]G&L, n=50	[2]VFGL, n=6	[3]VFG, n=8
Water Extractable Analysis				
pH		8.6	8.3	8.5
Electrical Conductivity	$\mu S\ cm^{-1}$	771	867	1096
Ammonium	$mg\ L^{-1}$	3	3	1
Nitrate	$mg\ L^{-1}$	43	144	144
Phosphorus	$mg\ L^{-1}$	15	14	14
Potassium	$mg\ L^{-1}$	1195	1135	1760
Magnesium	$mg\ L^{-1}$	16	21	20
Total Plant Nutrients and Organic Matter Content				
Nitrogen	%	1.1	1.2	1.1
Phosphorus	%	0.20	0.20	0.23
Potassium	%	0.70	0.71	0.74
Carbon	%	13.0	15.4	12.1
Loss on Ignition*	%	18.5	17.9	17.1
C:N	(ratio)	11.7	10.7	11.4
Potentially Toxic Elements				
Cadmium	$mg\ kg^{-1}$	0.50	0.64	0.47
Chromium	$mg\ kg^{-1}$	19	16	22
Copper	$mg\ kg^{-1}$	44	44	45
Lead	$mg\ kg^{-1}$	104	88	77
Mercury	$mg\ kg^{-1}$	0.1	0.2	0.2
Nickel	$mg\ kg^{-1}$	18.0	17.6	21.4
Zinc	$mg\ kg^{-1}$	187	166	182
Physical analysis				
Oven dry matter	%	67.2	56.2	65.9
Density	%	0.58	0.56	0.62
Particle Size Analysis				
< 1 mm	%	50.9	35.2	43.1
1-5 mm	%	36.5	35.8	43.0
5-10 mm	%	8.8	7.6	10.8
10-20 mm	%	0.8	2.8	0.5
>20 mm	%	0.0	0.2	0.0
Contaminants				
Viable Seeds	$vs\ L^{-1}$	0	2	1
Glass	%	0.03	0.06	0.12
Metal	%	0.00	0.01	0.03
Plastic	%	0.07	0.15	0.10
Pathogen Content				
Salmonella spp	Present or Absent in 25 g	Absent	Absent	Absent
Escherichia coli	Colony Forming Units g^{-1}	<10 (below limit of detection)	30	< 10 (below limit of detection)

[1] G&L= composted garden and landscape wastes
[2] VFGL= composted mixture of vegetable, fruit, garden and landscape wastes
[3] VFG= composted vegetable, fruit and garden wastes
* approximation for organic matter content

Source: The Composting Association, *pers comm*, 1998.

TABLE 4.9 TYPICAL ANALYSIS OF SPENT MUSHROOM COMPOST

Typical Analysis of SMC (% DM)		mg/kg DM	
Dry matter (%)	35	Manganese (Mn)	313
Ash	39	Cadmium (Cd)	0.52
Organic Matter	61	Chromium (Cr)	20
N	2.8	Copper (Cu)	50
P	1.0	Mercury (Hg)	0.08
K	2.0	Nickel (Ni)	14
Ca	6.6	Lead (Pb)	20
Mg	0.5	Zinc (Zn)	144
		Arsenic (As)	2.0

Source: Teagasc, 1993

space in the landfill for other non-degradable wastes. In terms of volume reduction composting can achieve ratios of 20:1 between raw material and end product prior to screening and weight reduction of more than 2:1. Appendix I gives further details on composting and the materials suitable for composting. The characteristics of composts made from source-separated organic wastes in the UK are listed in Table 4.8.

Composted household and/or green waste are useful sources of organic matter and nutrients. The composting of biodegradable waste at a landfill site reduces the amount of waste requiring disposal and produces a material with nutrient value suitable for use in restoration.

4.6.3 SPENT MUSHROOM COMPOST

Mushrooms are traditionally produced in compost manufactured from straw, horse manure, poultry manure and gypsum. When the mushrooms have been harvested, the remaining compost, which is only partly decomposed, is no longer capable of sustaining economic levels of mushroom production. This product is known as spent mushroom compost (SMC). A typical analysis of SMC is given in Table 4.9. The amount of compost used in Ireland amounts to approximately 280,000 tonnes per annum *(Teagasc, 1998)* giving rise to approximately the same quantity of SMC, as there is very little weight loss during mushroom production.

SMC is generally accepted as being an attractive material for improving soil structure as it has a high organic matter content, a low content of heavy metals, no weed seeds and no phytopathogens. The main potential problems are the high calcium content and the high salt content.

The use of SMC or composted SMC in landfill restoration will depend upon numerous factors, including availability, distance from source, soil types and organic matter levels and intended afteruse. SMC should be analysed prior to use to determine the level of nutrients available and this should be used in calculating fertiliser application rates to the proposed vegetation cover.

4.6.4 SEWAGE SLUDGE

Sewage sludge is the natural by-product of sewage treatment and contains nitrogen, phosphorus, organic matter, lime (if added during stabilisation) and may also contain some trace metals. The availability of nitrogen and the amount of organic matter present depends on the treatment process used. Sewage sludge which has undergone biological, chemical or heat treatment to reduce health risks and the fermentability of the sludge can be used in landfill restoration as a soil improver. Statutory guidelines on the use of sewage sludge particularly in relation to heavy metal concentrations and restrictions on use are given in Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 (SI No. 148 of 1998). Table 4.10 shows typical sludge analysis. Sewage sludge can be used in restoration to supply nutrients and organic matter. The organic matter content of sludge can improve the water retaining capacity and structure of some of the soils, especially subsoils used in restoration. Alkaline products such as dry quicklime (CaO) can be added to the dewatered sewage sludge which promotes odour absorption, granularity and structure. A chemical reaction, or heat pulse, occurs between the sludge and the alkaline admixture raising the temperature and pH level. The mixture is then placed into windrows for maturation *(Aitken et al. 1997).*

TABLE 4. 10 TYPICAL SLUDGE ANALYSIS

Sewage Sludge Type	[3] Total N	Total P	[1] Available N	[1] Available P
Liquid undigested (kg/m^3)	1.8	0.6	0.6	0.3
Liquid digested(kg/m^3)	2.0	0.7	1.2	0.3
[2]Undigested cake (kg/tonne)	7.5	2.8	1.5	1.4
[2]Digested cake (kg/tonne)	7.5	3.9	1.1	1.9

[1] available in first growing season
[2] wet tonnes
[3] nitrogen is present in sludge as ammonia.

Source: Commission of European Communities, 1994

4.7 IMPORTED SOIL

The use of indigenous soils is strongly recommended in the restoration of landfill to their proposed afteruse. However, in many cases, particularly existing sites, much of the indigenous soils has been lost or contaminated and other sources of soil and soil forming materials will have to be considered.

On existing landfill sites the quantity of soil available for restoration may be limited and alternative supplies may need to be sourced. Imported soils, soils from unknown sources and soil forming materials are some of the alternatives available in landfill restoration. In addition to the investigation required for the soil survey as described in section 3.2, one of the major concerns in accepting off site materials for restoration is the potential risk of contamination. The suitability of imported soils for use in restoration should be determined by carrying out a risk assessment of the soil. All materials should be examined closely for physical and any obvious chemical contamination before acceptance. The requirement for chemical analysis will need to be determined on a site specific basis taking into account the source of origin. Where the chemical analysis shows above average background levels for element or compounds then specialist advice should be sought in relation to their potential for use.

If imported soils are required for the restoration, ideally the landfill operator should know the source. An ideal imported soil should be of a loamy texture, be relatively stone free and fertile. Soils with a high clay content should be avoided as these are difficult to handle and vegetation establishment can be slow and poor. In the situation where the source is known, the landfill operator should consider:

- undertaking an in-situ soil survey, at the source if possible to identify soil properties;
- identifying the soil types and volume of topsoil, subsoil and parent material available at the source. In general the more consistent the soil type the easier and more successful the restoration results;
- assessing the stone content, as the degree of limitation imposed by stones depends on their quantity, size, shape and hardness. The main effects of stones are to act as an impediment to cultivations, harvesting and crop growth and to cause a reduction in the available water capacity and the nutrient capacity of the soil;
- carrying out a site specific risk assessment to determine the level of contamination (physical and/or chemical) in the soil under consideration (when applicable). The type and degree of contamination present and the risk to human health or the environment should be quantified during the assessment;
- cleaning of the soil by screening where physical contamination is present to remove builders rubble, wood, metal, glass etc.;
- where chemical contamination has been identified, the site specific risk assessment will determine the fitness for use of the soil taking into account the proposed afteruse; and

- where unacceptable levels of contamination is then this material should be disposed of in a suitable manner following discussions with the EPA.

In addition to the above, soil material from an unknown source should be examined for the following:

- does the material look like a soil?
- does the material have structure like natural soils or is the material like a slurry? (very wet soils should not be used)
- what colour is the material, is there evidence of mottling or water logging?
- is the material mixed or uniform ? and
- is organic matter present ? - organic matter such as humus, earthworms, roots etc., may indicate topsoil is present.

4.8 SOIL FORMING MATERIALS

4.8.1 INTRODUCTION

Where true soils are not available, the use of on-site soil forming materials will significantly reduce the amount of soil to be imported. Soil forming materials are those materials that are capable of forming a substrate which is capable of sustaining plant growth. Physically they must contain an adequate amount of soil-sized particles to promote water supply for plant uptake and chemically they must be non-toxic to plants *(Moffat & McNeill, 1994).*

Soil forming materials can be prepared from a wide range of materials including in-situ geological materials identified during site investigations, construction and demolition waste, dredgings etc. Some of the wastes coming onto the site can also be used as soil improvers e.g. composted waste. Soil forming materials should generally be used as subsoils or as topsoils in areas where lower fertility levels are acceptable or required. Their suitability as a growing medium should be tested prior to use in large scale restoration by carrying out bioassay growth trials. The main deficiencies encountered include low levels of plant nutrients, organic matter and poorly developed structure.

Key considerations in determining the suitability of a material for use in restoration include:

- sufficient depth of soil is required to prevent moisture deficit and provide adequate root zone depth;
- the materials must have reasonable structure to perform necessary functions of growth medium;
- the nutrient status of the materials and its capacity to hold nutrients must be established;
- stone content - stones and gravel present problems in reducing available water capacity, mowing, for amenity and playing areas (injuries) etc.;
- clay and organic matter content determine drainage characteristics, moisture retention, nutrient retention and supply and aeration;
- high organic matter soils and peats are soft and deform easily under use; and
- degree of contamination (physical and chemical).

4.8.2 DREDGINGS

Soil erosion processes result in the deposition of clay, silt and sand material in rivers, estuaries, harbours and deep water channels. Dredgings should be analysed for content of organic matter, nitrogen, total and extractable phosphorus, potentially toxic elements and organic contaminants if these are thought likely to be present *(Davis & Rudd, 1998).* The silts and clays in dredgings are also highly adsorptive of bacteria and viruses. Care may need to be taken in the case of dredgings taken from downstream of discharges form sewage works, storm sewage overflows and discharges form particular trades.

This material can be used successfully in landfill restoration; however, characteristics specific to these materials need to be considered prior to use *(Thomas & De Silva, 1991).* These include:

- dewatering - dredgings need to be dewatered before they can be used as soil forming materials. Most dredgings have very high moisture contents, permeabilities in the range of 10^{-5} to 10^{-9} m/s, liquid limit 60 - 150 (% w/w), plastic limit 20 - 70

(%w/w) and bulk density of < 1.3 tonnes/m^3;

- the most effective way to condition dredgings is to allow them to weather and become colonised with plants such as rushes *(Juncus sp.)* and reeds *(Phragmites communis)* which evapotranspire the excess water to induce cracking and structure development;

- desalination of estuarine materials in a wet state is not possible due to the almost impermeable nature of the dredgings. Again, the best way to desalinate is to allow the dredgings to colonise (or plant) with reeds as above. Gypsum is the standard amendment to counteract dispersion as salt and to enhance structure development within the dredgings;

- contamination - careful evaluation of dredged materials to determine contaminant concentrations is necessary to assess their suitability for land use. Metal contamination has important implications for phytotoxicity, while high sulphide content on oxidation leads to acid sulphate soils;

- mixing dredgings with organic waste material such as composted botanical waste, sewage sludge, tree bark and mushroom compost can improve the soil-like properties of the dredgings. Additions of 20% organic waste generally improve the nutrient content of inorganic dredgings particularly total and extractable nitrogen;

- nutrients - dredgings usually contain a large soluble pool of nitrogen that is either taken up by plant roots or lost from the system by leaching. This results in rapid vegetation establishment in the first season of growth. However, this level of biomass production is not sustainable into the following season *(Thomas & De Silva, 1991).* In older sediments nutrients are found to be limiting with noticeable responses to additions of NPK and lime; and

- long term success in using dredgings in landfill restoration requires the development of soil processes in order to recycle nutrients within the system. Nutrients and lime are essential additions to ageing dredged material.

4.8.3 PEAT FLY ASH

Peat fly ash is one of the main waste products produced from peat combustion at thermal power stations. The fly ash is entrained within the flue gas and subsequently transported out of the boiler for collection by mechanical grit arrestors. Water is then mixed with the peat ash to transport it as a slurry via pipelines to settling lagoons. The use of coal pulverised fuel ash is not recommended.

Peat fly ash chemistry varies with the type of peat burnt and the nature of the combustion process. Calcite ($CaCO_3$), hydrated lime ($Ca(OH)_2$), quartz (SiO_2), brucite ($Mg(OH)_2$) and magnesium carbonate ($MgCO_3$) are the main compounds present in peat fly ash. Fresh peat fly ash is characterised by its strong alkalinity, salinity, high conductivity and moderate to high concentrations of some potentially toxic elements. The elevated levels of some elements such as aluminium, arsenic, boron, molybdenum and cadmium present in peat fly ash are a major consideration in determining its suitability as a soil forming material. Table 4.11 compares the properties of a natural soil and peat fuel ash.

Only weathered peat fly ash should be used and a detailed chemical analysis of the material should be carried out. The landfill restorer must be able to demonstrate on a site by site basis, the suitability of peat fly ash as a soil forming material for use in restoration, and detail management operations such as transport and spreading, the addition of nutrients (organic and/or chemical) and planting or natural colonisation techniques. In addition to the properties of peat fly ash already listed, consideration needs to be given to the following:

- hardness and compaction - on exposure to rain peat fly ash tends to produce cemented layers which will need to be ripped;

- during handling operations dust generation may be a problem and dampening measures may be required;

- when placing the peat fly ash, it is important to ensure that the gradients of the placed peat fly ash will help encourage natural drainage;

- the addition of organic soil improvers such as compost, animal manures etc. will improve the nutrient status of the peat fly ash and will supply organic matter to promote biological activity and the development of structure;

- topsoil if available can be mixed or placed on the surface of the peat fly ash to promote successful vegetation establishment;

- in natural recolonisation, preliminary weathering allows the establishment of alkali tolerant mosses, grasses and herbs. This is followed by clovers and gorse before scrub woodland containing willow, birch and other species appears after about 10 years;

- only tolerant species should be planted on peat fly ash and bioassay trial plots should be used on an experimental scale to determine species suitability; and

- dietary supplementation of trace elements e.g. copper may be required for grazing animals and specialist advice should be sought e.g. Teagasc etc.

TABLE 4. 11 PROPERTIES OF PEAT FLY ASH

Natural Loam Soil	Peat Fly Ash
mixed particle size - gravel, sands, silts, clay and humus gives friable crumb structure	even-sized particles settle closely forming cemented mass with small air voids
contains 3 - 6% organic matter no organic matter	no organic matter
contains biologically active fauna, flora and micro-organisms	sterile when fresh but colonised slowly over time
balanced nutrient supply for plant growth	Nitrogen absent and other nutrients imbalanced Nitrogen (N) high application rates required as lack of organic matter allows leaching and high pH converts applied N to ammonia gas which is lost to the atmosphere Phosphorus (P) values appears adequate but high aluminium may renders it unavailable to plants Aluminium (Al) high levels of Al may limits plant response to fertiliser P Boron (B) relatively high levels of boron may limit plant growth Molybdenum (Mo) relatively high Mo could lead to copper deficiency in grazing stock. This sometimes occurs on natural soils and is corrected by dietary copper supplements
crumb structure gives adequate moisture retention with free drainage	moisture retentive, but settlement of even-sized particles causes poor drainage and waterlogging
generally good response and retention of applied fertiliser	poor response and retention of applied fertiliser
pH 7 neutral for mineral soils	pH high (8.0 - 11.0). pH decreases over time with weathering but plant growth restricted at high pH values.

Source: After National Power, 1994

5. RESTORATION AND AFTERCARE

5.1 INTRODUCTION

Restoration is a process which will return a site to a condition suitable for the selected afteruse. Restoration includes design, initial landscaping works, soil spreading, final landform construction and aftercare. Aftercare is the work done after the replacement of the soil and includes cultivations, fertilising, planting, construction of pathways, access points, vegetation maintenance and an ongoing long term commitment to the restored land. Appendices A to D describe in detail the restoration and aftercare of landfill sites to specific afteruses, as follows:

- **Appendix A - Amenity Restoration and Aftercare**
- **Appendix B - Woodland Restoration and Aftercare**
- **Appendix C - Agriculture Restoration and Aftercare**
- **Appendix D - Hard End Uses**

For successful restoration to be achieved it is essential that careful attention is given to the restoration requirements at each stage of the landfill process. This requires integration of restoration from the initial site selection and design through to the construction, initial landscaping, operation, decommissioning, soil placement, aftercare and post closure management. The afteruse is a critical design criterion and it is impossible to design successful restoration unless the afteruse has been agreed.

To achieve integration and successful restoration and aftercare, a site specific restoration plan needs to be prepared early in the life of the site so that the objectives of the original design are not lost. This restoration plan will form part of the landfill site environmental management plan as detailed in the Agency's manual on *Operational Practices* and also in Figure 1.1. This site specific plan will be phased to the working of the landfill as several stages of restoration can be in progression simultaneously across the landfill. A cycle of progressive restoration will follow a cycle of landfill across the site with one phase being restored, a second filled and a third prepared for filling. Soil handling operations such as stripping, transport, storage and placement will be detailed in the restoration plan and will occur in tandem with the phasing of the landfill operations. Figure 5.1 illustrates progressive landfilling and restoration.

5.2 RESTORATION AND AFTERCARE PLAN

The restoration and aftercare plan forms part of the sites environmental management plan. The plan must be site specific, up-to-date and flexible, having the ability to respond to and accommodate changing circumstances and technologies. Both new and existing landfills will require the preparation of a restoration plan. The aim of the plan is to implement the restoration and aftercare works on site. When changes are being made to the restoration plan reference should be made to the sites environmental management plan for information on the design and layout of the environmental pollution control systems. Some key aspects of restoration are summarised in Table 5.1.

Once the gas drainage layer, the barrier layer and the drainage layer (i.e. components of the capping system) have been successfully installed above the waste, the final restoration programme can be implemented.

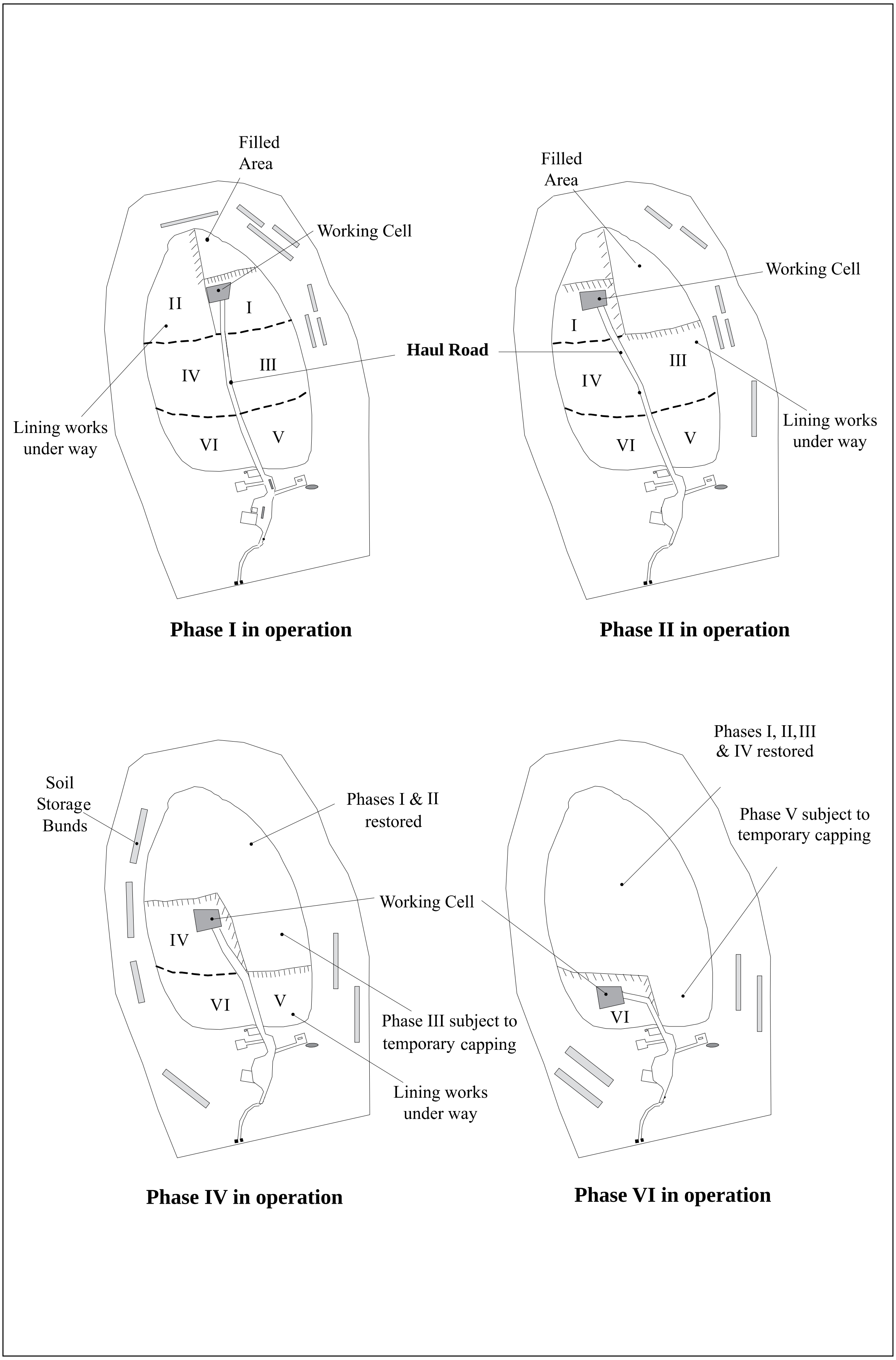


FIGURE 5.1 ILLUSTRATION OF PROGRESSIVE LANDFILLING AND RESTORATION

The restoration plan can be divided into two main stages:

Stage 1	Soil Placement	- soil handling operations - landform construction - landscaping features e.g. ponds, wetlands - soil depth, type and distribution
	Infrastructure installation	- pathways - access points and signposting - car parks - toilets etc.
Stage 2	Aftercare vegetation establishment	- cultivations - sowing - planting - fertilising - protection etc.
	Aftercare vegetation maintenance	- grazing - mowing - pruning - thinning - weeding - replacement of trees that have failed to establish - soil maintenance operations etc.
	Aftercare site maintenance	- fencing, gates, access points, ancillary facilities etc.

The aftercare plan, which forms part of a site's restoration plan, details the operations required after the replacement of the soil to bring the land up to the required standard for afteruse. It should also include an agreement between the relevant parties for the future management of the restored landfill. The persons responsible for implementing the aftercare programme should be clearly listed in the aftercare plan. The works, materials and personnel required for establishing the specific afteruse on each site must be specified, indicating the programme of works and timescale for each operation.

The aftercare plan should include details on:

- operations and materials required for vegetation establishment i.e. cultivations, seed type, origin and quantity, trees/shrubs and planting method and spacing, protection, fertiliser, lime, pest control;
- operations and materials required for vegetation maintenance i.e. pest control, weeding, mowing, grazing, pruning, thinning, replacement of failed trees etc;
- procedures for monitoring vegetation establishment and identification of potential conflicts which may arise, such as access and wear, nutrient additions and potential run-off etc;
- key personnel responsible for site management and maintenance;
- any important interim stages;
- the long-term aftercare management requirements;
- opportunities for extending areas of interest e.g. expanding nature conservation areas;
- provisions made to carry out regular checks on key physical site characteristics, such as drainage, soil compaction, soil fertility, soil structure and settlement; and
- site maintenance operations e.g. fencing, path maintenance, infrastructure etc.

5.3 THE TIMING OF RESTORATION WORKS

The timing of restoration works is influenced by site operations, settlement and seasonal considerations. The timing of restoration works in relation to site operations is summarised in Table 5.2

TABLE 5.1 KEY ASPECTS OF RESTORATION

Key Aspects of Restoration	
• programme of works after capping system and drainage layer installation for restoration and aftercare	– soil placement and landscaping – cultivations – vegetation establishment – vegetation maintenance – soil maintenance – infrastructure installation – remedial measures for settlement, drainage and non-establishment of vegetation
• phasing of restoration in tandem with the phases of the landfill	– initial/perimeter restoration – temporary greening – interim restoration – final restoration
• personnel and skills required	– soil scientists – agriculturists – horticulturists – silviculturist – ecologists – landscape architects – civil engineer
• effects of restoration on site operational practices	– landfill gas and leachate monitoring and control – settlement predictions – aftercare maintenance – access requirements

Source: After Environment Agency, UK 1996

5.4 PHASED RESTORATION

A landfill site should be divided into a series of phases (see Figure 5.1) and filled to final levels in succession and progressively restored. Operational and restoration benefits of phased landfilling include those listed in Table 5.3.

5.4.1 INITIAL RESTORATION AND TEMPORARY GREENING

Initial restoration involves landscaping around the perimeter fence to screen the landfill operations. This will help reduce the visual impacts of the landfill and will improve the external appearance of the site. Careful landscaping and vegetation maintenance around the site entrance is crucial as this will be the first point of contact between the general public and the landfill. The choice of species should reflect the broad patterns of the surrounding landscape and ground vegetation.

The benefits of temporary greening by planting vegetation on phases of the landfill and on soil storage mounds include:

- reduction of soil erosion;

TABLE 5.2 THE TIMING OF RESTORATION WORKS IN RELATION TO SITE OPERATIONS

Site design and operation	Restoration design and site works
• landfill design	– integrated design proposal for the overall restoration and aftercare of the site
• preparation and development	– retain as much of the existing site undisturbed as possible by controlling the extent of the initial preparation and development works – soil stripping and formation and seeding of soil storage mounds – screening and perimeter landscaping – entrance landscaping – management of non-landfilled areas
• landfilling	– progressive screening in advance of phased landfilling – screening and recycling of suitable wastes to provide soil improvers and soil forming materials – temporary greening of areas not required for landfilling to improve the appearance of the site and avoid soil erosion – good litter control on the site should avoid litter being blown onto non-landfilling areas and restored areas
• filled landfill phases - install environmental pollution control systems	– interim restoration following placement of barrier layer, drainage layer and/or filter layer – reinstatement of disturbed lands by interim restoration following remedial measures and work to environmental pollution control systems particularly following settlement and gas pipework installation – light cultivations and seeding interim restored areas with grass to prevent soil loss through water and wind erosion
• final restoration and aftercare	– final placement of full soil profile – vegetation planting, establishment and maintenance – soil maintenance operations such as subsoiling and amendments
• post closure management	– spot drainage – regular inspection of drainage ditches to maintain outfalls – vegetation maintenance – soil maintenance to alleviate any problems such as compaction and low spots where sod stripping, soil filling and resodding may be needed – fencing operations and maintenance – maintain access for monitoring and maintenance of environmental pollution control systems – decommissioning of gas/leachate installations and restoration of redundant compounds

TABLE 5.3 OPERATIONAL AND RESTORATION BENEFITS OF PHASED LANDFILLING

Phased Landfilling	
• operational benefits	– stricter control and organisation of disposal operations – reduction in the volume of leachate generated – possible reduction in noise and litter – positive visual impression which promotes public confidence in site
• restoration benefits	– minimal disturbance of non-landfilled areas, with parts of the site being retained in their original state for as long as possible – minimal disturbance to habitats and wildlife – improved soil handling operations by enabling soil stripping and replacement to occur in one phase thereby avoiding the need for soil storage (see Chapter 4) – reduced soil traffic movements, damage and loss of soil resources – phases of landfill returned to specified afteruse before landfilling is complete – allows site specific restoration progress and techniques to be monitored, and amended if necessary – helps identify plant species which have adapted well to site conditions which should be used on remaining phases requiring restoration – enables replacement wildlife habitats to be created before the original is destroyed and allows local plant types to be re-established on the site if required

- improvement of landscape and visual appearance of the site during landfill operations;
- stabilisisation of soil storage mounds;
- reduction of the visual intrusion caused by storage mounds;
- reduction of windblown dust; and
- prevention of the build up of noxious weeds.

5.4.2 INTERIM RESTORATION

Interim restoration involves the replacement of part of the full subsoil depth onto the filled landfill phase and carrying out some limited cultivations necessary to establish vegetation on the area. The replaced soil profile is normally seeded with grass. Figure 5.2 shows an example of an interim restoration profile. The need to carry out interim restoration should be assessed on a site by site basis. Interim restoration is recommended to minimise the difficulties which are encountered during aftercare resulting from the installation of

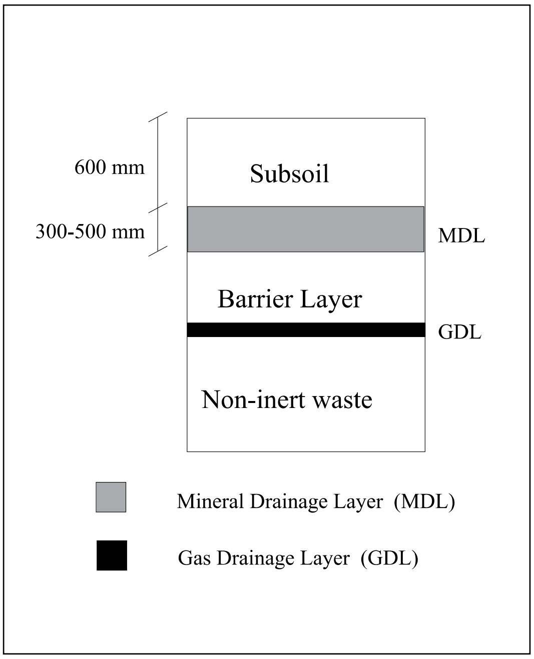


FIGURE 5.2 ILLUSTRATION OF INTERIM RESTORATION PROFILE

TABLE 5.4 SUMMARY TABLE FOR INTERIM RESTORATION

Interim restoration	
• benefits of interim restoration include	– higher standards of final restoration – reduced soil damage – facilitation of installation of environmental pollution control systems and remedial works which may be required due to settlement – improved site appearance while frequent work on the engineering systems is needed – protection of the cap and reduced water infiltration through the soil – control of surface water run-off and erosion if exposed soil is sown with grass – most of the subsoil and all of the topsoils on site will remain unused and uncontaminated and will therefore be available for final restoration – avoids having to strip off full soil profile and remove trees and shrubs in areas where remedial work is required on the environmental pollution control systems – corrections can also be made to gradients which have been affected by settlement
• interim restoration is appropriate on most sites particularly on sites where:	– gas control system are to be installed or existing ones modified – on areas where vegetation cover is required but which may be subject to further engineering works – on sites accepting biodegradable wastes where remedial works to the environmental pollution systems will be needed because of settlement
• interim restoration works on site involves	– spreading a shallow depth of soil or soil forming materials to protect the cap and support grass growth e.g. • 500 mm of subsoil; or • 300mm glacial till covered by 300mm of subsoil. – stone picking – light cultivations, fertilisation and grass seeding

the gas control system. It also allows for settlement and any remedial works which may be required and should be considered during the design phase for new sites or during new phase developments on existing sites. Table 5.4 summarises the benefits, the site conditions where interim restoration is most appropriate and what works are required on site for interim restoration.

5.4.3 FINAL RESTORATION

The need for full integration of the restoration plan within the site operations is critical and will be reflected in the quality and success of the final restoration. The restoration plan should show restoration as a developing process which responds to site operations to achieve sustainable long term restoration and aftercare. Final restoration involves replacing the final soil profile and carrying out landscaping works detailed in the design of the landfill. Every effort should be made to minimise soil compaction or contamination. Soil placement should be carried out as soon as possible (weather permitting) over the barrier layer to protect this from desiccation, damage and weathering. Figure 5.3 shows examples of a final restoration profile for a landfill site accepting inert waste while Figure 5.4 and Figure 5.5 illustrate final restoration profiles for non-inert landfills restored to various afteruses.

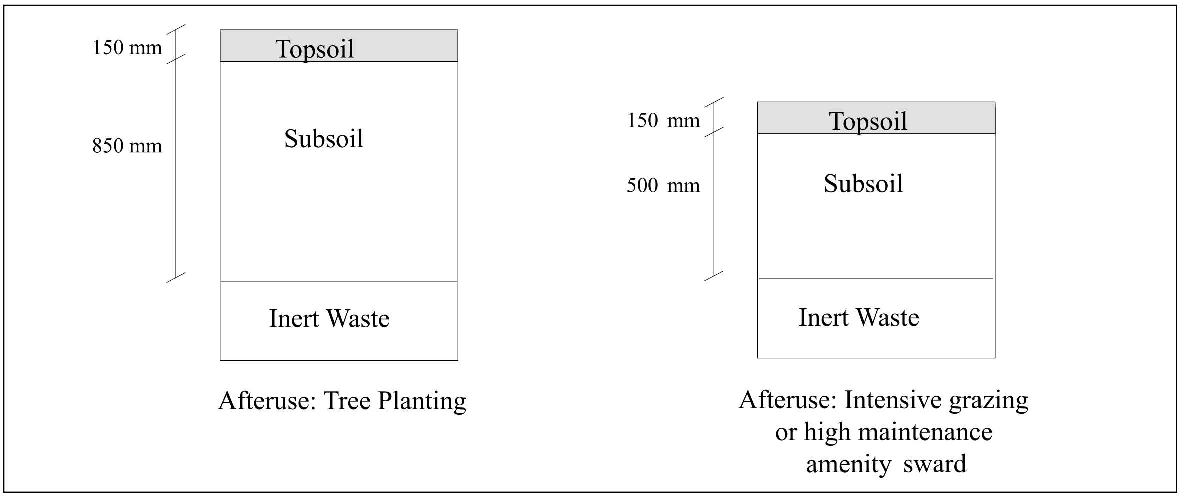


FIGURE 5.3 ILLUSTRATION OF FINAL RESTORATION PROFILE FOR LANDFILL SITES ACCEPTING INERT WASTE

Timing of final restoration works on site is influenced by numerous landfill operational factors which include:

- settlement rates across the site, particularly sites accepting biodegradable waste;
- recirculation of leachate for accelerated stabilisation. For further information on leachate recirculation refer to the Agency's manual on *Landfill Site Design*;
- installation of the environmental pollution control system; and
- seasonal considerations.

5.4.3.1 SETTLEMENT RATES AND FINAL RESTORATION

Sites accepting biodegradable wastes will settle over time. Settlement values of between 10 and 25% can be expected for such landfills. Most of the settlement takes place in the first five years after filling. It is therefore not recommended to replace the full soil profile directly after landfilling has ceased. For further details on settlement refer to the Agency's manual on *Landfill Site Design.* Interim restoration should be practised, replacing part of the soil profile until the landfill has settled and the environmental pollution control systems have been installed. However, on sites accepting inert waste there is generally no need to delay final restoration and the

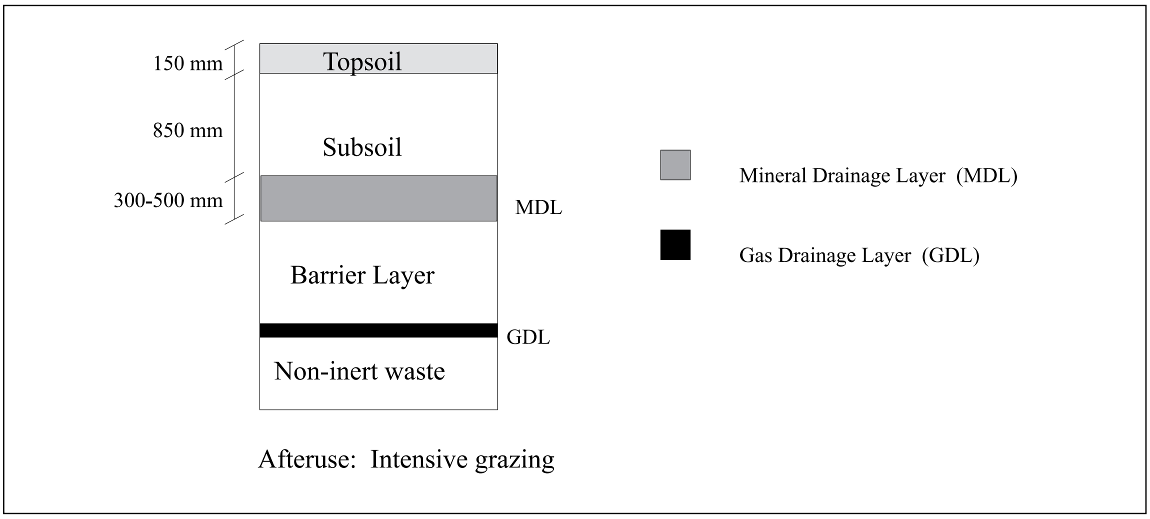


FIGURE 5.4 FINAL PROFILE FOR LANDFILL SITE ACCEPTING NON-INERT WASTE RESTORED TO INTENSIVE GRAZING

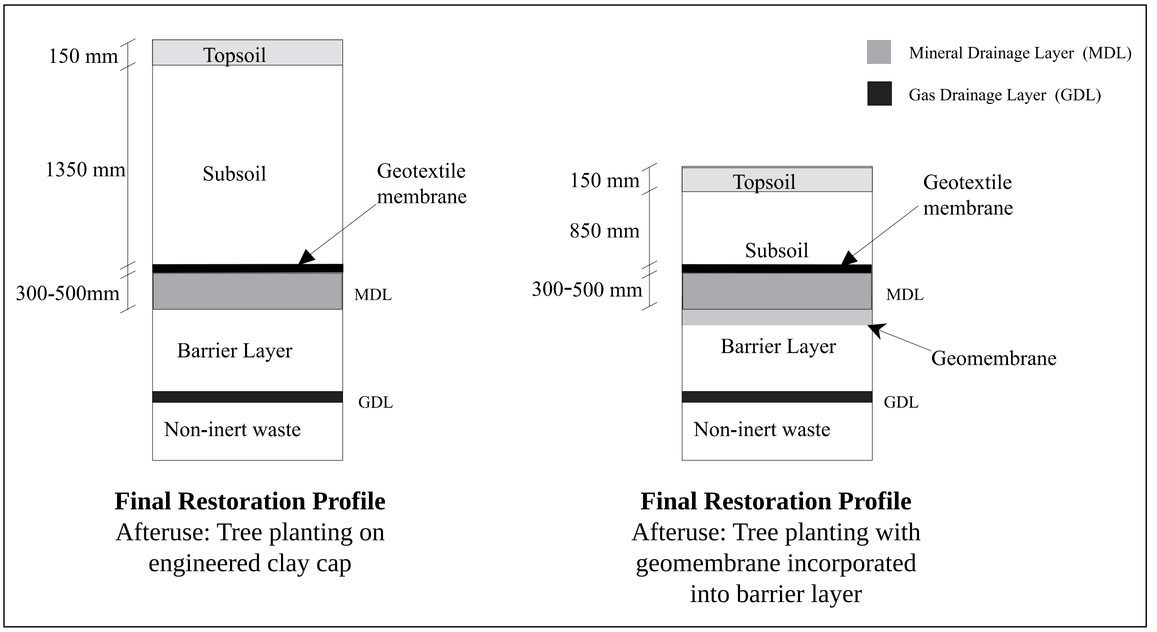


FIGURE 5.5 FINAL PROFILE FOR LANDFILL SITE ACCEPTING NON-INERT WASTE RESTORED TO WOODLAND

final soil profile should be replaced and landscaped after landfilling has ceased.

5.4.3.2 RECIRCULATION OF LEACHATE AND FINAL RESTORATION

The recirculation of leachate through areas of emplaced waste uses the landfill as an uncontrolled anaerobic filter/reactor where additional microbial degradation can occur. Additional advantages of leachate recirculation are enhanced methane gas generation, the ability to buffer peak flows in leachate generation, early stabilisation and enhancement of landfill settlement. The components of the leachate recirculatory system and the timing of these operations in relation to final restoration need to be considered. These include:

- the installation of a reintroduction system;
- the installation of distribution pipes for leachate recirculation should occur when landfilling has ceased;
- an adequate monitoring system for determining the level of leachate in the waste;
- the installation of the system before the gas control system is completed;
- substantial remedial work on the pipework system because of settlement affecting the falls in the pipes and possible damage to the system when the gas control system is being completed; and
- remedial works may necessitate the lifting of the barrier layer which will impact on interim restoration and delay final restoration.

5.4.3.3 INSTALLATION OF GAS CONTROL SYSTEM

During final restoration it is necessary to integrate the installation of the gas collector pipes with the replacement of the final soil profile and the landscaping works on site. Further details are given in the Agency's manual on *Landfill Site Design.* Factors specific to final restoration include:

- the gas pipework system should be installed before final restoration to avoid damage to the soil such as compaction, contamination and loss;
- the gas control system will require remedial work during the first 2 to 5 years after installation due to the effects of settlement. Settlement can cause the pipework system to deform causing low

spots where condensate can accumulate. It may also cause pipework connections to distort and fracture and vertical wells to deform. Interim restoration will help accommodate partial soil placement and installation of the gas control system;

- 500 mm of subsoil (or 300 mm non-soil material overlain with 300 mm subsoil) should be placed over the cap to protect the cap and to protect and accommodate the gas transport/transfer pipes which should have a minimum fall of 1:30 to assist drainage of condensate;

- the gas transport/transfer pipes selected must be able to withstand traffic loading during restoration and aftercare and must also withstand loading caused by settlement. Ideally these pipes should be a bright colour to be easily identified during any remedial works after installation;

- drilling and excavation for the gas system and soil placement should be done during dry weather and good soil conditions; and

- tree and shrub planting should be delayed until all the remedial work on the gas system has been carried out and initial settlement has occurred. Areas subject to such delays will require interim restoration and seeding with grass, thereby delaying final restoration for up to 5 years. This will be more cost effective and will improve the standards of long term restoration.

5.5 AFTERCARE

The aftercare period is designed to ensure that the restored land achieves the required standard for the proposed afteruse. As restored soils are fragile, special care is needed to avoid damage and to assist soil development. The main objective of the initial aftercare period is to improve the physical and chemical status of the soil *(RPS Clouston & Wye College, 1996).*

The length of the aftercare period will vary from site to site; however, the holder of a landfill waste licence will be responsible for the aftercare of the site up until the date when the Agency accepts the surrender of the waste licence as specified under section 48 of the Waste Management Act, 1996.

Successful aftercare is dependent upon the following factors which include:

- preparation of a site specific aftercare plan;

- on-going monitoring of emissions and environmental media e.g. landfill gas, leachate, dust, odours, surface water, groundwater, landfill settlement, landfill stability, and flora and fauna;

- annual meetings should be held between the site operators, aftercare managers of the site and all relevant interested parties such as local community and farmer representatives, planning and local authorities, ecologists, wildlife groups, Teagasc, Coillte etc.;

- maintenance of an effective drainage system;

- construction of landform and landscape features appropriate to proposed afteruse;

- integration and protection of environmental pollution control systems;

- effective organisation of operations with particular reference to seasonality factors;

- appropriate choice of plants and species for afteruse;

- good practice during planting, weeding, fertilising and tree protection; and

- regular soil maintenance checks on the physical and chemical status of the soils to identify areas requiring attention such as compaction, depressions and ponding, vegetation dieback etc.

5.6 ASPECTS OF RESTORATION SPECIFIC TO EXISTING AND CLOSED LANDFILL SITES

A restoration strategy for these sites must take into account their previous history. It should include a desk top study, investigations and risk assessment. From these findings, remedial measures particularly in relation to gas and leachate migration need to be designed and implemented alongside the restoration plan. A detailed desk study followed by a site specific assessment will furnish the restorer with the information necessary to carry out successful restoration. The site characteristics and specific problems encountered during investigation of sites include:

- gas and leachate migration;
- unsightly landform which is visually obtrusive;
- windblown litter and tipping particularly along perimeter of landfill;
- presence of rank invasive weeds;
- differential settlement, ponding and waterlogging;
- inadequate soil cover resulting in poor vegetation cover and scavenging by birds and other animals; and
- inadequate soil resources.

5.6.1 DESK STUDY AND INVESTIGATIONS

The desk top study and the subsequent investigations will help identify characteristics of the landfill site which need to be taken into account during restoration design and the preparation of the restoration plan. The information and assessments required include:

- type and quantities of waste deposited;
- the age of the site and date of closure;
- assessment of existing emission control and monitoring structures and installations;
- estimates of quantities of gas and leachate produced and identification of possible migration routes;
- drainage status;
- surface and groundwater quality;
- existing vegetation on site and its significance; and
- environmental designations (if applicable).

5.6.2 REMEDIAL MEASURES

Currently available remedial measures can be classified into two broad groups *(Harris et al. 1994):*

- Civil engineering based methods: these employ conventional civil engineering techniques to remove or contain contamination sources, or to block the pathways by which contaminants such as leachate can reach targets such as groundwater, surface waters or soils. Typical remedial measures include excavations, surface covers, in-ground barrier and hydraulic measures such as pumping for collection and subsequent treatment.
- Process based methods: these use specific physical, chemical and biological processes to remove, destroy, or modify contaminants. Process based methods include thermal processes, physical processes such as soil washing, chemical processes such as in-situ soil leaching and biological processes such as engineered reed-beds.

Appropriate remedial measures will need to be determined a site by site basis following investigation and risk assessment. Professionally qualified specialists should be employed when investigating, designing and implementing remedial measures on landfill sites. Further information on remedial measures for contaminated sites are given in *ICE design and practice guides: Contaminated land: investigations, assessment and remediation* by Mary Harris and Sue Herbert (1994) and also *CIRIA SP 101-112: The remedial treatment of contaminated land* by Harris, Herbert and Smith (1994), CIRIA, London.

5.6.3 RESTORATION DESIGN

The restoration design for these sites must take account of the Development Plan, Waste Management Plan and any proposals that may currently exist for landuse. The designer should consider the following issues:

- carry out active liaison with local communities during the design phase;
- site characteristics such as existing landform and environmental setting. Ideally, the

designer should try and work with the existing landform to avoid having to excavate emplaced wastes which would pose health, safety and environmental risks;

- the quantity and type of soils available on-site for restoration and the use of soil forming materials;
- design and integration of pollution control and monitoring systems particularly the capping, gas and leachate control system;
- restoration, aftercare and afteruse; and
- funding for restoration.

5.6.4 RESTORATION WORKS

A restoration plan will be required for these sites which will follow similar guidelines as discussed in section 5.2. and those outlined in detail for the various afteruse in Appendices A to D. However, some aspects of restoration are particularly significant on closed or existing sites and the restoration plan will need to accommodate these differences. Aspects peculiar to these sites include:

- capping system and soils - the design of the barrier layer and the choice of afteruse must take into account the availability of suitable material for capping and restoration on-site or within the locality of the site. In general, most older sites will not have enough clay material or soils on site and provision will have to be made to obtain the materials. It is important to try conserve soil resources for use in restoration and to use, where appropriate, artificial capping materials such as geomembranes and bentonite;
- interim restoration should be considered to protect the barrier layer while soils are being acquired for final restoration. These interim restored areas should be sown with grass following light cultivations; and
- the design, installation and maintenance of the pollution control systems will need to be integrated with restoration. Again, interim restoration is recommended so that remedial works to these systems can occur with minimum damage to soils and vegetation. If an active gas extraction system is installed, settlement will occur and must be accounted for in the restoration design.

6. MAINTENANCE OF ENVIRONMENTAL POLLUTION CONTROL SYSTEMS DURING AFTERCARE

6.1 INTRODUCTION

On-going monitoring of emissions and environmental media is required during the aftercare period and the minimum requirements are detailed in the Agency's manual on *Landfill Monitoring.* The pollution control systems which require maintenance and protection during the aftercare period include:

- the landfill gas management system;
- the leachate management system;
- the landfill capping system including drainage system;
- surface water collection, storage and discharge systems;
- groundwater monitoring boreholes;
- surface water monitoring points; and
- any other item set out by the Agency in conditions of a licence.

6.2 SITING CONSIDERATIONS

The most effective protection measure is to design the monitoring systems so that the above ground components are not sited in vulnerable locations. The design of new landfill sites must take into account the need for continuous monitoring after landfilling has ceased. On existing sites the risk of damage can be reduced by careful selection of the afteruse in relation to environmental pollution control systems.

On sites prone to vandalism appropriate security and prevention measures will be required. The above ground components particularly wellheads, gas compounds, flare stacks and passive venting columns are natural targets for vandalism and therefore require special attention. Security design must take into account health and safety issues particularly in relation to access to chambers, fire risks etc.

The operator of the landfill site must keep construction *(as built)* records of underground service corridors which must be referred to before any subsequent excavation is carried out. On new sites the soil depth must be sufficient to prevent damage during subsoil ripping or laying of field drainage system. The location of all underground pipe systems such as gas collection pipes, leachate transfer pipes, etc. should be recorded. These records must be available on site and referred to before any work commences on site.

6.3 MAINTENANCE OPERATIONS

6.3.1 INTRODUCTION

Remedial works to pipework systems and wellheads have the potential to impact severely on afteruse of the site. Interim restoration should be practised to allow most remedial works to be carried during this stage in the restoration process rather than after full restoration has occurred. All appropriate measures should be taken to minimise the damage to the restored land. The timing of works, supervision and machinery used are all critical factors which need to be considered prior to carrying out remedial works. Good working practice to minimise the impact of remedial works on the afteruse includes:

- agree plan of works - this should be done in advance with the user of the restored land to cause minimal impact on afteruse. Particular attention should be paid to the timing of works in relation to stage of crop growth, nature conservation aspects such as breeding seasons, etc.;
- supervision - all operations should be supervised to minimise damage to restored land;
- minimum disturbance - use minimum practical working area and suitable access;
- soil conditions - work when soil conditions are suitable and ensure that all soil resources are stripped and stored carefully for reuse;

- use appropriate machinery - use plant which will avoid/minimise soil compaction;
- woodland areas - employ silviculturist to prune back any trees and shrubs which are outside the working area but are close enough to interfere with remedial works; and
- reinstatement - should be carried out to the same standards as the original works by landscape contractor.

6.3.2 LANDFILL GAS MANAGEMENT SYSTEM

Regular monitoring of the boreholes and checks on the gas wells for performance and gas yield will identify areas where maintenance works are required during the aftercare period. These works will include:

- remedial works to wells and pipework;
- extension works to include recently capped cells;
- changing systems from passive to active extraction;
- relocating gas flare system; and
- decommissioning and removing redundant structures.

Once gas extraction is exhausted, the gas compound should be decommissioned and all redundant equipment removed. The site operator must ensure that the works required have minimal impact on the afteruse and users of the restored site.

6.3.3 LEACHATE MANAGEMENT SYSTEM

The components of the leachate system which require regular checks and maintenance include:

- fixed leachate monitoring points;
- leachate pumps;
- leachate lagoons; and
- leachate treatment plant and all equipment used in treatment processes.

Any remedial works or modifications to the leachate system should be carried out with minimal impact on the afteruse. Where problems arise with the leachate collection system some remedial measures will be required. Where possible these works should occur along field boundaries to minimise disruption to the afteruse.

When the leachate collection and treatment system is no longer required the operator should remove all leachate from the collection chambers and storage lagoons. These should be cleaned out and backfilled with inert material for health and safety reasons. The pumps, treatment plant and any ancillary structures should be removed from the site.

6.3.4 CAPPING SYSTEM

Maintenance requirements to the capping system should be minimal. However, on sites where leachate recirculation is practised, maintenance to the recirculation system will result in the cap being disturbed. For further details on leachate recirculation refer to the Agency's manual on *Landfill Site Design.*

Differential settlement across the landfill can lead to low spots where waterlogging can occur. The amount of remedial work required will depend on the degree of settlement. In some areas the soils will have to be stripped and the cap removed to infill the shallow areas. It is important that the repaired cap is properly sealed with the original to prevent the ingress of water.

The effectiveness of the drainage system must be monitored and any remedial works to the drainage layer and/or the surface water collection system should be carried out when required.

REFERENCES AND FURTHER READING

- Adams, W.A. and Gibbs, R.J. (1994) *Natural turf for sport and amenity.* CAB International, Wallingford, UK.
- ADAS (1985) *Drainage Aftercare:* MAFF, Northumberland, UK.
- Andrews, J. and Kinsman, D. (1990) *Gravel pit restoration for wildlife: a practical manual.* RSPB, Bedfordshire, UK.
- An Foras Taluntais (1980) *Soil Associations of Ireland and their landuse potential: Soil Survey Bulletin No. 36.* AFT, Dublin.
- Ash, H.J., Bennet, R. and Scott, R. (1992) *Flowers in the grass.* English Nature, Peterborough.
- Aitken, M., Chambers, B. and Nicholson, F. (1997) *Liming and Nutrient Supply Properties of N-Viro Treated Sewage Sludge.* Paper presented at the International Society for Horticultural Science and SAC International Symposium on Composting and Use of Composting Materials for Horticulture, 5-11 April 1997 at SAC Auchincruive, Ayr, Scotland.
- Bending, N.A.D., and Moffat, A.J. (1997) *Tree establishment on landfill sites: Research and updated guidance.* Department of the Environment, Transport and the Regions, HMSO, Norwich.
- British Standards Institution. (1981) *Code of practice for Site Investigations. BS 5930 : 1981.* BSI, UK.
- Bulfin, M. (1992) *Trees on the farm.* Tree Council of Ireland, Dublin.
- Bullock, P. and Gregory, P. (1991) *Soils in the urban environment.* Blackwell Scientific Publications, Oxford, London.
- Countryside Commission (1993) *Landscape Assessment Guidance.* Countryside Commission, Northampton.
- Commission Decision (94/923/EC) (1994) *Commission decision establishing the ecological criteria for the award of the Community eco-label to soil improvers.* 94/923/EC - OJ L 364/21, 31st December 1994.
- Commission of the European Communities (1997) *Proposal for a Council Directive on the Landfill of Waste. Working document* 30/10/97.
- Commission of the European Communities (1994) *Wastewater and Sludge Re-Use - Guidance Note.* Amber, 1994.
- Curtis, T.G.F. and McGough, H.N. (1988) *Irish Red Data Book I: Vascular Plants.* Government Publications Office, Dublin 2.
- Davies, M.C.R. (Ed) (1991) *Land reclamation: An end to dereliction?.* Elsevier Applied Science, Essex, UK.
- Davis, R,D. and Rudd, C. (1998) *Investigation of the criteria for, and guidance on, the landspreading of industrial wastes.* Environment Agency, DETR & MAFF, Wiltshire, UK.
- Design by Nature/ Irish Wildflowers (1998) *Irish Wildflower Manual.* Design by Nature, Co. Carlow.
- Department of Agriculture, Food and Forestry. (1996) *Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates.* Government Publications, Dublin.
- Department of the Environment (1997) *Sustainable development: A Strategy for Ireland.* Government Publications, Dublin.
- Department of the Environment (1994) *Protection of New Buildings and Occupants from landfill Gas.* Government Publications, Dublin.
- Department of the Environment (1997) *Technical Guidance Document C Site Preparation and Resistance to Moisture.* Government Publications, Dublin.
- DIN 38414 (S4) (1984) *Determination of leachability by water.* Beuth Verlag, GmbH, Postfach 11 07, D-1000, Berlin 30, Germany.
- Dobson, M.C. and Moffat, A.J. (1993) *The potential for woodland establishment on landfill sites.* Department of the Environment, HMSO, London.
- Dobson, M.C. and Moffat, A.J. (1995) *Site capability assessment for woodland creation on landfills.* The Forestry Authority Research Division, Surrey, UK.
- Environment Agency, UK (1996) *Waste Management Paper 26E: Landfill restoration and post closure management (consultation draft).* Environment Agency, UK.

- Environment Agency, UK (1996) *Restoration of riverine trout habitats: A Guidance Manual, Fisheries Technical Manual 1*. Environment Agency, UK.
- Environmental Protection Agency (1996) *National Waste Database Report 1995*. Environmental Protection Agency, Wexford.
- Environmental Protection Agency (1995) *Landfill Manuals: Investigations for Landfills.* Environmental Protection Agency, Wexford.
- Environmental Protection Agency (1995) *Landfill Manuals: Landfill Monitoring.* Environmental Protection Agency, Wexford.
- Environmental Protection Agency (1997) *Landfill Manuals: Landfill Operational Practices.* Environmental Protection Agency , Wexford.
- *Environmental Protection Agency Act 1992*. Government Publications, Dublin.
- ETSU B/LF/00474/REP/1 *A Review of the Direct Use of Landfill Gas - Best Practice Guidelines for the Use of Landfill Gas as a Source of heat.*
- Flower, F.B., Gilman, E.F. and Leone, I.A. (1981) *Landfill gas, what it does to trees and how its injurious effects may be prevented. Journal of Arboriculture* Vol 7, No. 2, pp 43-52.
- Forestry Commission (1987) *Trees and Weeds: Weed control for successful tree establishment.* Forestry Commission Handbook 2, HMSO, London.
- Gardiner, M.J. and Radford, T. (1980) *Soil Associations of Ireland and their land use potential.* An Foras Talúntais, Dublin.
- Gawn, P. E. (1991) *Landscape Architecture: Gas Monitoring Techniques.* In*: Practical Landfill Restoration and Aftercare of Landfill Sites,* Proceedings of a NAWDC Training Course, Welwyn, April 1991.
- Harris, M. and Herbert, S. (1994) *ICE design and practice guide: Contaminated land; investigation, assessment and remediation.* Thomas Telford, London, UK.
- Harris, M., Herbert, S. and Smith, M. (1994) CIRIA SP 101-112: *The remedial treatment of contaminated land.* CIRA, London, UK.
- Hawkins, K. and Latham, B. (1995) *Landfill Architecture: The Integrated Approach.* Proceedings Sardinia 95, Fifth International Landfill Symposium, S. Margherita di Pula, Calgliari, Italy; 2-6 October 1995.
- Hodgkinson, R.A. (1989) *The drainage of restored opencast coal sites. Journal of Soil Use and Management*, Vol 5, No. 4, pp 145-150.
- Holmes, J. (1991) *Introduction - Landfill and the future.* In: *Practical Landfill Restoration and Aftercare of Landfill Sites*, Proceedings of a NAWDC Training Course, Welwyn, April 1991.
- Hickey, D. (1997) *Evaluation of Environmental designations in Ireland* (Second edition). The Heritage Council, Kilkenny.
- Institution of Engineers of Ireland and Geotechnical Society of Ireland. (Draft) *New Specification for Ground Investigations.* IEI, Dublin.
- International Society of Soil Mechanics and Foundation Engineering (ISSMFE) TC 5. (1997) *Environmental geotechnics.* Jessberger & Partner GmgH, Bochum, Germany.
- IWM Scientific and Technical Committee. (1994) *Down to Earth Composting - of municipal green wastes.* IWM, Northampton, UK.
- Land Use Consultants (1992) *The use of land for amenity purposes - A summary of requirements.* The Department of the Environment (UK), HMSO, London.
- Land Use Consultants (1992) *Amenity reclamation of mineral workings: Main report.* The Department of the Environment, HMSO, London.
- Land Use Consultants in association with Wardell Armstrong (1996) *Reclamation of Damaged land for Nature Conservation.* Department of the Environment (UK), HMSO, Norwich.
- Latham, B. (1994) *The everlasting question of landfill settlement.* Journal of Waste Management, June.
- Lee, J. (1991) *Soil Mapping and Land Evaluation Research in Ireland.* In: *Soil Survey: A basis for European Soil Protection*, Commission of European Communities, pp 39 - 56.
- *Local Government (Water Pollution) Act, 1977 (Water Quality Standards for Phosphorus) Regulations, 1998 (SI No. 258 of 1998).* Government Publications, Dublin.

- Maher, M.J., Lenehan, J.J. and Staunton, W.P. (1993) *Spent mushroom compost: Options for use.* Teagasc, Kinsealy and Grange Research Centres, Ireland.
- Manassero, M., Van Impe, W.F. and Bouazza, A. (1996) *Waste Disposal and Containment.* Technical Committee on Environmental Geotechnics, ISSMFE, Preprint of special lectures from 2nd International Congress on Environmental Gotechnics, pp. 193 - 242.
- McClintock, D. and Fitter, R.S.R. (1974) *Collins Pocket Guide to Wildflowers.* Book Club Associates, UK.
- McKendry, P. (1996) *Landfill restoration: soils, specifications and standards.* IWM Proceedings, July, 1996.
- McLaren, R.G. and Cameron, K.C. (1990) *Soil Science: An introduction to the properties and management of New Zealand soils.* Oxford University Press, Oxford.
- Merrit, A. (1994) *Wetlands, Industry & Wildlife.* The Wildfowl and Wetlands Trust, Gloucester, UK.
- Moffat, A.J. and McNeill, J. (1994) *Reclaiming disturbed land for forestry.* Forestry Commission Bulletin 110, HMSO, London.
- Moffat, A. (1995) *Minimum soil depths for the establishment of woodland on disturbed ground.* Arboricultural Journal, Vol 19, pp 19-27.
- Mulqueen, J. (1998) *Depth, spacing and length of mole drains with application to afforestation.* Journal of Agriculture and Food Research, Vol. 37.
- National Power. (1994) *Engineering with Ash: Ash in the Landscape.* National Power, Swindon, UK.
- Olsen, P. and Collier, P. (1994) *Source-separated Waste Composting: the Quest for Quality.* Journal of Waste Management and Resource Recovery, Vol. 1, No 3, pp 113-117.
- Polunin, O. (1976) *Trees and Bushes of Britain and Ireland.* Oxford University Press, Oxford.
- Pow, S.J. (1997) Pulverised fuel ash: its composition and weathering. In paper presented at 17th Annual Groundwater Seminar on *Soil and Groundwater Contamination and Remediation,* IAH (Irish), Portlaoise, Co. Laois, Ireland.
- Press, B. (1992) *Field Guide to Trees of Britain and Europe.* New Holland Publishers, London.
- Putwain, P.D. and Rae, P.A.S. (1988) *Heathland restoration: a handbook of techniques.* Environmental Advisory Unit, Liverpool University & British Gas, Southampton, UK.
- Ramsay, W.J.H. (1986) *Bulk soil handling for quarry restoration.* Journal of Soil Use and Management, Vol. 2, No. 1, pp 30-39.
- Reeve, M. (1991) *Soil handling and restoration materials*. In: *Practical Landfill Restoration and Aftercare of Landfill Sites, Proceedings of a NAWDC Training Course*, Welwyn, April 1991.
- Rimmer, D.L. (1991) Soil storage and handling. In: *Soils in the Urban Environment* (eds) Bullock, P & Gregory, P.J. pp 76-86. Blackwell Scientific Publications, Oxford, UK.
- Royal Commission on Environmental Pollution. (1996) *Nineteenth Report: Sustainable Use of Soils.* HMSO, London.
- The Royal Society for the Protection of Birds, the National Rivers Authority and the Royal Society for Nature Conservation. (1994) *The New Rivers and Wildlife Handbook.* RSBP, NRA and Wildlife Trust, UK.
- RPS Clouston and Wye College (1996) *Guidance on good practice for the reclamation of mineral workings to agriculture.* Department of the Environment, HMSO, Norwich.
- RPS Clouston and Wye College (1996) *The reclamation of mineral workings to agriculture.* Department of the Environment, HMSO, London.
- Ruark, G.A., Mader, D.L. and Tattar, T.A. (1983) *The influence of soil moisture and temperature on the growth and vigour of trees - a literature review:* Part II. Arboricultural Journal, Vol. 7, pp 39-51.
- *Safety, Health and Welfare at Work Act, 1989.*
- *Safety, Health and Welfare at Work Regulations (SI No. 44 of 1993).*
- *Safety, Health and Welfare at Work (Construction Sites) Regulations (SI No. 138 of 1995).*
- Simmons, E. (1992) Restoration of landfill sites for wildlife. *Journal of Waste Planning*, June, 1992.
- Simmons, E. (1992) The importance of restoration in waste disposal by landfill. *Journal of Waste Management*, December, 1992.

- Simmons, E. (1996) Landscape design and vegetation management. *Journal of Waste Management,* February, 1996.
- Stewart, N.F. and Church, J.M. (1992) *Red Data Book of Britain & Ireland: Stoneworts.* The Joint Nature Conservation Committee, Peterborough, UK.
- Street, M. (1989) *Parks and lakes for wildfowl.* The Game Conservancy, Fordingbridge, Hampshire, UK.
- Sutherland, W.J. and Hill, D.A. (1995) *Managing Habitats for Conservation.* Cambridge University Press, Cambridge, UK.
- Teagasc (1994) *Soil analysis and fertiliser, lime, animal manure and trace element recommendations.* Teagasc, Wexford.
- Teagasc (1996) *The concentrations of major and trace elements in Irish soils.* Teagasc, Wexford.
- Teagasc (1998) *Phosphorus and potash fertiliser recommendations.* Teagasc, Wexford.
- Teagasc (1998) *Census of Mushroom Production.* Teagasc, Kinealy Research Centre, Dublin.
- Thomas, B.R. and De Silva, M.S. (1991) Topsoil from Dredgings: A solution for land reclamation in the coastal zone. (Ed) Davies, M.C.R. *In Land Reclamation: An end to dereliction?.* Elservier, London, UK.
- Towers, W. and Horne, P. (1997) *Sewage sludge recycling for agricultural land: the Environmental Scientist's Perspective.* Journal of the Chartered Institution of Water and Environmental Management, Vol. 11, No 2, pp 126-132.
- UK Department of the Environment (1986) *Waste Management Paper No 26, Landfilling Wastes.* HMSO, London.
- UK Department of the Environment (1991) *Waste Management Paper No 27, Landfill Gas.* HMSO, London.
- UK Department of the Environment (1993) *Waste Management Paper No 26A, Landfill Completion.* HMSO, London.
- UK Department of the Environment (1995) *Waste Management Paper No 26B, Landfill design, Construction and Operational Practices,* HMSO, London.
- UK Department of Transport (1994) *Design Manual for Roads and Bridges Volume 10: Environmental Design: Section 4: Horticulture: The Wildflower Handbook.* HMSO, London.
- Van der Sloot, H.A., Heasman, L. and Quevauviller, Ph. (1997) *Harmonization of leaching/extraction tests.* Elservier, Amsterdam.
- Wallace, R.B. and Urlich, C.M. (1995) *Closure of landfills: future landuse.* Proceedings Sardinia 95, Fifth International Landfill Symposium, S. Margherita di Pula, Calgliari, Italy; 2-6 October 1995.
- *Waste Management Act (1996)* Government Publications, Dublin.
- *Waste Management (Licensing) Regulations, 1997 (SI No. 133 of 1997).* Stationery Office, Dublin.
- *Waste Management (Licensing) (Amendment) Regulations, 1998 (SI No. 162 of 1998).* Stationery Office, Dublin.
- *Waste Management (Use of Sewage Sludge in Agriculture) Regulations, 1998 (SI No. 148 of 1998)* Stationery Office, Dublin.
- White, R.E. (1979) *Introduction to the principles and practice of soil science* (second edition). Blackwell Scientific Publications, London.
- White, R. J. and Brynildson, O. M. (1967). *Guidelines for management of trout stream habitat in Wisconsin: Technical Bulletin No. 39.* Deptartment of Natural Resources Division of Conservation, Madison, Wisconsin, USA.
- Wild, A. (Ed) (1988) *Russell's soil conditions & plant growth.* Longman Scientific & Technical, Essex, UK.
- Wilde, A. (1993) *Threatened Mammals, Birds, Amphibians and Fish, Irish Red Data Book 2: Vertebrates.* HMSO, Belfast.
- Willoughby, I. and Dewar, J. (1995) *The use of herbicides in the Forest: Field Book 8.* The Forestry Authority, HMSO, London.
- Wilson, G. (1991) *Post closure problems on landfill sites.* In: *Practical Landfill Restoration and Aftercare of Landfill Sites,* Proceedings of a NAWDC Training Course, Welwyn, April 1991.

APPENDICES

APPENDIX A.
AMENITY RESTORATION AND AFTERCARE

A.1 INTRODUCTION

Amenity covers a multitude of afteruses which can range from nature conservation and informal recreation to formal sports, both water and land based. There are a large number of factors which are likely to influence the choice of afteruses for individual sites in amenity restoration and these include:

- regional and local strategies;
- county development and waste management plans;
- identification of local needs for formal or informal sports facilities through consultations with local sports bodies and communities;
- identification of local nature conservation requirements through consultations with various regional and local nature conservation organisations;
- site specific technical aspects;
- long term management requirements;
- cost of restoration;
- specialist provision for access (including disabled);
- educational potential; and
- environmental designations and management plans for sensitive areas e.g. SPAs, Proposed NHAs, Proposed SACs, National Parks, areas of landscape/scenic value, river catchment plans.

A.1.1 ENVIRONMENTAL DESIGNATIONS

The restoration of landfill sites must take account of any existing or proposed environmental designations in and/or adjacent to the landfill. It is intended that the development of future landfill sites will avoid areas where certain environmental designations exist or are proposed. Currently in Ireland a number of existing landfill sites occur in or adjacent to some formal designations. Many of these older sites were operated on the principle of dilute and disperse and therefore have the potential to cause ongoing environmental pollution. There is therefore a requirement to introduce appropriate and site specific mitigation measures to reduce the impacts of the pollution from these existing landfill sites. Any proposed mitigation measures will be governed by existing or proposed legislation.

Environmental designations of importance include:

- Natural Heritage Area (NHAs proposed)

The NHA designation is the base of the system for protection of Irish natural habitats. All other nature designations overlap with NHAs. The NHA is a proposed designation and has no legal basis until the Wildlife Act has been amended and adopted. However, the prevention of some damaging activities will be covered by the Planning Acts;

- Special Protection Areas (SPAs)

Since 1981, Ireland has been legally required to designate sites under the Birds Directive (EU Directive 79/409/EEC on the conservation of wild birds) to protect bird species and their habitats because of their rarity or vulnerability.

The current legal backing for SPAs is now the EU Directive 92/42/EEC on the conservation of natural habitats and of wild flora and fauna (Habitats Directive). This supersedes the Birds Directive and the Conservation of Wild Birds Regulations (SI No. 291, 1985). Ireland is obliged to *"take appropriate steps to avoid pollution or deterioration of habitats or any disturbances affecting the birds.....".* Designation of sites which qualify as SPAs is mandatory. This legislation also requires the avoidance of pollution or deterioration of habitats generally, outside specifically protected sites;

- Special Area of Conservation (SACs - proposed)

Proposed Candidate Special Areas of Conservation are currently being designated under the EU Directive 92/43/EEC on the conservation of natural habitats and of wild flora and fauna and which has been adopted into Irish legislation as the EC (Natural Habitats) Regulations (SI No. 94 of 1997). The main aim of the Habitats Directive is to conserve the best examples of natural and semi-natural habitats and species of flora and fauna throughout the EU. Each SAC must be given sufficient protection so as to conserve adequately the listed habitats and/or species in the annexes of the Directive. A number of priority habitats are listed which deserve special attention. These include designated peatlands, sand dunes, limestone pavements, and turloughs. Permission for damaging developments in priority habitats may only be given for overriding health and safety reasons while permission for damaging developments in non-priority habitats may only be given for imperative reasons of overriding public interest *(Hickey, 1997)*.

A.2 AMENITY RESTORATION

The amenity and nature conservation afteruses listed below are covered in this manual. However, many of these afteruses are very specialised and cannot be dealt with in depth within the scope of this volume. Reference should be made to *Reclamation of Damaged Land for Nature Conservation* by Land Use Consultants & Wardell Armstrong, 1996, and other relevant literature for further details. Many sites will also provide for a combination of different uses e.g. some nature conservation areas will also provide opportunities for informal recreation and education for local communities. Specialist advice will be required and consultations between the landfill operators, restoration specialists and intended users will be paramount to the success of the restoration.

- Sports and Recreation
  - Sports Pitches or Playing Fields
  - Golf Courses and Pitch and Putt
- Nature Conservation
  - Wildflower and Grassland Meadows
  - Woodlands and Nature Conservation (covered in Appendix B)
  - Heathlands
  - Wetlands and Standing Open Waterbodies

A.3 SPORTS PITCHES

The requirements for sports pitches are very specific, particularly in relation to slopes, drainage and grass seed mixtures. Gradients are very gentle or flat and are therefore very sensitive to differential settlement. It is recommended that on sites where settlement is predicted that interim restoration be undertaken (see section 5.3.2). This should allow imperfections in the gradient to be corrected before final soil replacement and drainage. Integration of the environmental pollution control systems with the sports field layout and ancillary facilities is crucial. The gas and leachate management systems must be designed so that any above ground components are located off-pitch and away from other facilities.

In general, it is desirable not to build on land where biodegradable waste has been deposited. However, where building occurs the use of appropriate engineering technologies and structures is essential. The potential hazards associated with any development on restored landfill sites must be clearly understood and taken into account during the design of the sports facilities. The potential hazards of landfill gas are mostly associated with the asphyxiating and explosive properties of methane gas and the asphyxiating properties of CO_2 and depletion of O_2. An active gas extraction system may need to be installed incorporating alarm systems. Continuous gas monitoring will also be essential. Further details on the potential hazards associated with built structures on landfill sites is given in Appendix D.

As with all other end uses, the persons responsible for the management and the long term aftercare of the end use must be clearly listed in the siteís aftercare plan.

A.3.1 LANDFORM AND DRAINAGE

The landform and drainage requirements will be site specific but will include the following features:

- pitch size will vary depending on use. The dimensions for various playing fields are listed in Table A.1.;
- the surface should be well drained, stable and free of irregularities;

TABLE A.1 SIZE SPECIFICATION FOR PLAYING FIELDS

Type of Pitch	Length (metres) Minimum	Length (metres) Maximum	Width (metres) Minimum	Width (metres) Maximum
Gaelic Football and Hurling	130	145	80	90
Camogie	95	110	60	80
Hockey, rugby, soccer etc.	95	100	60	65

- the slopes should encourage surface runoff but not interfere with use. Standard slopes are:

  - 0.6° (1 %) across the line of play; and

  - 0.6° (1 %) along the line of play;

- the soil profile should be ripped to alleviate any soil compaction that may occur during replacement (see section 4.4.9); and

- effective drainage is mandatory and the exact specifications will depend on the individual site conditions. Designing and installing a drainage system for playing fields requires specialist skills.

A.3.2 SOILS AND CULTIVATION

In general, playing fields require light textured soils with a high percentage of sand. Ideally, sandy loams and/or loamy sands should be used with a mix of 3 parts sand to 1 part topsoil being most suitable. These soils should be reasonably fertile to promote good grass growth and hard wearing surface capable of withstanding heavy use and wear in all weather. All-weather sand carpet designs are also available.

- topsoils - 150 mm over inert and capped waste sites

- subsoils - 1 meter of subsoil over inert and capped waste sites

The topsoil should be cultivated using harrows and rolled after seeding. Specialist advice should be sought during the placement of soil. All gravel and stones should be picked and removed from the surface soil to avoid injuries to players. This must be done by raking the surface soil layer prior to seeding.

A.3.3 VEGETATION ESTABLISHMENT

An ideal playing field should establish quickly, provide a smooth surface and have the ability to tolerate and recover from high levels of wear. Most grass mixtures are based on late heading, prostrate perennial grasses with the inclusion of species with rhizome growth to encourage rapid infill where damage has occurred to the sward.

An example mixture would include:

50% *Lolium perenne*
20% *Poa pratensis*
20% *Festuca rubra*
10% *Agrostis tenuis*

Sowing rate: 200 kg/ha

Once the grass has been sown, regular checks should be made of the condition of the sward and the efficiency of the drainage system. The following maintenance operations should be carried out:

- mowing is an important part of establishment as it encourage the grasses to tiller and cover the bare ground. Grass should be maintained at 20 - 35 mm height;

- fertiliser should generally be applied at establishment and usually on an annual basis thereafter however, this should be confirmed by soil analysis. The fertiliser application should be split into two or more applications and should supply in the region of 45 kg N, 10 kg P and 45 kg K/ha/yr.; and

- weeds will need to be controlled and an appropriate herbicide should be used at the correct time. All manufacturers recommendations should be followed in relation to application rates, timing, health and safety and environmental protection.

A.3.4 LONG TERM AFTERCARE

The long term aftercare of playing fields involves two basic components, vegetation management and use management. Long term vegetation management of sports pitches will be determined by the sport standards required and the frequency of use, e.g. hockey requires a more level playing field than camogie. Regular sports pitch maintenance includes mowing, spiking to improve soil aeration, drainage maintenance, rolling, top dressing with fertiliser, scarifying, weeding and general repair work.

The management of the ancillary facilities will include maintenance of the club house and/or changing rooms, storage and maintenance of equipment and marking out.

A.4 GOLF AND PITCH AND PUTT COURSES

The restoration of landfill sites to golf or pitch & putt courses will require specialist skills particularly in relation to design, drainage, landform, and the establishment and maintenance of vegetation especially on the tees and greens *(Adams and Gibbs, 1994).* Rough areas can be developed as semi-natural habitats and consideration should be given to the provision of informal recreation possibilities such as pathways, orienteering and cross country running.

A.4.1 LANDFORM AND DRAINAGE

The landform and drainage requirements will be site specific and will depend on the size of the intended course. In general, a rolling topography will be required with a variety of indents e.g. tree belts, hedges, water bodies etc. The area required will depend on the golfing facility to be constructed.

- Size:

- 18 hole	50 - 60 ha
- 9 hole	25 ha
- par 3 18 hole	10 ha
- pitch and putt	2 - 4 ha
- driving range	1 - 2 ha

- Good drainage is critical and slopes should avoid the creation of damp hollows and frost pockets. Gradients should be in the range of:
  - minimum gradient 1° (1:60)
  - maximum gradient 14° (1:4)

The drainage system will require maintenance and should be regularly checked for efficiency. Further details on drainage design is given in section 2.3.5 and in the Agency's manual on *Landfill Site Design.*

A.4.2 SOIL AND CULTIVATION

In general, golf courses will require topsoils which are slightly acidic, well textured and stone free. Specialist advice should be sought in relation to the most appropriate soils for the various areas of the golf course i.e. fairways, tees etc. High fertility soils are not usually required.

The depth of soils will also vary according to areas and features being constructed but in general

- topsoil: minimum depth 150 mm (after placement)
- subsoil: minimum depth 1000 mm (after placement)

Subsoil ripping will be required to alleviate any compaction that may occur during soil replacement. See section 4.4.9 for further details. The type of cultivations and the machinery required will again be determined by the areas which are cultivated. Cultivations will normally be carried out by a tined cultivator and after sowing, the seed bed should be firmed around the seeds using a roller. All stones and gravel should be removed prior to seeding.

A.4.3 VEGETATION ESTABLISHMENT

The grass seed mixtures required will differ according to the areas being planted. For fairways fine turf is required with a proportion of grasses with rhizomes e.g. *Festuca rubra* to give quick establishment and recovery from divot scars. The grass should also be relatively hard wearing. Roughs can be developed as semi-natural habitats. An example of species included in a fairways grass mix would include:

40% *Festuca rubra* ssp. *commutata*
35% *Festuca rubra* ssp. *litoralis*
15% *Poa pratensis*
10% *Agrostis castellana*

Sowing rate: 180 - 300 kg/ha

Trees and shrubs should be planted for landscape reasons as well as adding to the course features. Care should be taken in choosing appropriate species, planting patterns and maintenance of the trees to avoid excessive shading of the newly planted grass mixtures. Trees should be protected against bark stripping by mowing machinery, strimmers and/or wildlife. A weed free area of 1 metre diameter around individual trees will promote good growth and establishment. Specialist advice on the tree and shrub species appropriate to golf courses should be sought.

Mowing: Tees and greens will require high level inputs with mowing up to 5 times/week with regular rolling, scarifying, spiking, weed control and fertilising. The optimum height on the fairways is 20 mm while maintenance of the roughs will depend on the desired vegetation characteristics.

Fertiliser: fertiliser applications should be made depending on the mowing regime and results from soil analysis. Fertiliser is usually applied in the form of artificial compound, N-P-K fertiliser and the rate of application will be site specific. The application should be split and carried out twice per year.

Weed control: weeds will need to be controlled in all areas, particularly on the fairways, greens and tees. Any noxious weeds should be spot treated. Weed control in tree areas is also important (see Appendix B.7.2).

A.4.4 LONG TERM AFTERCARE

As with all other end uses, the persons responsible for the management and the long term aftercare of the end use must be clearly listed in the site's aftercare management plan. To achieve successful restoration to golf courses it is essential that people with specialist skills are employed during the implementation of the restoration plan and subsequent management. For example, the long term aftercare of golf courses will require professional green keepers. These will be responsible for the maintenance of the course. It is generally recommended that an 18-hole course will require 4 to 5 full time greenkeepers, while a 9 hole course will require 2 to 3 greenkeepers. The maintenance works required will include mowing, weeding, rolling, fertilising, remedial repairs to grass surfaces, spiking etc.

Long term aftercare involves the management of the ancillary facilities. These will include the built structures i.e. clubhouse, changing rooms, bars etc. Infra-structures that require maintenance include car parks, linked pathways and provisions for informal recreation.

The potential hazards associated with any development on restored landfill sites must be clearly understood and taken into account during the design and construction of ancillary facilities. The potential hazards of landfill gas are mostly associated with the asphyxiating and explosive properties of methane gas and CO_2. An active gas extraction system must be installed incorporating an alarm system on sites where biological degradation of waste occurs. Continuous gas monitoring will also be essential. See Appendix D for further details on restoration to hard end uses.

A.5 NATURE CONSERVATION

A.5.1 INTRODUCTION

The establishment of areas of nature conservation can be a highly effective afteruse for restored landfill sites and may allow for multi-purpose use e.g. providing bird watching hides close to a habitat created to attract wildfowl. Restoration can lead to the creation of new habitats providing the opportunity for increased biological diversity. Equally important is the necessity to consider important habitats requiring protection during the site selection process and the introduction of appropriate mitigation measures. For example in some instances there may be cases where species translocation is a feasible option e.g. badgers, newts, plant species etc. The translocation of protected species requires a licence under the Wildlife Act; these are issued by Dúchas, The Heritage Service. In the case of existing sites and sites outside the licensing system, the works required may involve habitat reconstruction and improving insensitive works carried out during site development e.g. realignment of watercourses.

Equally, through natural colonisation, many areas of damaged land will have developed highly valuable habitats which support locally, regionally or nationally rare species and habitats. Where there are existing nature conservation interests and/or where habitat creation is proposed, a professional ecologist should be a member of the restoration team.

When integrating nature conservation and mitigation proposals into any restoration scheme, some key principles need to be considered throughout the lifecycle of the landfill from planning and design through to the aftercare management plan. Consideration should be given to the following:

- planning should allow for any extra land requirements which are needed for offsite habitat re-creation due to habitat destruction during landfill development. This would be applicable for wetland areas and standing open water bodies which greatly increase the landfill's visual and wildlife interests but should not increase the risks of increasing leachate volumes. Ponds and wetlands can be considered on inert landfills and at the edges of sites outside the landfilled areas;

- consultations with all relevant nature conservation bodies e.g. Dúchas and the Central and Regional Fisheries Boards;

- views of local communities;

- incorporation of existing nature conservation interest within the site and surrounding the site e.g. existing habitats may provide seed sources for restored areas;

- use of native species (wildflowers and trees) and other species common to Ireland;

- the influence of the size of the site - in general, the larger the site the greater the likelihood that nature conservation can be successfully integrated with other uses, the smaller the site the greater the care required to ensure that other uses do not destroy the nature conservation interests;

- timescales - for nature conservation, restoration timescales are an important consideration particularly on sites which are highly visible and considered an eyesore and where natural colonisation is used. It also provides an opportunity to use trial plots to assess vegetation establishment success;

- aftercare management - nature conservation sites will require specialist management of both habitats and use. Where sites are well used or where environmental education/community involvement is a primary objective, wardening becomes critical; and

- monitoring - monitoring will be required to determine whether nature conservation objectives are being achieved. This will enable corrective measures and/or alternative options to be investigated in the event of failure.

A.5.2 ESTABLISHMENT TECHNIQUES

Numerous techniques have been and are currently being developed for plant establishment and habitat creation on damaged land. The techniques used will depend on site specific characteristics and the use of local and indigenous species, where available, is encouraged. In all cases, the use of native Irish seed sources is recommended. In choosing the appropriate establishment technique, specialist advice should be sought from landscape horticulturists. The types of establishment techniques include:

- encouraging the speeding-up of natural colonisation and succession;

- turf transplantation;

- soil/litter transfer;

- seed rich litter and green hay; and

- slot seeding, plug planting and live mulching.

Specific details on the above methods of establishment are given in *Reclamation of Damaged Land for Nature Conservation* by Land Use Consultants & Wardell Armstrong, 1996. It is important to ensure that the source areas are not designated under any existing or pending environmental designations.

A.5.3 WILDFLOWER MEADOWS

Wildflowers can be grown as a pure stand of wildflowers or in a mix with suitable grass species. Wildflowers mixed with commercial strains of grasses bred for vigour do not perform well under Irish climatic conditions as grass growth can be vigorous requiring greater maintenance. The types of species mix required will vary depending on prevailing site conditions and a suitable wildflower mix must take into account factors such as site drainage, soils types, pH, existing vegetation and fertility levels.

Wildflower meadows will also attract butterflies and can be used for creating or protecting essential wildlife corridors. It is important to use species which occur locally and are appropriate to the area. The landfill restorer should talk to Irish wildflower producers well in advance of sowing to enable seeds to be collected locally and used in seed mixes. This section will cover the general requirements for establishing wildflower meadows. For further advice on various wildflower meadows and establishment techniques refer to *Irish Wildflower Manual* by Design by Nature, 1998.

A.5.3.1 LANDFORM AND DRAINAGE

The landform and drainage requirements are site specific, but in general gentle undulating topography is ideal and this should blend in with the surrounding landscape. Substrates should be stable to minimise erosion.

A.5.3.2 SOILS AND CULTIVATIONS

Wildflower stands and wildflower meadows are most easily created on low fertility substrates with low available nitrogen and low available phosphorus. A scarcity of nutrients allows species with a wide range of growth rates to co-exist in a semi-stable equilibrium provided they are subject to appropriate mowing or grazing regimes which inhibit the more vigorous plants and undesirable invaders. Substrates suitable for wildflowers include very shallow topsoils (25 - 50 mm) and subsoils. Generally, relatively dry subsoils or soil forming materials of low fertility are ideal. However, wet soils are ideal for establishing wetland wildflower mixtures. Topsoils are generally not required and if soils are fertile the following management practices should implemented:

- a suitable species mix, such as yarrow and wild carrot, which will use up excess nutrients should be used. On slopes where there is a risk of soil erosion, species which form a dense fibrous/woody mat of roots (e.g. rhizomes) which can help bind the soil particles together should be planted e.g. yarrow and tussock grass;
- meadow should be cut regularly and cutting removed;
- nurse crops are used prior to sowing and during sowing to reduce fertility; and
- very fertile topsoil on smaller sites can be removed particularly in low rainfall areas where pure stand of wildflowers is being proposed.

Subsoil ripping may be required to alleviate soil compaction. A firm fine textured weed free seed bed is required and this can be achieved by harrowing and then rolling prior to seeding and roll again after seeding with a cambridge roller. The nutrient status of the soils should be assessed by soil analysis and any amendments, such as addition of organic matter should be added and harrowed in during cultivations. The nutrient status for restoration to wildflowers and wildflower meadows should be low to discourage the more aggressive tall plants, which would shade out many flower species. Correct moisture control during seeding is critical.

A.5.3.3 VEGETATION ESTABLISHMENT

The various methods for vegetation establishment include natural colonisation, green hay, turf transplants or conventional sowing with wildflower seeds.

- Seed Mix and Sowing Rates

Where baseline surveys have been undertaken, the species mix as recorded should be used in determining an appropriate site specific seed mixture. Wildflower seed mixes can comprise the following:

- wildflower species only (annuals, biennials and perennials). The annuals and biennials can act as a nurse crop for the perennials and will flower in the first years. The annuals and biennials may need to be cut to prevent the perennials from being smothered out. Sow at a rate of 15-20 kgs/ha which in certain cases should include a nurse crop;
- wildflower (annuals, biennials and perennials) and grass species. Grass species should be suitable for growing with wildflowers. Use species commonly found in Ireland. Mixes should comprise of 80% grasses and 20% wildflowers and should be sown at a rate of 40 kgs/ha;
- on very fertile sites 5 kgs/ha more flower seeds should be sown and on very infertile sites 10 kgs/ha less grass seeds except where grasses are used to help stabilise soils; and

- wildflowers should be obtained separately from grasses as the latter can be sown by machine and wildflowers sown by hand.

Ideally seeds should be collected from an existing local species rich grassland to ensure species of local genotype, again ensuring that the source area is not designated. Alternatively, a commercially prepared seed mix using Irish wildflower seeds and grass species common to Ireland should be used. Specialist advice should be sought on a site by site basis prior to choosing an appropriate seed mix.

Wildflowers and grasses species suitable for wildflower stands and wildflower meadows are listed in Appendix Q.

- Timing of sowing

Seeds can be sown at most times of the year prior to wet weather. The ideal sowing times are mid-August to late September or as late as October if the soil is above 4°C. Early autumn sowing should produce flowers the following year. Late autumn and spring sowing (Feb - May or up to June following a cold spring or wet conditions) will produce flowers after one year's growth. Specialist advice should be sought on sowing times.

- Weed control

Weeds can occur in meadows where the site was not properly cleaned prior to sowing. Invasive weed species such as docks, nettles, thistles and scutch grass will need to be controlled by spot application of herbicide or by hand pulling. Where weeds occur in larger numbers the use of a weed wipe is recommended when the particular weed grows above the meadow. These weeds are most likely to cause problems when soils have been imported or turf transplanting has occurred; however, regular mowing will reduce most weed competition as flowers lock up nutrients.

- Fertiliser

Ideally, trial plots should be established to assess nutrient requirements for establishment and aftercare as these are site specific and depend upon the nature of the soils/substrates used in restoration. This can be undertaken during the early stages in phased restoration. On very nutrient poor substrates an application of 20-30 kg/hectare N and 10 kgs/hectare P should be applied.

A.5.3.4 LONG TERM AFTERCARE

Intensive post-planting management is essential during the first three years to ensure successful establishment, and specialist advice should be sought. The timing of maintenance is critical and as a general rule for wildflower and grass mixes growth should be cut to 10 cm and the material removed when growth passes 15 cm. For pure wildflower stands cutting and removal of material should be done when growth height passes 20 cm. Except for annuals and biennials and nurse crops all sowings must be regularly mown in the first year especially where grasses are included in the mix. Cut hay should always be removed to prevent a matt developing on the surface.

Traditional wildflower meadows were managed by either grazing or cutting regimes and restored wildflower areas should aim to imitate the management practices which produced this diversity of grassland species. The removal of a flower's bloom does not harm the plants but ensures vigorous vegetative growth which results in a richer display in the successive year. The timing and intensity of cutting will depend on site and locality and should include a combination of cutting for hay and grazing. Sheep grazing is recommended rather than cattle grazing as this will reduce the risk of poaching. Where stray dogs are a problem, avoid using sheep.

Monitoring should be undertaken annually to assess germination and establishment rates and this will govern subsequent remedial works.

A.5.4 HEATHLANDS

A.5.4.1 INTRODUCTION

Heathlands are open, relatively treeless landscapes dominated by the dwarf shrub heather *Calluna vulgaris* (Ling) and *Erica* spp. Heathlands are characterised by thin acid soils of low fertility, which exhibit a degree of podzolisation and pH values in the range of 3.5 - 5.5. Heathland restoration should ideally be created on landfills where there are existing areas of heathland nearby which can supply a local source of seeds and vegetation. The aim of restoration should be to create the full complement of species (including non-vascular plants such as mosses etc.) appropriate to the location, topography and ground water conditions rather than just a cover of heather. Consideration should be given to other associated habitats during restoration particularly edge habitats of trees and scrub, acidic grasslands and ponds.

A.5.4.2 LANDFORM AND DRAINAGE

The restored heathland should blend in with the surrounding landscape. Surface erosion is a major problem in the restoration of heathlands. Young heather seedlings can be washed away or suffer root exposure as a result of sheet erosion, rain splash or frost heave. Methods used to reduce soil erosion include use of companion crops, forestry brashings or cut heather shoots. It is important that the landform provides the appropriate drainage conditions for heathland establishment.

A.5.4.3 SOILS AND CULTIVATIONS

Heathlands develop on acid soils which have a degree of podzolisation and have pH range of 3.5 - 5.5. This habitat type is found in Ireland in association with peaty podzols, lithosols and outcropping rock, brown podzolics and lithosols i.e. soil associations 1,4, 9 and 23 as specified in *Soil Associations of Ireland and their Land Use Potential* by Gardiner and Radford. A heathland soil profile is typically stratified into distinct horizons, with a peaty humic layer. The depth of soil required is very site specific and is dependent on the establishment technique used. Heathland soils can be very shallow with the upper peaty organic layer usually less than 150 mm depth. However, if soil or turf transplant is the method (see section 9.5.2) used then the quantity of soil required will be equivalent to the amount present on the donor site.

The degree of subsoil ripping required to alleviate compaction will be dependent on the type of heathland to be established i.e. dry or wet. In areas where heather litter or natural colonisation is used to establish the vegetation, a firm friable seed bed should be created by cultivating to 100 mm depth.

A.5.4.4 NUTRIENT REQUIREMENTS

The amount of nutrients required will depend on existing fertility levels in the replaced soils. Soils on which heathlands are found are usually deficient in available phosphorus and nitrogen. Ideally, field trials should be carried out prior to full scale restoration to determine the quantity of nutrients required for successful restoration. The aim should be to provide enough phosphorus for heathland species *Calluna and Erica* but to avoid excess applications as this will encourage competition form sown nurse crops and grasses. Occasionally where very acidic condition exist in the soils, some lime application may be required.

A.5.4.5 VEGETATION ESTABLISHMENT

Heathland vegetation is dominated by evergreen dwarf shrubs, in particular members of the heather family. The exact species composition of heathers, grasses and species such as bilberry, gorses etc., will depend on the soil characteristics, drainage, altitude and geographical location. The aim should be to restore species native to the locality and suited to the condition of the site. Various methods have been used to successfully establish heathland vegetation on restored landfills (refer to *Land Use Consultants & Wardell Armstrong, 1996* and *Putwain and Rae, 1988* for further details on establishment techniques). These include:

- natural colonisation;
- heathland turf transplantation;
- heathland topsoil transfer;
- harvested heather litter/heather shoots; and
- commercial transplants.

The method used is site specific; however, the use of local shoot source is recommended. Turf transplant and soil transfer require a donor site and the use of these techniques should be driven by the need to salvage an existing habitat which is to be lost rather than the need for habitat creation. Donor sites which have existing or pending environmental designations should not be used. Natural colonisation is appropriate on sites lying close to areas of existing heathland. The use of heather litter does not require the destruction of an existing habitat.

- Nursery Species

Companion species may be sown to stabilise bare soils and provide a suitable micro-environment at the soil surface to encourage germination. It is important that the companion species does not produce a dense sward which will suppress heather establishment. Suitable grass species include:

Agrostis canina	Bent grass
Deschampsia flexuosa	Wavyhair grass
Festuca ovina	Fine leaved sheeps fescue
Festuca rubra ssp *commutata*	Chewings fescue

Sowing rate: sowing rates should be low at approximately 20 kgs/hectare.

Where the substrate is prone to erosion, the newly sown heathland area can be covered with a light covering of forestry brashings (lower branches of trees removed to allow access for thinning in forestry). An alternative is to use synthetic materials such as 'Geojute' pegged over the soils.

A.5.4.6 LONG TERM AFTERCARE

All aftercare management requirements should be guided by the aftercare management plan which should detail the vegetation and ecological management for the restored heathland. Monitoring of the heathland will be required to assess the results of the restoration. Aftercare management will include:

- Protection/fencing

Newly established heather is very sensitive to damage particularly from trampling. Restored areas will require fencing to keep grazing animals out during the first 5 years.

- Weeding

The disturbance of heathland topsoil may encourage the germination of species such as *Betula pendula* (Silver birch) or *Betula pubescens* (Downy birch), *Ulex* (Gorse or Furze) and *Juncus* spp. (Rush family). Of particular concern is common gorse *(Ulex europaeus)* and Rhododendron *(Rhododendron ponticum)*. Common gorse can be a fire hazard and rhododendron is a very invasive exotic weed. It is important when carrying out weed control to distinguish between common gorse *(Ulex europaeus)* and western or autumn gorse *(Ulex galii)* which is a low growing member of Irish heath communities and which does not present the same fire risk as common gorse. Gorse control on restored landfill sites will be necessary particularly where the restored landfill is close to forestry plantations and/or private dwellings. Thistles and docks may also grow in response to fertiliser application; therefore, hand pulling or spot treatment with herbicide will be necessary to remove unwanted species.

- Fertiliser

On most sites no further fertiliser will be needed as soil fertility must be kept low to control the growth of the nursery crop. However, on very nutrient poor sites, some fertiliser may be required 2 to 3 years after restoration. A slow releasing fertiliser with a relatively high P content should be used.

- Grazing/Cutting

Heathland is traditional managed by grazing, burning or cutting. Grazing should be excluded for the first 5 years after restoration to allow the vegetation to establish. Ideally, management should create a range of age classes within the heather and also provide fire breaks. Burning on restored landfill sites is not recommended. Grazing is usually the best technique for maintaining traditional heathland plant communities. The choice of grazing animal i.e. sheep, cattle, horses etc. and stocking density will be determined by site specific characteristics such as the age of the heather, the proportion of grass species present and local climate. No more than 40% of the current year's growth should be removed.

A.5.5 WETLANDS AND PONDS

A.5.5.1 INTRODUCTION

Wetlands and ponds greatly increase a restored landfill's visual and wildlife interest. Wetlands and ponds are important as habitats for a range of breeding and wintering wildfowl and waders, invertebrates, marginal and aquatic vegetation, amphibians and fish. Wetlands and ponds should be considered on non-landfill areas surrounding the site, on areas designated and set aside during the planning phase and/or on sites accepting inert waste. Reedbeds can also be used to facilitate settlement of sediments and the retention of some pollutants. Wetlands are usually associated with poor drainage and are underlain by soils with a fairly high clay content or over a high watertable. Wet grasslands typically contain grasses and herbs adapted to seasonal or permanently waterlogged conditions.

When designing wetland and ponds it is important to recognise the continuum of habitat types and the vegetative stages associated with succession in

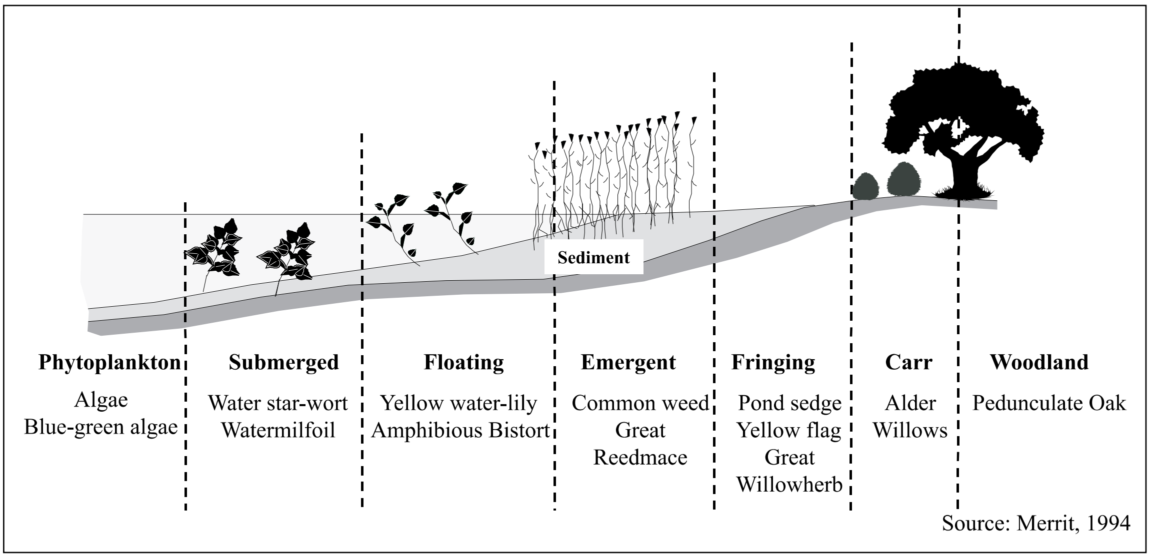


FIGURE A.1 ILLUSTRATION OF VEGETATION STAGES OF WETLANDS AND PONDS

shallow ponds. Figure A.1 illustrates the vegetative stages associated with wetlands and ponds and the zones used to describe classes of wetland vegetation i.e.

- aquatic - phytoplankton, submerged and floating - e.g. algae, water star-wort, yellow water lily;
- marginals/emergents - e.g. common reed, amphibious bistort;
- fringing - e.g. pond sedge, great willowherb;
- carr - e.g. willows, alder; and
- woodland - e.g. oak, ash, birch, rowan.

Water bodies of greatest value to wildfowl are those with large areas of shallows, supporting emergent species. The zone of the pond which has the greatest potential for making shallow feeding sites is the shoreline.

All sizes of water body can be valuable for nature conservation, although some species require large areas for feeding/breeding. Generally, the length of edge and proportion of shallows will be more important than the surface area of the water. A varied and irregular shoreline including peninsulas and islands with their long axes running at right angles to the prevailing winds is recommended. Figure A.2 illustrates various shorelines and Figure A.3 illustrates some appropriately shaped islands designed to encourage colonisation by birds. Good water quality is important with the ability to control and alter water levels using sluices etc. Public access may need to be restricted during the breeding season.

A.5.5.2 LANDFORM

- Depth

The principal requirement for wildfowl is the creation of extensive areas of shallows up to 1500 mm deep which provides good feeding conditions by supporting marginal and emergent species and which may take up to two thirds of the total water area. An uneven lake bed is desirable for biological productivity and habitat diversity. The facility to alter the water level is important.

- Shoreline and Islands

A varied irregular shoreline with sheltered bays, peninsulas and low profile islands is important for birds. Roosting areas are provided by forming long islands or peninsulas having their long axis at 90° to the prevailing winds. These islands should have bare, rocky or shingle beaches for loafing birds on their downwind side. These should be arranged in staggered rows across the pond so that the shelter produced by one island overlaps the next. The ideal shapes for islands is a horseshoe or semi-circular atoll or cruciform shape with the mouth facing away from the prevailing winds as illustrated in Figure A.3.

A variety of underwater habitats should be created during restoration e.g. by covering the pond bed

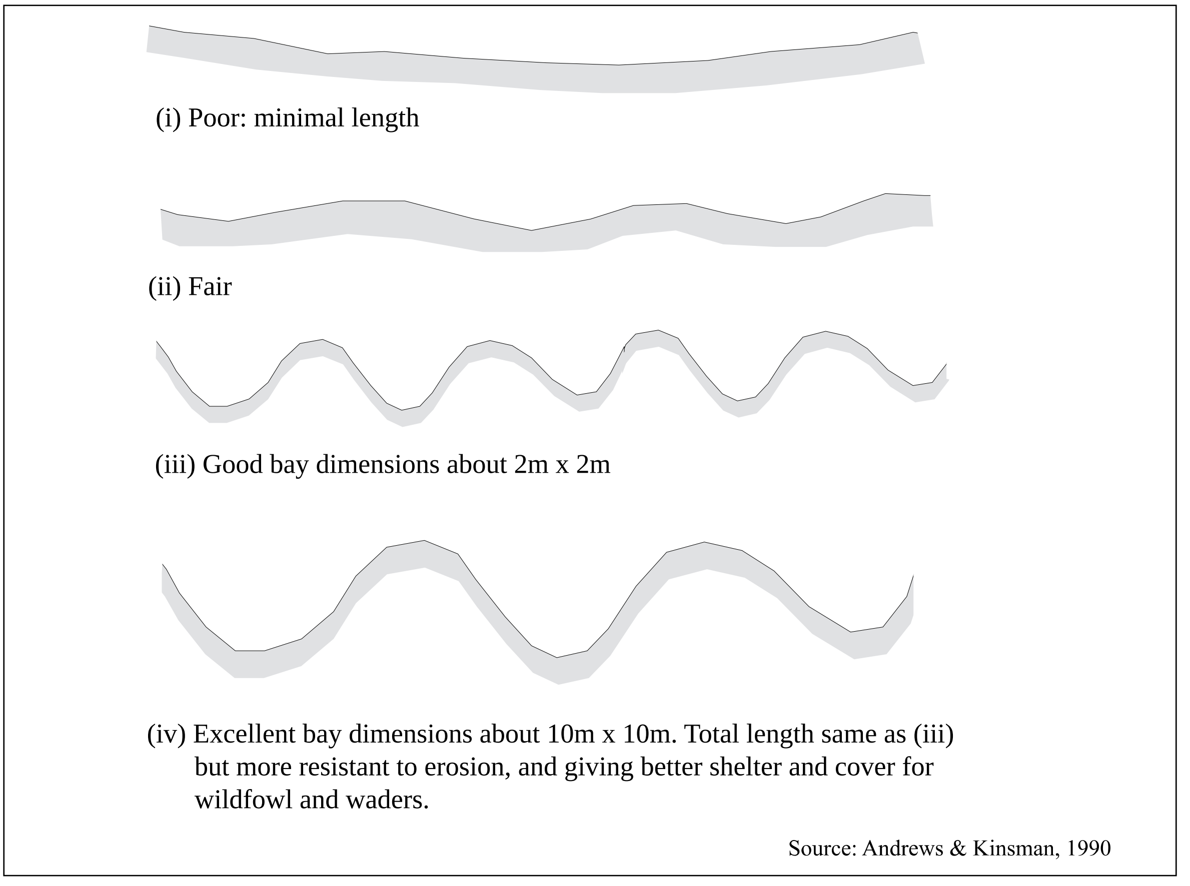


FIGURE A.2 ILLUSTRATION OF SHORELINES OF WATER BODIES

with 150 - 200 mm layer of sand, gravel or large boulders.

- Banksides

The shore gradient should be as gentle as possible, ideally 1 in 5 or less, right down into deep water. Figure A.4 illustrates the appropriate bankside gradients. Where marginal vegetation needs to be contained, a sharp change in gradient to greater than 2m depth will help.

- Water Level Control and Water Quality

Water level control can be achieved by the use of sluices, dams, bunds etc. The ability to control water levels is important for effective management. Good water quality will allow maximum light penetration for the growth of submerged plants. Methods for improving water quality include use of silt traps, settling ponds, reedbed treatment etc.

- Fringe Habitats

Manipulation of the land surrounding the pond is critical to encourage a natural progression of habitat types. Screening and shelter can be provided by appropriate tree planting and bund construction. A security dyke around the site can reduce disturbance and poaching. Approaches to any hides should be screened to allow people access without being seen.

A.5.5.3 SOILS

Soils are not essential for the establishment of aquatic plants. However where the primary aim is to attract wildfowl the addition of 300 mm topsoil to planting bays and 150 mm of topsoil across the lake bed can boost nutrient levels, provide a food source for organisms and increase the rate of plant growth. The composition of soils used to create islands should reflect the species of birds that are intended to occupy them e.g. estuarine birds (with long bills) require soft soils while turnstones require a stony substrate. Care should be taken with nutrient additions as this may cause eutrophication and de-oxygenation. Prior to any additions of soil, a soil analysis and a nutrient budget should be carried out.

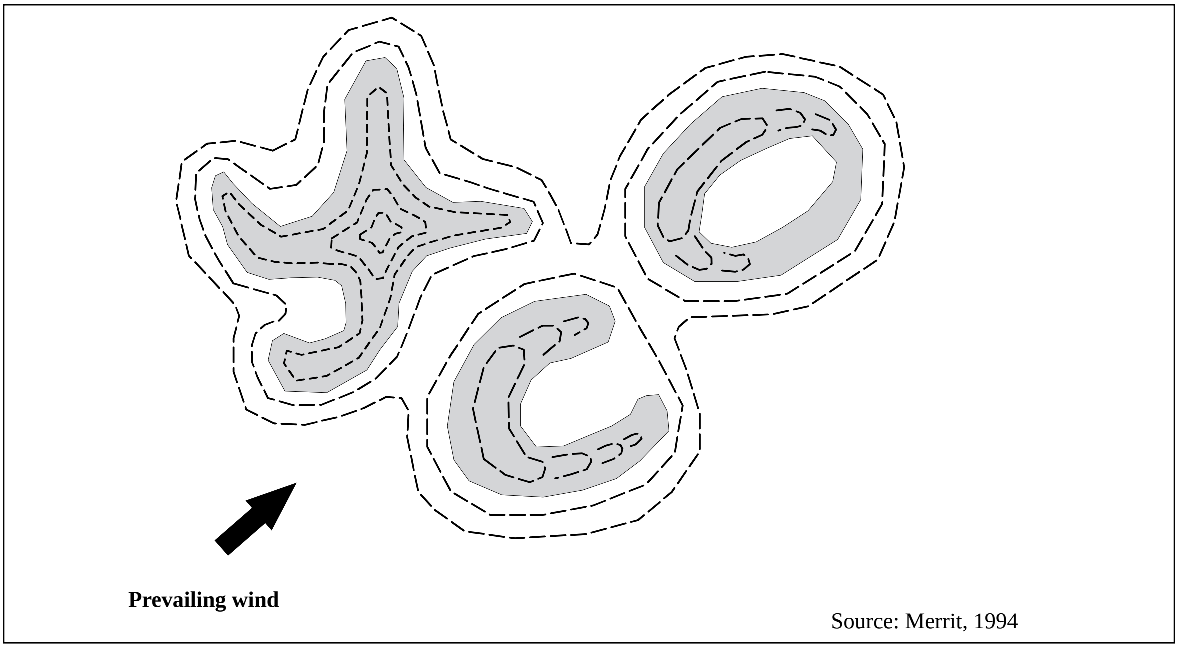


FIGURE A.3 ILLUSTRATION OF SHAPES OF ISLANDS SUITABLE FOR BIRDS

Fertile uncompacted topsoils should be spread on the banks to produce areas of nutritious grasses for herbivorous waterfowl. In areas designated for tree planting alleviation of compaction and good drainage are essential. Reference should be made to Appendix B for more details on tree planting and management.

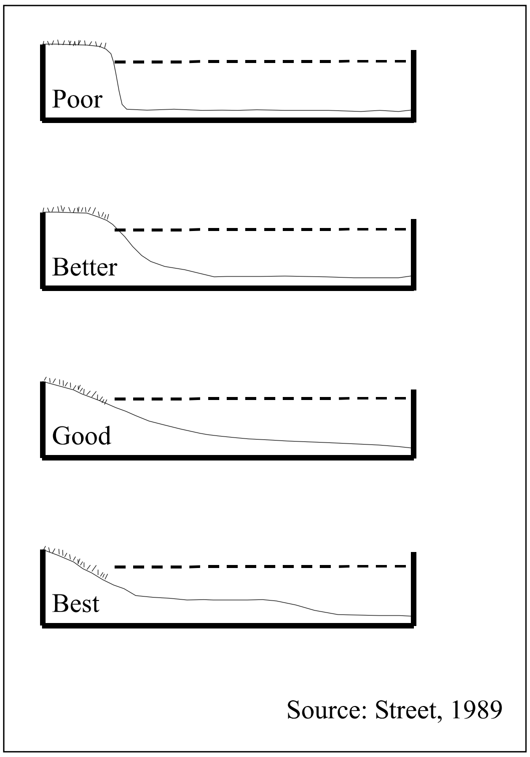


FIGURE A.4 ILLUSTRATION OF BANKSIDE GRADIENTS APPROPRIATE FOR WILDLIFE

A.5.5.4 VEGETATION ESTABLISHMENT

Different species are required for each ecological niche and should include:

- submerged plants to produce food and habitat for insects;
- emergent and marginal plants to provide screening, cover and shelter;
- grasslands to produce grazing ; and
- trees and shrubs for nesting cover and shelter.

Appendix R lists appropriate species for planting in wetlands and ponds.

Newly created water areas will very quickly revegetate by natural colonisation. This will need to be controlled, otherwise the resultant plant community will be dominated by only a few species e.g. willows and reedmace, thereby reducing habitat diversity.

Various methods of planting can be used and these will be determined on a site by site basis. Suitable plants should be selected from existing stands growing locally, if available; however, specialist advice should be sought prior to removal and planting. Marginal and emergent plant rhizomes can be lifted by digging or pulling with a fork and these roots must be kept moist and transplanted quickly. The rhizome sections can be trampled or pushed into the soil just above the waterline. Submergent and floating plants should be planted at depths similar to those at which they were collected ensuring the shoot tip is above the water. Floating plants can simply be thrown out onto the water. Some submerged plants will grow from cuttings, others produce tubers or over-wintering buds and these can be collected in autumn and broadcast onto the water.

A.5.5.5 LONG TERM AFTERCARE

An aftercare management plan should be drawn up outlining the management requirements and the personnel responsible for the maintenance. Aftercare maintenance will include:

- control of succession and invasive weeds;
- mowing and grazing of bankside and surrounding vegetation;
- maintenance of newly planted trees;
- specific areas for management including banksides, islands, vegetated and open shallows; and
- monitoring of water quality and controlling water levels.

Over longer periods, a water body may start to dry out because of silt deposition. This would eventually result in natural succession to woodland. This is more likely to occur in shallow areas or where siltation rates are high. Silt traps can be built to catch the silt prior to entering the water and when required, dredging of the ponds will remove accumulated organic matter. Where the conservation of wildfowl is not the primary objective, allowing natural succession to occur can be beneficial, creating a succession of habitat types over time.

A.5.6 WATERCOURSE REALIGNMENT AND IMPROVEMENTS

A.5.6.1 INTRODUCTION

Watercourse realignment involves replacing existing channels with a completely new one and on most landfill sites this should be avoided where possible. However, in situations where this is unavoidable or where degradation of existing watercourses has already occurred an opportunity exists for habitat enhancement and/or creation. The new alignment should mirror as closely as possible the image of the original channel, therefore the implementation of a ‘mirror image’ scheme is usually the best initial approach to channel realignment.

A.5.6.2 SURVEY REQUIREMENTS

Prior to undertaking any realignment or enhancement works on site, a survey of the existing stream and/or river features should be undertaken. This will establish the wildlife value of the watercourse and give an understanding of the physical processes operating in the location. It is essential for anyone intending to undertake watercourse realignment or construct by-pass channels to be able to identify and understand the hydrological and ecological link between rivers and floodplains, river morphology and fluvial processes. Surveys which should be undertaken on existing and/or new landfills include:

- river morphology survey;
- river corridor survey;
- plant surveys;
- otter survey;
- bird survey;
- fish stock assessment and survey;
- invertebrate survey; and
- amphibian survey.

For further details on survey methodology refer to *The New Rivers and Wildlife Handbook*, 1994 published by The Royal Society for the Protection of Birds, the National Rivers Authority and the Royal Society for Nature Conservation. Other useful references include *Restoration of riverine trout habitats: A Guidance Manual, The Game Conservancy Trust, Fisheries Technical Manual 1* by Environment Agency, UK, 1996., and *Guidelines for Management of Trout Stream Habitat in Wisconsin - Technical Bulletin Number 39* by White and Brynildson, 1967.

Environmental conservation and enhancement opportunities should be integrated into the design. Specialist skills will be required and all relevant bodies should be consulted including:

- Central and Regional Fisheries Boards;
- Dúchas, The Heritage Service;
- Hydrometric Section of the Office of Public Works;
- Local authorities; and
- Local wildlife and angling groups

A.5.6.3 REALIGNMENT CONSIDERATIONS

For any realignment or by-pass works to be successful the following steps should be undertaken *(RSPB, NRA and Wildlife Trusts, 1994)*:

- check existing and pending environmental designations e.g. salmonid water designation;
- consider all options available on site for the realigned channel e.g. old meander traces can offer alternative routing on site;
- the same length of channel (or more in previously shortened rivers) must be created to preserve the gradient of the river and facilitate the re-establishment of a regime similar to the original;
- a natural channel should be excavated i.e. steep cliffs on the outside of bends, shoals on the inside, with variable bed levels and few straight lines;
- riparian zones occupy the transitional zone between the aquatic and terrestrial environments and offer diverse habitats for wildlife. Planting design should recognise the continuum of habitat types from trees lining the banks to floating and submerged plants;
- where possible existing species should be translocated to the new alignment and the river allowed a chance to settle into its new geometry prior to replanting riverside vegetation. Natural regeneration will occur over time and this should be assisted where appropriate;
- exposed soils vulnerable to erosion will require some form of protection. This can take the form of flat batters or revetments. Specialist advice should be sought from the Central Fisheries Board and/or the Engineering Section of The Office of Public Works. If revetments are required, live timber that will grow and consolidate the bank over time should be used;
- bed levels should be raised locally to avoid exposing sands and gravels which are prone to erosion but create shallow riffles where exposure is safe;
- regional fisheries boards should be called in to carry out fish rescues prior to the closure of the original channel; and
- it is important not to impose a precise and fixed geometry to the river and time should be devoted to on-site variation as work proceeds.

APPENDIX B. WOODLAND RESTORATION AND AFTERCARE

B.1 INTRODUCTION

Tree planting and woodland establishment on restored landfill sites provide an attractive form of restoration. Appropriate tree planting and woodland establishment on landfill sites have the potential to integrate the site with the adjoining land uses, enhance local landscapes, improve wildlife habitat and species diversity, and offer an opportunity for amenity and recreation. On most restored landfill sites some degree of tree planting will occur. The principal objective of tree planting is landscape integration. This usually includes the planting of hedgerows, individual trees, perimeter screening and relatively small areas of tree and shrub planting. Other factors which need to be considered include:

- the capping system;
- the type of wastes accepted by the site;
- the expected settlement rates;
- integration with the environmental pollution control systems;
- land use zoning/development plans;
- local community needs; and
- public access.

B.2 RECENT RESEARCH FINDINGS

In the past, concern was expressed with regard to the potential damaging effects of tree roots on the capping system of landfills and as a result tree planting was discouraged. Early research work examined the rooting patterns of individual tree species and factors which influence root penetration. The research found that although genetically inherited characteristics play an important role in determining root distribution, the modifying effects of site and, in particular, soil conditions are of far greater importance in determining rooting depth than genetics. Root depth is determined ultimately by the ability of the tree to maintain root growth when the soil conditions are limiting. Roots will grow in that part of the soil where moisture, aeration and mechanical properties are favourable.

Recent research work carried out by the Forestry Authority in the UK *(Dobson & Moffat, 1993, 1995, and Bending & Moffat, 1997)* has concluded that tree planting on restored landfill sites which have accepted biodegradable wastes should be encouraged, subject to certain recommendations. The main findings and recommendations include:

- a 1.0m thick clay cap compacted to a bulk density of 1.8 to 1.9 tonnes/m^3 achieving a hydraulic conductivity of 1 x 10^{-9} m/s is capable of preventing root penetration. However, a synthetic barrier layer should be used to augment the effects of the clay cap on areas intended for tree planting, unless it can be shown by physical analysis in the field and laboratory that the recommended requirements for clay densities and permeabilities have been met;
- in all instances where a drainage layer is employed above a clay cap, a geotextile membrane should be placed above the permeable fill beneath the area to be planted;
- there should be 1 metre minimum depth of soil cover (both topsoils and subsoils) after placement on all areas to be planted; and
- only tree species which can be grown without threatening the integrity of the capping system and that are suitable to environmental conditions present on individual sites should be planted. Poplars *(Populus* spp*)*, crack *(Salix fragillis)* and white willows *(Salix alba)* are not recommended.

For further details on recent research findings refer to Appendix L and *Tree Establishment on Landfill Sites- Research and Updated Guidance* by Bending and Moffat, 1997.

B.3 LANDFORM AND DRAINAGE

The final landform of the restored site should be designed to encourage natural surface water drainage. A site specific drainage system needs to be designed and installed and should follow the guidance given in section 2.3.5 and the Agency's manual on *Landfill Site Design.* Gradients of 1 in 10 (6^{o}) are the minimum gradient for tree planting; however, trees can be established on shallower gradients where soils are reasonably well drained. The maximum gradient for amenity planting is 1 in 3 (18^{o}) as steeper slopes cause problems for tree management. The absolute limit for forestry equipment (downhill only) is 1 in 2 or approximately 27^{o} *(Environment Agency, UK, 1996).* On steep slopes measures such as planting with grass and using cut-off berms will reduce the level of soil erosion.

B.4 SOIL REQUIREMENTS

For successful tree establishment to occur on landfill sites, trees must have an adequate soil depth, soils should not be compacted and should have effective drainage. Compaction of soils is probably the most critical factor affecting tree growth and it should therefore be minimised and alleviated wherever possible. Ideally, soils should be loose tipped but where this cannot occur, some compaction is inevitable. This compaction will need to be alleviated prior to planting with trees.

The depth and types of soils required on landfill sites targeted for woodland restoration will be determined by the need to ensure sustained healthy trees and to protect the integrity of the capping system. Factors which need to be considered in determining soil depth and type include:

- the depth of soil required will need to be increased where freely draining soils are used;
- all trees grow better in soils that are free draining and uncompacted;
- compaction should be alleviated using subsoil ripping;
- topsoil is not essential for amenity tree planting as topsoil encourages vigorous grass and weed growth which competes for available nutrients, moisture and light; and
- in general depending on landfill type and capping system the following soil depths are recommended:
    - a minimum of 1.0 metre of soil (topsoil and subsoil) depth after placement is required over a capping system which incorporates a geosynthetic membrane e.g. LLDPE; or
    - a minimum of 1.5 metres of soil (topsoil and subsoil) depth after placement is required over a clay cap where the cap has been compacted to bulk density of 1.8-1.9 tonnes/m^3 achieving hydraulic conductivity of 1×10^{-9} m/s ; or
    - a minimum of 1.0 metre of soil (topsoil and subsoil) after placement over uncapped inert site.

B.5 CULTIVATIONS

An assessment of the site should be undertaken prior to any cultivation operations to determine the most appropriate method. Restored soils which have been recently loose tipped are usually in a suitable condition for immediate tree planting. Soils which have been replaced several years before planting and where planting has been delayed to allow for settlement will require cultivations. The entire area to planted should be loosened and drained to prevent the lines of planting from becoming water logged resulting in tree deaths. If organic materials such as compost, sewage sludge or farm yard manure have been applied to the surface these will need to be incorporated into the soils using equipment such as disc harrows.

B.6 VEGETATION ESTABLISHMENT

B.6.1 GRASS ESTABLISHMENT PRE-PLANTING

Advance sowing of grass on areas planned for tree planting is recommended and has the following advantages for the site:

- reduction of soil erosion by establishing ground cover before the winter months;
- stabilisation and reduction of erosion on steep slopes;
- improvement of the visual appearance of the site;

- help in controlling weed infestation on the site; and
- facilitates site specific nature conservation objectives such as the establishment of wildflower meadows etc.

Care should be taken in selecting grass seed mixes as an aggressive grass sward will compete with the trees for moisture, light and nutrients. An area of 1 meter diameter around each tree should be kept clear of grass and weed growth. The choice of grass mixes used is site specific; however, grass mixtures used should include non-competitive species and should be sown at reduced seed rates. Research has shown that spot application of herbicide is superior to band or total. A band of tall grass and herbs between the rows has been shown to have a positive effect upon the growth of broadleaves due to its sheltering effect.

Legumes can also be used as they fix nitrogen but care should be taken in choosing varieties. Clovers can compete with trees therefore a mixture of less aggressive clovers and smaller legumes may be more appropriate. Legumes will aid in the development of soil structure, fertility levels and addition of organic matter. They do not tolerate shade and will recede over time.

B.6.2 CHOICE OF TREE SPECIES

Several factors will govern the selection of tree species for planting schemes on landfills. However, consideration should only be given to those species that can be grown without threatening the integrity of the capping system and that possess an ability to grow satisfactorily in such an environment. The selection of trees for landfill sites should only be made after a thorough evaluation of actual or expected site conditions. Choice of tree and shrub species will be influenced by a wide range of factors including:

- capping system;
- the role to be performed i.e. amenity, shelter, wildlife conservation, screening etc.;
- landscape and ecological fit;
- soil drainage and hydrological conditions;
- soil type, nutrient status and pH e.g. heavy clays, calcareous or acidic soils;
- exposure - related to elevation and topography and distance from sea;
- local micro-climate;
- types of environmental pollution control systems on site particularly with reference to landfill gas and leachate management systems; and
- conditions specified by the Forest Service, Department of Marine and Natural Resources for areas planted under the Afforestation Grant and Forest Premium Schemes.

The choice of tree species must clearly reflect the objectives for the planting i.e. landscaping, wildlife conservation, shelter, amenity or commercial. Native tree species are more appropriate for amenity and nature conservation whereas more productive species should be chosen for commercial plantations. For large woodlands, the design should include interlinked areas of open space to create a series of glades and rides thereby maximising habitat diversity. A varied depth of edge should be created by using a mix of shrubs, edge, nurse and climax species at planting. Figure B.1 shows irregular shaped woodland with varying depth of edge created by mixed planting and Figure B.2 illustrates a planting regime that would be suitable for nature conservation.

Inclusion of a nurse species involves planting fast-growing and relatively short-lived robust shrub and tree species adapted to site conditions. The choice of nurse species will depend on the desired objectives. Many nurse species provide a simple shelter effect. Others provide a nutritional effect upon the target species while many provide both.

In addition, care must be exercised in choosing a nurse species that the growth rates of the species in the mixture are compatible. Where nurse species have been planted, it is important that these are managed correctly to ensure that the growth rates of the desired woodland species are not suppressed in the longer term. Where the preferred species has established well, the nurse species can start being removed from years 5 to 7 or even earlier depending on plant spacing.

Appendix M lists tall and medium tree species most likely to grow well on restored landfill sites, and gives an indication of their relative ability to tolerate adverse soil conditions. Appendix N lists

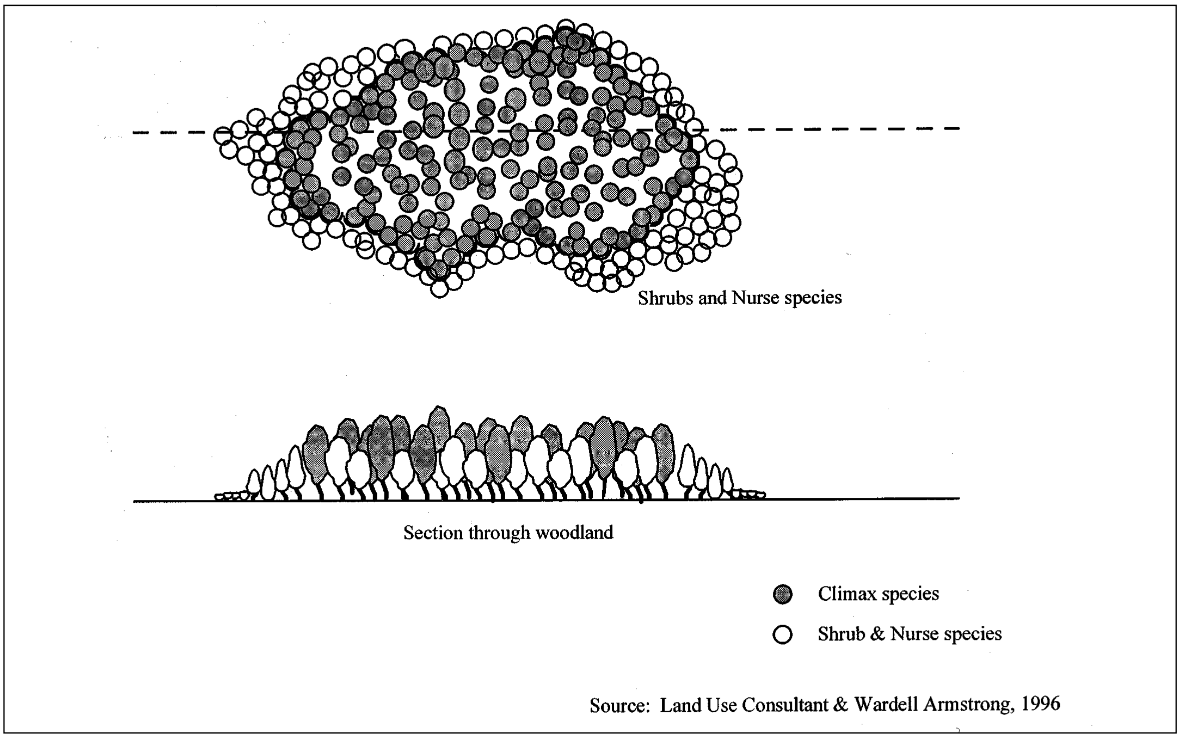


FIGURE B.1 ILLUSTRATION OF WOODLAND PLANTED TO GIVE IRREGULAR EDGE WITH VARIED DEPTH

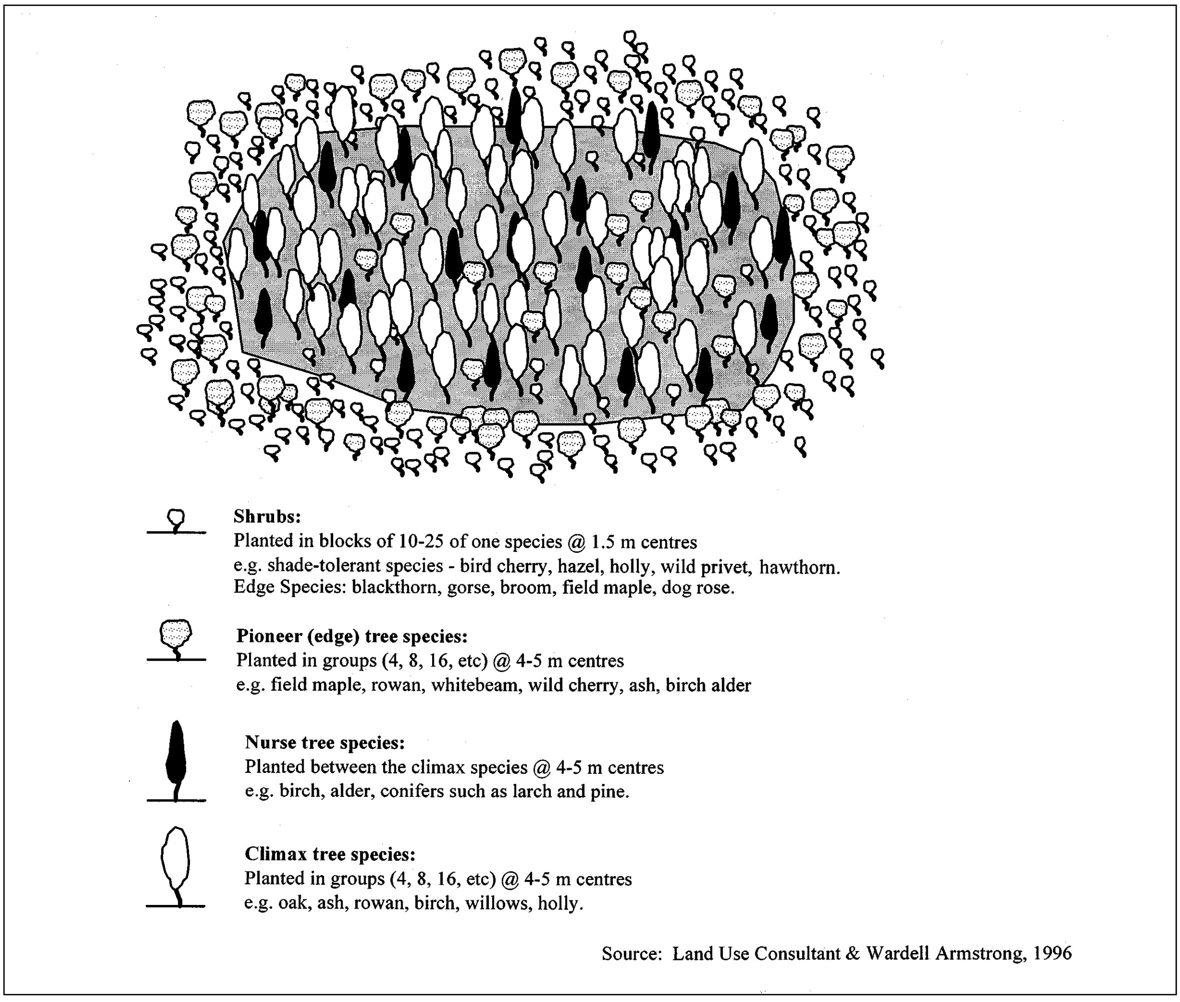


FIGURE B.2 ILLUSTRATION OF PLANTING REGIME FOR NATURE CONSERVATION small trees suitable for planting on landfill sites.

While actual species to be planted will depend on the individual site characteristics some general rules may be followed in selecting a suitable mix:

- on most sites nurse species should be provided in the ratio of one nurse to every 3-6 climax species, with higher nurse numbers on more exposed areas;

- on nutrient poor restored sites the nurse species should consist of nitrogen fixing species. Nitrogen fixing species can be divided into two main classes:

  – actinorhizal species e.g. alder, which fix nitrogen through their symbiotic relationship with the bacterium-like micro-organism *Frankia sp.* which forms root nodules; and

  – leguminous species e.g. lupins, clover, etc., and the tree false acacia which have a symbiotic relationship with the bacteria *Rhizobium sp.* which also form root nodules;

- the mix should include between 3 and 6 different climax species and should take account of the vertical woodland structure i.e. include canopy, sub-canopy and shrub species;

- choose a small number of well matched species rather than a diverse mixture of many different species which may be difficult to manage in the future; and

- a separate edge mix, primarily consisting of shrubs (e.g. hawthorn, blackthorn, wild cherry etc.) should be provided around the edge of larger planting blocks.

B.6.3 CHOICE OF STOCK

Tree planting stock are normally specified according to their age, height, root collar diameter and root system. Restored sites are normally planted with nursery raised stock and in general terms a small sturdy 2 + 1 or 1+ 2 with a good fibrous roots system is best (sturdy refers to root collar). The EU has adopted a number of Directives on the marketing of forest reproductive material. These are primarily concerned with ensuring that seed, cuttings and young plants used in forestry are selected from vigorous, high quality trees. The marketing of forest reproductive material is thus restricted to sources which are identified and certified to be of genetically high standard. This is achieved through the use of Certificates of Provenance. Stock should always be obtained from a reputable nursery and should be healthy and free from obvious pests and diseases. A Provenance Declaration Form should also be obtained. Where available, planting stock from registered Irish seed sources should be used. For further advice on planting stock consult with the Forest Service, Department of the Marine & Natural Resources.

It is essential to minimise the delay between lifting the trees in the nursery and planting on site. One of the prime causes of tree failure, other than soil compaction, is the drying out and damage to tree roots sustained during transportation and handling prior to planting. Where bare-rooted transplants are used as stock, trees with the most favourable root to shoot ratio should be used. The most useful stock types are:

- transplants - use small trees of 30-40 cm high on landfill sites. These are categorised according to the number of years spent in seedbeds and transplant lines. The formulae commonly used by suppliers are 1+1, 1+2, 2+2 etc. 1+1 means that a plant has spent one year in the seedbed and 1 year in the transplant line. Transplants should not spend more than two years in the transplant line;

- undercuts - use the same size and age as transplants. These are grown as seedlings, then undercut without moving, to sever side and downward growing roots. These are categorised as transplants - 1u1, 1u2 etc. 1u1 means that a plant has spent one year as a seedling and then undercut and has spent another year in seedbed; and

- container grown - seedlings grown in small tubs and obtainable in a range of sizes, ages and types. Where containers are used they must be either biodegradable or allow roots to grow through them. The main benefit in using these is minimal root disturbance.

B.6.4 TIMING AND METHOD OF PLANTING

If possible, planting of trees should not commence until after the period of initial settlement of the landfill has occurred. This delay will allow installation and remedial works to be carried out on the environmental pollution control systems without causing damage to planted areas. On inert landfill sites delaying tree planting is unnecessary. On most sites, however, there will be opportunity for early tree planting for screening and landscape enhancement around the perimeter of the site and on areas which have not been landfilled. For further details on timing and methods of planting refer to Appendix O.

B.6.5 FERTILISER AND TREE PROTECTION

A soil survey and analysis will determine the fertiliser requirements of the area planted with trees. Nitrogen fixing species in the tree mix will help tree growth rates and many young trees also contain substantial supplies of nutrients from the nursery which will be sufficient for establishment. Usually mineral soils in Ireland contain sufficient P for establishment and early growth (3 to 4 years). Foliar analysis can subsequently be used to assess fertiliser needs.

Application of mulch can aid tree establishment by improving soil moisture conditions, reducing extremes of soil temperature and suppressing weed growth. Granular or sheet mulches can be provided at the time of planting. Granular materials such as composted green waste, straw, chopped bark etc. should be spread to a diameter of 0.7 - 1.0m around the tree to 25 - 50 mm depth. Sheet materials such as polythene can also be used and should be about 1 m diameter and pegged or weighted down *(Land Use Consultants, 1992).*

Trees will require protection from animal damage (rabbits, hares, cattle, sheep, goats, deer etc.). Large woodland blocks can be protected by appropriate stock/rabbit proof fencing. Individual tree protection rarely works well on large scale planting as it is expensive and requires considerable maintenance. For small groups of trees it is generally preferable to fence (stock and rabbit). For individual trees, tree guards can be used where appropriate. Specialist advice should be sought in relation to tree protection. The more common forms of tree protection are given in Appendix P.

B.7 LONG TERM AFTERCARE

Trees planted on restored landfills will require careful management for a period of at least 10 years after planting. The type of management depends on the objective for planting whether for landscape integration, amenity or commercial production. The long term aftercare requirements for the restored site must be detailed in the aftercare management plan. The persons responsible for implementing the required works must be listed in the plan along with the programme of works to ensure successful establishment. The management plan should include:

- the objectives for management - multi-purpose use, nature conservation, recreation or timber production;
- woodland type and desired characteristics for each area of woodland;
- open space areas - management requirements of open spaces within wooded areas;
- details and timing of silvicultural operations within the plan period;
- consultations with relevant bodies, organisations and local community; and
- materials required and sources of these materials.

B.7.1 WEED CONTROL

Weed control is the single most important aspect of aftercare, as it eliminates competition for moisture, nutrients and light and is critical in the early growth stage of trees. The continued control of competitive herbaceous species around each tree is essential for successful tree establishment. So long as it is compatible with objectives of the site, weed control is best achieved by using approved chemical herbicides suitable for forestry use. Individual herbicides have times during the year when they work best and manufacturers' recommendations on timing of spraying should be followed. Mowing or hand weeding may actually increase competition *(Forestry Commission, 1987).*

Weed control should be carried out at the start of the growing season in March or April and may need to continue throughout the growing season. Weed control should aim for a minimum 1 metre free area around each tree, irrespective of method used. Care should be taken not to damage the tree and manufacturers recommendations should be adhered to. Weed control will be required for at least the first three growing seasons and the number of applications per growing season will be dependent upon weed infestation levels. Up to 3 herbicide applications a year may be required. Mulching can be used as an alternative. For further guidance refer to *Forestry Commission Field Book 8: The use of herbicides in the Forest*, 1995 by Willoughby & Dewar. The Forest Service, Department of the Marine & Natural Resources should also be consulted.

B.7.2 BEATING UP

Replacement of trees which have failed to establish will be required and should be done as soon as the failures become apparent. In large blocks up to 20% loss evenly spread may be acceptable, but in small blocks even 5% loss can be detrimental, requiring replacement of all failures. Beating up (i.e. the replacement of trees which have failed) should be carried out as soon as possible after the initial planting, otherwise new planting will be suppressed by the establishing trees. Delays in beating up will also extend the weeding requirements of the establishing crop.

B.7.3 FERTILISER

Regular annual checks should be carried out to ensure that plants are not deficient in nutrients. There is some debate about the value of fertilising newly planted trees and prevailing site conditions need to be considered when deciding on fertiliser applications. Fertiliser applications should only be considered where foliar analysis indicates that fertiliser is required.

B.7.4 TREE PROTECTION MAINTENANCE

Regular checks should be made and maintenance carried out on the tree protection measures. It is important that on exposed areas regular maintenance should be carried out to ensure that the shelters remain firmly attached to the stakes thus avoiding damage by abrasion.

B.7.5 THINNING

The primary aim of thinning is the removal of a proportion of the growing trees to increase the space available for climax trees and/or for nature conservation purposes. In woodlands planted for nature conservation the site manager/landscape architect or horticultural expert will need to maintain and increase species and structural diversity. Species diversity is increased by planting native shrub and understorey species after removal of dominant or nurse species. Topping back or lopping nurse species which are too vigorous should also be considered. This will allow more space for the slower-growing long term species. Specialist advice should be sought from Dúchas and the Forest Service on the management of woodlands for multi-purpose uses.

B.7.6 FORESTRY INFRASTRUCTURE

The aftercare management plan must make provisions for regular maintenance of the woodlands infrastructure. Foothpaths, signposting, litter control, access points, firebreaks etc. will require maintenance during the aftercare period.

B.8 NATURE CONSERVATION AND WOODLANDS

Woodlands provide good opportunities for multi-purpose use and are able to combine objectives for nature conservation, recreation and timber production. In general, the establishment and management operations described above are applicable for nature conservation objectives, however particular consideration should be given to:

- woodland design and structure;
- choice of species;
- planting patterns;
- introduction of woodland herbaceous species; and
- long term aftercare for nature conservation.

B.8.1 WOODLAND DESIGN

For large woodlands, the design should include interlinked areas of open space to create a series of glades and rides. There is no minimum size for areas of tree planting but small areas less than 40 x 40 m or very narrow strips of woodland less than 15 m wide are unlikely to develop woodland ground flora as light levels will be too high, favouring shrub and scrub communities. Open areas are important as they provide:

- routes and spaces for recreational use;
- dispersal and colonisation network for plants and animals;
- diversity and variety in habitat; and
- areas for natural colonisation *(Land Use Consultants & Wardell Armstrong, 1996).*

The woodland edge requires special attention and it should be intermediate in character between open spaces and woodland. Straight edges and square woodland blocks should be avoided. Irregular edges should be created. It is important to consider the long term management requirements when designing woodlands as very complicated designs and planting patterns may prove very difficult to manage. See Figure B.1 and Figure B.2.

B.8.2 CHOICE OF SPECIES

On restored sites where natural colonisation is already underway consideration should be given to woodland establishment through natural colonisation. The diversity of communities which develop this way will depend on the local seed source and substrate conditions. Natural colonisation can be encouraged and speeded up by the preparation of a seed bed, reducing soil compaction and the addition of fertiliser to establishing saplings. See section 8.6.2 and Appendices M and N for further details on species choice.

B.8.3 PLANTING PATTERNS

The main principles for tree planting for nature conservation are:

- plant in single species clumps or in clumps of 2 to 3 mixed species which are compatible;
- clumps/groups should generally be of between 9 and 25 trees;
- plant slower-growing trees in large clumps to prevent shading from adjacent groups of more vigorous growing trees;
- vary the extent and form of gaps between clumps;
- include a fringe of shrubs around the edge of the woodland; and
- avoid rigid uniform rows and grids.

B.8.4 INTRODUCTION OF WOODLAND HERBACEOUS SPECIES

New plantings on restored sites will require the introduction of woodland herbaceous species which are usually associated with semi-natural woodland ecosystems. Species such as primose *(Primula vulgaris),* bluebell *(Hyacinthoides non-scripta)* and bugle *(Ajuga reptans)* are poor colonists of damaged sites and will need to be planted to form an attractive field layer beneath the planted woodlands. The method of introduction is site specific and can include soil transfer, seeding and planting.

B.8.5 LONG TERM AFTERCARE

An aftercare management plan should be drawn up clearly stating the management objectives and the personnel responsible for managing the woodlands for nature conservation. Certain management practices are required and include:

- removal of non-native species and nurse species;
- coppicing appropriate species (i.e. coppicing is a management practice which involves harvesting shoots produced from the cut stumps (called stools) of the previous crop to produce small round-wood products);
- reducing the canopy cover by thinning to create appropriate light conditions; and
- rotational management by coppicing or thinning of the secondary canopy species such as birch, hazel etc. to encourage the establishment of climax species.

APPENDIX C. AGRICULTURAL RESTORATION AND AFTERCARE

C.1 INTRODUCTION

The opportunities for agricultural restoration depend upon numerous factors which include:

- integration and installation of gas and leachate management systems;
- availability of adequate supplies of good quality topsoil and subsoil;
- landowner requirements;
- planning requirements;
- local landuse, topography and site characteristics; and
- local community needs.

To achieve successful agricultural restoration, the operator must consider the design of the gas control system at the same time as the restoration and aftercare design. The gas control system unless well designed could severely interfere with normal agricultural practices particularly where large machinery is used for cultivations and harvesting operations e.g. silage harvesters. Gas control systems commonly have gas wellheads located at regular intervals over the site at 40-60 m spacing. The gas wellheads are generally situated at or above ground level and have the potential to seriously impact on agricultural operations. There is also the risk of causing damage to both the wellheads and farm machinery. Significant loss of productivity can result from crop loss and machinery traffic for access and remedial works. In general the potential for loss will be greatest for more intensively managed crops such as grassland cut for silage or hay and less for grazing.

On many existing landfill sites the availability of good quality topsoil will be limited and will therefore affect the choice of agricultural production systems. All agricultural crops including grass generally require fertile conditions. Topsoil, fertilisers and lime are needed to maintain soil fertility.

C.2 LANDFORM AND DRAINAGE

The post-settlement landform of a restored landfill should blend the site with the surrounding landscape and have gradients which replicate existing landforms. The final gradients should enable normal agricultural activities to be carried out without endangering machinery operatives or causing excessive rutting or slippage. The gradients recommended are site specific and should take account of the types of wastes accepted for landfilling. Some differential settlement may occur creating hollows where water will accumulate. These should be infilled during interim restoration and regraded. A site specific drainage system needs to be designed and installed and should follow the guidance given in section 2.3.5 and the Agency's manual on *Landfill Site Design*. The minimum slope should promote site drainage by assisting surface water run off. Reference should be made to Table 2.1 for further information on slopes in relation to land use. The gradients recommended for agriculture restoration include:

- minimum gradients of 1 in 25 to 1 in 15 are recommended on landfills which may settle, depending on local soil and climate;
- gradients of 1 in 25 up to 1 in 3 are appropriate for grassland; and
- gradients steeper than 1 in 3 are not suitable for pasture land.

As gradients increase, the risk of soil erosion and rapid surface runoff increases. This may also lead to problems of increased suspended solids in drainage waters. Erosion control methods and practices should be adopted on sites where soil erosion may occur. These include:

- the establishment of vegetation as early as possible on restored soils;
- the establishment of grass in areas where interim restoration has occurred or areas awaiting tree planting;
- the carrying out of cultivation operations out across the slope to avoid creating downslope channels;

- the formation of vegetated buffer zone around the perimeter of the site will reduce the speed of surface water run-off and result in the depositing of suspended solids across the buffer strip; and

- the encouragement of the development of good soil structure which will increase water infiltration. This can be achieved by improving fertility, selecting crops which develop extensive fibrous root system, alleviation of compaction and installation of effective field drainage.

C.3 SOIL REQUIREMENTS

The soil profile for agricultural restoration is site specific and should take into account the amount of soil or soil forming materials available on or off site. Successful restoration for agricultural production depends upon an adequate supply of good quality soils which when replaced provide fertile soils which are free draining and have a high available water capacity. An absence of structures that would interfere with cultivations is essential. The soil profile should include:

- minimum depth of soil required after placement is 1000 mm, which should consist of:
  - topsoil - 150 - 300 mm topsoil is required for intensive agricultural production systems, and
  - subsoil - 700 - 850 mm minimum subsoil is required over the capping layer;

- the degree of limitation imposed by stones depends on their quantity, size, shape, hardness and the crops to be grown. The use of soils with a high stone content is not recommended;

- organic matter content at least 1 to 2 % by dry weight;

- pH 5 to 8; and

- avoidance of soils with high silt/clay content.

C.4 CULTIVATIONS

The two main objectives of cultivations are to break the soil down to a sufficiently fine tilth for seed germination and root growth and to bury weeds and vegetation residues. The choice of cultivation equipment depends on soil conditions. Cultivations should produce a sufficiently fine seed bed for the particular crop, without damaging the soil structure. They are generally carried out using agricultural equipment such as ploughs, powered rotavators, spring or coil tine harrows, spike harrows, chain harrows or discs. Where mould board ploughs are used, they should be set in relation to depth and rake to prevent burying topsoil below subsoil layer. The seedbed preparation is usually completed using chain harrows to incorporate seed and fertiliser, and rollers to compress the soil around the seeds.

C.5 VEGETATION ESTABLISHMENT

The choice of crop to grow on restored landfills will be determined by the need to ensure adequate production and good ground cover. Consideration should also be given to crops which will help improve the soil's physical, chemical and biological status. Other important criteria include:

- local climate and location, particularly aspect, slope, height above sea-level, local knowledge of crops already grown in the area and soil type;

- effects of gas and leachate management systems on farming the crop;

- soil structure improvement and ground cover - a crop that will cover the ground quickly and persist through the winter, should be chosen;

- avoidance of soil damage - a crop which does not require field work during late autumn, winter or early spring, should be chosen;

- avoidance of crops giving poor soil cover over the winter months;

- planting of nitrogen fixing plants e.g. clover and other legumes, to increase the nitrogen content of the soil; and

- landfill type - grass is generally more tolerant to landfill gas than other crops.

C.5.1 CHOICE OF CROP AND SEED MIXTURES

Grass is considered the most suitable agricultural crop for the aftercare period as it is tolerant of poor soil conditions, provides all year around soil cover, promotes the development of soil structure and can accommodate the environmental pollution control systems. The choice of grass varieties is site specific and dependent on the intended afteruse.

- short term grass leys - suitable on well drained fertile soils and may suit sites where regrading due to settlement is required. These mixes usually contain perennial grasses with high yielding potential and clover;
- long term leys - suitable on poorer soils, less intensively managed and generally contain ryegrasses, meadow fescues, timothy and clovers;
- seeding rates - generally 40 - 50 kgs/ha depending on the seed mix; and
- sowing - grass is generally sown in the spring or in late summer, early autumn.

C.5.2 FERTILISER, WEED AND PEST CONTROL

Soil analysis will identify the nutrient status of the soils indicating the fertiliser requirements of the growing crop. Advice is available on fertiliser application rates in relation to soil index values and Teagasc's *Soil analysis & fertiliser, lime, animal manure & trace element recommendations* should be consulted. Fertiliser can be applied during cultivations, at sowing or applied as a top dressing to the growing crop.

A wide range of control methods, both mechanical and chemical, are available to control weeds and damage to crops by pests such as frit fly and slugs. These pests rarely cause problems in established grassland, however, newly sown grass should be inspected regularly for signs of damage. Guidance on chemical pesticide use, particularly application method, rates, timing and safety precautions is available, and operators must adhere strictly to these recommendations. It is crucial when using chemicals for weed and pest control that all health and safety precautions and environmental protection methods are employed during their use, transport and storage. Ideally, any pesticides used should have low persistency, be water soluble and have breakdown products which are non-toxic.

C.6 AGRICULTURAL INFRASTRUCTURE

C.6.1 FENCING AND HEDGES

Fencing and hedges provide field boundaries and stock proof barriers. Hedges also provide landscape features and are important wildlife habitats as well as acting as wildlife corridors.

- Fencing - four types of fencing are generally used on agricultural land: post and wire, stockproof mesh fencing, post and rail and stone walls. Reference should be made to relevant standards for fencing.
- Hedges - normally comprise of a line or narrow belt of closely spaced woody trees and shrubs, which are managed so as to form a more or less continuous barrier. Planted hedges should act as a link to existing hedges and enhance the network of wildlife corridors in the area. The choice of species is site specific and should reflect the existing hedgerow species. Nevertheless, the predominant species seen in native hedgerows are hawthorn and ash. For further details on hedges reference should be made to Appendix K.

C.6.2 FARM ACCESS AND WATER SUPPLY

Farm access gates and tracks should be designed to utilise the existing access routes for the monitoring and maintenance of the environmental pollution control systems. Tracks should be located, where possible along headlands to avoid trafficking on restored soils. The type of material used to construct the tracks will depend on the intended use i.e. machinery routes, livestock etc. Suitable materials brought on site during landfilling can be utilised to construct the tracks, while purpose designed geotextiles are also available. Specialist advice should be sought when constructing tracks which will be utilised by livestock particularly dairy cows.

An adequate supply of clean drinking water is essential for grazing livestock. This should usually be supplied by a pipe water system connected to drinking troughs. The capacity of the troughs will be dependent upon the intended stocking densities and animal type. The water supply system should integrate with access routes and environmental pollution control systems.

C.7 LONG TERM AFTERCARE

The long term management requirements of the restored site must be detailed in the aftercare management plan. The persons responsible for the annual management of the site must be clearly listed in the plan along with details of the works programme. All aftercare operations must consider the protection and maintenance requirements of the siteís environmental pollution control systems. The long term aftercare management requirements for agricultural land can be broken down into two main areas:

- soil husbandry; and
- crop husbandry.

C.7.1 SOIL HUSBANDRY

Soil husbandry practices which encourage the development of a fertile soil should be carried out on a regular basis and include:

- assessment of the soil fertility by sampling and analysis to monitor the level of plant nutrients in the soil. Care is needed when applying fertiliser to prevent pollution of the surrounding watercourses by leaching or surface water runoff;
- organic matter levels in restored soils are generally depleted and should therefore be increased by the addition of organic manures, sewage sludge and/or compost. Sewage sludge and compost should be analysed for heavy metals content prior to application;
- soils should be checked regularly for signs of soil compaction. See section 4.4.9 for further guidance;
- the correct timing of operations in relation to soil conditions is critical to avoid damaging the restored soils; and
- the drainage and surface water collection systems should be checked regularly and maintenance should be carried out when required.

C.7.2 CROP HUSBANDRY

The choice of cropping will be influenced by local conditions and farming practices. Good crop husbandry should be practised at all times. Factors which need to be considered include:

- crops which promote good fibrous root growth and give good ground cover should be used as this will encourage soil structure development;
- machinery operations on the restored land should be kept to a minimum;
- overstocking with animals should be avoided and livestock should be managed to minimise poaching the land when wet weather and poor soil conditions prevail; and
- weed and pest control may be necessary from time to time and all health and safety guidelines relating to use and protection of the environment should be followed.

APPENDIX D. HARD END USES

D.1 INTRODUCTION

The use of former landfill sites for the construction of hard standing areas and built development must take into account the potential hazards associated with construction on such sites. The operator and/or developer must be aware of the risks, design accordingly and use appropriate building technology to ensure that the buildings are safe for the chosen afteruse. Landfills are generally considered to be unsuitable for hard forms of development due to the potential hazards unless remedial treatment is carried out prior to construction. Remedial treatments are often complicated and expensive to implement. Residential development on landfill sites particularly sites accepting biodegradable waste is generally not recommended. Expert advice should be sought where consideration is given to the development of landfill sites to hard end uses such as warehouses, factories, parks, car parks, roads and playgrounds. All relevant literature and legislation should be consulted including Department of Environment & Local Government *Protection of New Buildings and Occupants from Landfill Gas* and *Building Regulations, 1997; Technical Guidance Document C: Site Preparation and Resistance to Moisture*.

The potential hazards associated with the use of former landfill sites for construction and hard end uses are:

- the presence of explosive and flammable gases resulting from the biodegradation of waste and associated problems of gas migration;
- health and safety of construction workers during the construction phase;
- the presence of toxic gases such as H_2S and CO_2 which effect entry into confined spaces;
- poor ground conditions, instability and settlement;
- the presence of flammable material within the landfill mass; and
- corrosive materials/liquids which may damage construction materials.

D.2 SITE INVESTIGATION AND RISK ASSESSMENT

The most suitable form of development cannot be decided until site investigations have been undertaken. These involve a thorough examination to assess the significance of the hazards on site. These investigations need to be carried out by a specialist to ensure that they are sufficiently detailed to enable the choice and design of the development to proceed. The types of wastes accepted by the landfill has a significant bearing on the type of future developments. Sites accepting inert waste only will have significantly less settlement and gas production potential in comparison to site accepting biodegradable wastes.

D.3 POTENTIAL HAZARDS

Landfill gas is primarily composed of methane, carbon dioxide and water vapour and evolves on the commencement of the anaerobic decomposition of the waste. Methane is flammable and explosive at concentrations of 5 - 15% v/v in air. The gas is usually saturated with moisture and is corrosive. If not properly monitored and controlled, landfill gas can give rise to flammability, toxicity, asphyxiation and other hazards, as well as vegetation dieback.

Settlement of the completed waste mass will occur as a result of the decomposition of biodegradable waste within the landfill. Reference should be made to the Agency's manual on *Landfill Site Design* for further information on settlement rates. The structural precautions will depend on the type of waste fill, the rate of waste input and the method of operation. A geotechnical investigation of the site should be undertaken prior to the design of foundations or other structures. The design must also take into account the corrosive nature of the waste, landfill gas and leachate when selecting the building materials for construction. All materials must be robust and durable to site specific conditions.

Where there are proposals to design and construct hard end uses on landfill sites consideration should be given to the following which include:

- high compressibility of waste resulting in settlement of the landfill over time;

- integrity of the capping system;

- design of foundations to avoid the possibility of unventilated spaces within or beneath the building;

- provision of gas traps or other special precautions at the points of entry of essential building services, especially water supplies, drains and electricity cables;

- provision of adequate internal ventilation for both below ground and above ground parts of the building, with monitors and alarms to respond to a build up of hazardous gases;

- corrosive properties of leachate;

- use of services of technical experts in relation to ventilation, foundation design and structural engineering;

- continuous gas monitoring on-site and around the site to check for gas migration. Monitoring guidelines are set out in the Agency's manual on *Landfill Monitoring*;

- regular maintenance of active gas extraction system on site;

- safety mechanisms to prevent vandalism of the extraction, monitoring and alarm systems; and

- reference to all relevant published guidance and legislation including:

  - Department of Environment & Local Government, *Protection of New Buildings and Occupants from Landfill Gas;*

  - Department of Environment & Local Government, *Building Regulations, 1997 Technical Guidance Document C Site Preparation and Resistance to Moisture;*

  - Safety, Health and Welfare at Work Act, 1989;

  - Safety, Health and Welfare at Work Regulations (SI No. 44 of 1993);

  - Safety, Health and Welfare at Work (Construction Sites) Regulations (SI No.138 of 1995);

  - Building Regulations, 1997 (SI No. 497 of 1997); and

  - Site Investigation Steering Group (Part 4) (1993): *Guidelines for the safe investigation by drilling of landfills and contaminated land.* Thomas Telford, London.

APPENDIX E. SOIL CLASSIFICATION IN IRELAND

The soils of Ireland may be divided into three broad categories, lowland mineral soils, mountain and hill land and peat. These are further subdivided into major land units as shown in Table E.1.

TABLE TABLE E.1 LAND CLASSES IN IRELAND

Land class	Area (million ha)	Percent land area
Lowland mineral soil (dry)	2.83	41
Lowland mineral soils (wet)		
-moderately wet	0.93	13
-impermeable	0.81	12
Mountain, hill and high-level peat	1.53	22
Low-level peat		
- blanket peat	0.41	6
- basin peat	0.41	6

Source: Lee, 1991

The land classification system adopted in Ireland evaluates the degree of suitability of each soil unit for a set of uses including cultivations and grassland where all types of use have equal rank. This system could be extended to include suitability for forestry or urban development. Soil suitability depends largely on the physical properties of the soil and the environment. The degree of limitation is assessed for such factors as wetness (w), drought (d), liability to flooding (f), slope (s), rockiness (r), boulders (b), textural and structural properties affecting tilth and susceptibility to poaching (t). Productivity is the dominant criterion in the ranking of suitability for grassland.

For cultivated land the dominant criterion is the effect of soil properties on the ease of cultivations and on productivity. The degree of limitation increases from the higher to the lower categories. On the basis of these factors soils are grouped into five classes designated A, B, C, D and E for grassland, and I, II, III, IV and V for cultivation (A or I - very good, B or II good, C or III moderate, D or IV poor, E or V very poor). Suitability classes are divided into sub-classes by principal limiting factor as indicated by a subscript for the kind of limiting factor. For example AId indicates class A for grassland, class I for cultivations and liability to drought as the dominant limitation, while CIIIw indicates class C for grassland, class III for cultivations and wetness as the dominant limitation *(Lee, 1991).*

Forestry production potential is based on Sitka spruce as the indicator tree species. Sitka spruce is the most commonly planted species and is used on a wide range of soils. The output of any site is given as a Yield Class range. Yield class is the standard method of indicating forestry output and is measured in cubic meters of timber. For example Yield Class 20 (YC20) represents an average production of 20 cubic meters of timber per hectare per annum over the duration of a rotation. Forestry rotations are normally set at the number of years of growth to maximise mean annual production.

For new and existing landfill sites it is important that soil suitability for the proposed afteruse is evaluated by reference to the Soil Association maps of Ireland and the county maps. These maps will indicate the limitations imposed by the soils on crop growth and will indicate the types of vegetation that will successfully establish on restoration soils.

APPENDIX F. DESIGN CONSIDERATIONS FOR POLLUTION CONTROL SYSTEMS

Pollution Control System	Design Considerations
• Capping System	– Gradients · maximum gradient of 1 in 3; however, for most landuses maximum workable gradient is 1 in 5 · gradual changes in gradients may be required for landscaping · minimum gradients of 1 in 30 for surface water runoff – Topsoil and subsoils · minimum total soil depth after placement varying between 0.5 to 1.5m depending on type of landfill and the proposed afteruse (see chapter 4 for further details) – Filter layer · filter layers may be required between the soil (subsoil and/or topsoils) and the drainage layer (granular layers or geosynthetic) to prevent the ingress of fines and roots into the drainage layer · if a coarse drainage layer is to be placed onto a geomembrane, a protection layer is required to protect the geomembrane from puncture and over stressing – Drainage system · in general all restored sites will require the design and installation of a site specific drainage system which will include a drainage layer a filter layer and surface water collection system – Barrier layer · a compacted low hydraulic conductivity mineral layer with a minimum thickness of 0.6 metres and hydraulic conductivity of 1×10^{-9} metres/sec, or · where a geosynthetic material is used it should provide equivalent protection
• Gas Control System (Passive venting and/or active control and flaring)	– Integration of gas management system with the restoration landscape design and the afteruse. Selection of gas system with design features which are most appropriate to the proposed afteruse. – Gas monitoring boreholes · location along field boundaries and in non-agricultural areas where possible · protection against damage by machinery, livestock and vandalism

Pollution Control System	Design Considerations
	· provision of adequate access for monitoring – Gas Venting · location of vent stacks and/or gravel filled trenches is site specific but should be designed to prevent water ingress · protection against damage by machinery, livestock and vandalism · provision of adequate access for maintenance – Gas Wells and Wellheads · well location and spacing is site specific. As a general rule wells should be located between 20 and 60m apart depending on whether they are intended for utilisation or control *(ETSU B/LF/00474/ REP/1)* · location along field boundaries and in non-agricultural areas where possible · protect against damage by machinery, livestock and vandalism. Wellheads should be encased in lockable headworks · provide adequate access for maintenance, repairs and monitoring gas quality and suction pressure – Gas collection pipework system and extractor pumps · the location and the layout of the pipe collection system is site specific · pipes should be laid in the subsoil on sand or gravel bedding and have a minimum of 600 mm of cover above. Use pipe colouring system or warning tape to indicate pipes contain landfill gas · pipework should be laid so that plant and machinery can run over it without causing damage – Gas Condensate · pipes should be laid to a minimum fall of 1 in 30 to assist drainage of condensate · location of siphon tubes or condensate knock out tubes at low points but careful consideration to the proposed afteruse is required · provision of access for maintenance and repairs – Gas Flares · the siting of flaring equipment should take into account sensitive receptors prevailing wind etc. and should be located as to minimise odour nuisance and visual intrusion

Pollution Control System	Design Considerations
	· risk of fire from flare stacks and heat emitted will influence choice of species and planting regime around the stack – Gas Compound · size and location determined at design stage and integrate the compound into landscape design · mounding and planting should be used for visual screening and noise abatement · slope of mounds should enable easy maintenance of vegetation and ensure safe conditions for operators
• Leachate system	– Leachate collection and removal · base of cells should be sloped to allow gravitational flow to sumps or leachate header pipes · sites engineered for accelerated stabilisation may include recirculatory pipework which will need consideration in the design phase · no recirculation should be carried out unless an appropriate lining system and leachate collection system is in place · fixed leachate monitoring points within each landfill phase · locate, where possible, field boundaries adjacent to above-ground components of the leachate management system · protection of manholes and monitoring points against damage from machinery, livestock and vandalism · consideration should be given to the proposed afteruse when siting the sites leachate storage and treatment facility · leachate pipework system to take leachate from the collection manholes to the storage lagoon, treatment plant or off-site · provision of access and manoeuvring space for tankers if required to transport leachate for treatment or disposal · combine components of leachate management system with gas compound if possible to simplify screening design · screening with mounding and tree/shrub planting
• Ancillary services	– Screening of workshops, parking, roads/entrance, security fencing and power supply · appropriate screening using mounds, shrubs and trees

Pollution Control System	Design Considerations
	· access and maintenance requirements of vegetation should be considered when selecting species · entrance landscaping should fit in with the landscape design of the whole site and plants to be used in the compound or at the entrance should be carefully selected. Semi-ornamental species should not be used. Thorny shrubs collect windblown litter and this becomes difficult to remove · trees used for temporary screening may become an attractive landscape feature and local residents may object to their removal · landscape proposals adjacent to the compound and at the site entrance should be designed so that the compound can be removed and restored with minimal change to the planting

APPENDIX G. SOIL PROPERTIES

G.1 SOIL PROFILE

Physical and chemical weathering, denudation and redeposition combine with the activities of a succession of colonising plants and animals to form soils with a porous fabric that can retain water and exchange gases. The water contains dissolved organic and inorganic solutes and is called the soil solution. While the soil air consists primarily of nitrogen and oxygen, it usually contains higher concentrations of carbon dioxide than the atmosphere, and traces of other gases that are by-products of microbial metabolism. The four major components of soils are mineral matter, organic matter, water and air.

The process of soil formation, called pedogenesis, results in the formation of series of distinct horizontal zones that constitute the soil profile. The soil profile refers to a vertical section of the soil down to and including the geological parent material. The nature of the profile is important in many aspects of plant growth including root development, moisture storage, aeration and nutrient supply. The profile is therefore the basic unit of study in assessing in-situ soils on landfill sites. The profile displays a succession of layers that may differ in properties such as colour, texture, structure, porosity, chemical constants, organic matter content and biological composition. These layers - known as soil horizons - occur approximately parallel to the land surface.

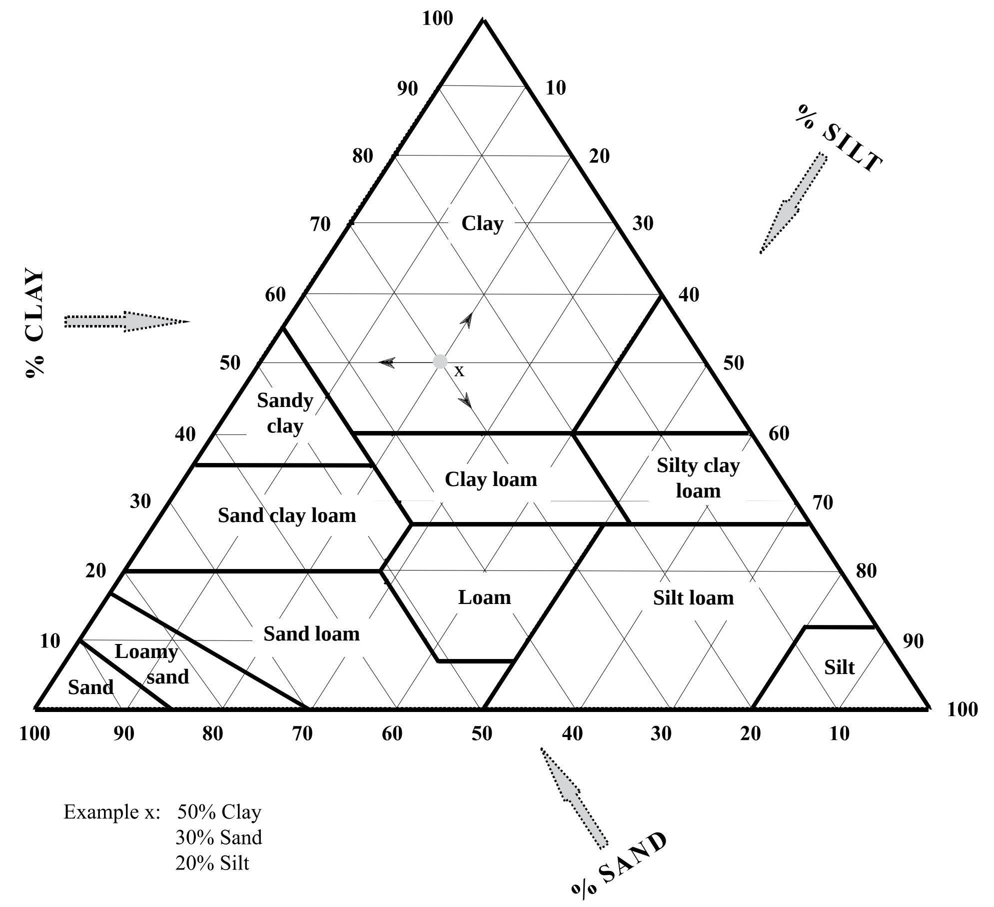
Most soil profiles include three main horizons that are usually identified by the letters A, B, and C. The combined A and B horizons constitute the ‘true’ soil whilst C refers to the parent material. The A horizon is the uppermost layer in mineral soils and corresponds with surface or top soil layer. It is that part of the soil in which living organisms and organic matter is usually most abundant. Being closest to the surface, this is the first to be reached by rainfall and is therefore, more leached than underlying horizons. The B horizon lies immediately beneath the A and corresponds closely to the subsoil. Lying between the A and C horizons, it possesses some of the properties of both. Living organisms are fewer than in A but more abundant than in the C horizon. The B horizon is one of accumulation and usually has a relatively high content of iron and aluminium oxides, humus or clay that have been partly leached form the overlying horizon. The C horizon refers to the geological material beneath the A and B horizons. It consists of the upper part of the loose and partly decayed rock or other geological material, such as glacial drift. The C horizon is less weathered, has less organic matter and is usually lighter in colour than overlying horizons. There are conflicting views amongst practitioners involved in landfill restoration on what defines a soil particularly in its lower depths. There are also numerous definitions of these horizons, but for the purpose of this manual, the nomenclature used in Figure 4.1 will be used.

A soil survey carried out prior to development of the landfill will provide a description of the soil profiles for the patterns of soils on site. A complete soil profile description involves recording the properties for each horizon identified in the soil profile.

G.2 SOIL TEXTURE

Soil texture is defined as the particle size distribution of the solid inorganic constituents of the soil. It refers to the relative proportion of clay, silt and sand in the mineral fraction less than 2 mm in diameter. Larger particles such as gravel and stones and organic matter are recognised by qualifying textural terms. Table G.1 amalgamates the terms used by soils scientists, agriculturists and geotechnical people to classify different soil types according to texture.

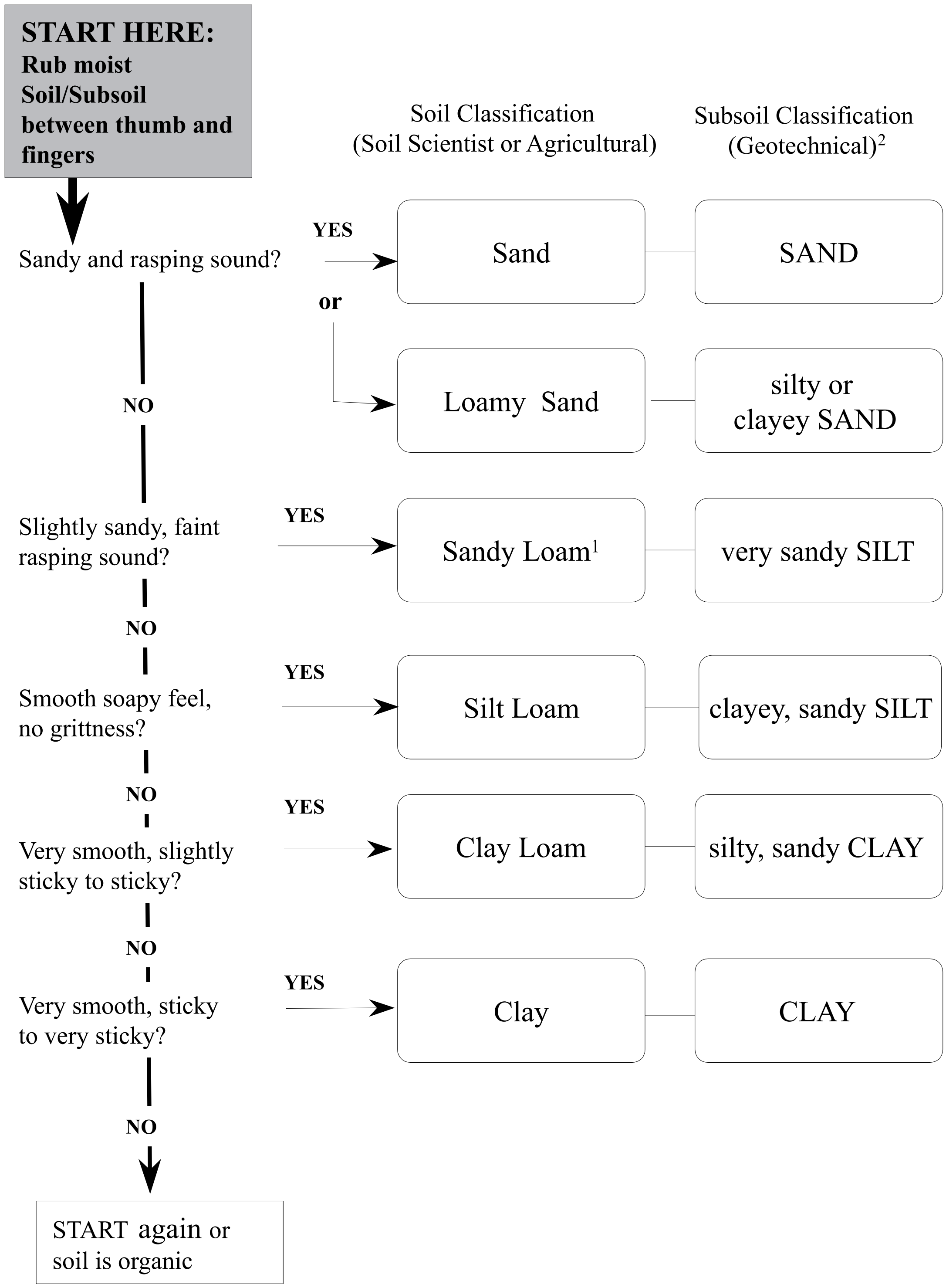
Texture which is one of the more important of the soil’s physical characteristics, influences factors such as moisture retention, drainage, tilling properties of the soil, its resistance to damage by stock and machinery and earliness of crop growth. Classes of texture are based on different combinations of sand, silt and clay. Figure G.1 shows the different textural classes for soils. The characteristic behaviour of six of the more commonly occurring soil textural classes are summarised in Table G.2.



Source: After Soil Survey Manual, USDA Handbook No. 18, 1951

FIGURE G.1 SOIL TEXTURAL CLASSES

TABLE G.1 SOIL/SUBSOIL CLASSIFICATION CHART



[1] Loam : A soil composed of a mixture of sand, silt and clay such that the properties of no one group dominates its characterisitics is called a Loam.

[2] Classification system used in BS 5930:1981 .

TABLE G.2 TEXTURE DETERMINATION OF MOISTENED SOIL

Feel and Sound	Cohesion and Plasticity	Field Soil Textural Class
sand paper feel and rasping sound	cannot be moulded into a ball	**Sand**
	will almost mould into a ball but disintegrates when pressed flat	**Loamy Sand**
slight sandy feel, faint rasping sound	moulds into cohesive ball which fissures when pressed flat	**Sandy Loam**
smooth soapy feel, non-sandy feel	moulds into cohesive ball which fissures when pressed flat	**Silt Loam**
very smooth, slightly sticky to sticky	plastic, moulds into a cohesive ball which deforms without fissuring	**Clay Loam**
very smooth, sticky to very sticky	very plastic, moulds into cohesive ball which deforms without fissuring	**Clay**

Source: After McLaren & Cameron, 1990

The main characteristics of the three main soil types are as follows:

- Sandy soils tend to dry out quickly so that crops growing on them suffer drought. These soils are often inherently acid and infertile but this can be corrected by the use of lime and fertiliser. They are generally more prone to water and wind erosion. They are light and easy to cultivate and therefore easily moved by mechanised soil handling;
- Clayey soils are often plastic and heavy and suffer from poor drainage. They are more fertile than sandy soils and are more difficult to cultivate and move by mechanised soil handling; and
- Loamy and silty soils have good moisture holding capacity but usually drain easily. They are usually fertile and moderately easy to cultivate. However, they can be easily damaged by mechanised soil handling, especially silty ones.

Cobbles and gravels dilute the volume of the actual soil and those larger than 50 to 60 mm can interfere with cultivation operations.

G.3 SOIL STRUCTURE

The term soil structure refers to the shape, size and degree of aggregation, if any, of the primary soil particles into naturally or artificially formed structural units (peds, clods and fragments). Peds are natural, relatively permanent aggregates, separated from each other by voids or natural surfaces of weakness. Less permanent aggregates, termed fragment or clods, formed at or near the surface by cultivations or frost action are not true peds *(McLaren & Cameron, 1990)*.

The productivity of a soil and its response to management depends on its structure to a large extent. Soil structure influences pore space, aeration, drainage conditions, root development and ease of working. Soils with aggregates of spherical shape have a greater pore space between peds, are more permeable and are generally more desirable than soils that are massive or coarsely blocky. Field description of soil structure indicates the shape and arrangement, the size and distinctiveness and durability of the aggregates. Peds are described according to:

- grade of soil structure - the proportion of the soil mass that is in the form of peds;
- class of soil structure - the size range of peds within each structure type; and

- type of soil structure - the shape and arrangement of peds.

A good soil structure provides sufficient pore space for excess water to drain downward and for plant roots to penetrate to depth but also sufficient fine pores to retain water and air that can sustain plant growth. Soil structure is the most easily damaged property of soils during restoration. The degree of damage is dependent upon the type of soil structure and conditions particularly, moisture content.

G.4 SOIL CONSISTENCE AND PLASTICITY INDEX

Soil consistence refers to the inherent qualities of soil that are expressed by the way in which the soil material holds together, deforms or ruptures when put under pressure. The consistence of soil depends on the kind of cohesive and adhesive forces which hold the soil material together and can vary greatly depending on the soil water content at the time when consistence is assessed. The consistence categories vary from loose or non-coherent to friable, up to extremely firm.

The plastic limit is the gravimeteric moisture content at which a soil changes from being friable into being plastic. It therefore represents the minimum amount of water at which puddling will occur and the maximum amount of water that a soil can hold when it is friable. The plastic limit is also refereed to as the ‘lower plastic limit’ and is assessed by measuring the water content of a sample of finely ground soil when it can be rolled into a thread 3 mm in diameter without breaking.

The liquid limit is the gravimetric moisture content at which the soil changes from being plastic and starts to behave as a viscous liquid. The liquid limit is also referred to as the ‘upper plastic limit’. The plasticity index is the difference in water contents between the upper and lower plastic limits *(Wild, 1988).*

G.5 POROSITY AND ROOTS

Porosity of the soil is conditioned by the shape, size and abundance of the various crevices, passages and other soil cavities which are included under the general name of soil pores. Porosity refers mainly to the voids between the soil structural units, which is strictly the structural porosity. Soil porosity is influenced largely by the type of structure, it is also influenced by the rooting and by the activity of earthworms and other soil macro-organisms. Porosity may be determined indirectly from the bulk density and particle density. Bulk density is defined as the mass of oven-dry soil per unit of volume and depends on the densities of the constituent soil particles and their packing arrangement. Values of bulk density range from < 1 tonne/m^3 for soils high in organic matter, to 1.0 - 1.4 tonnes/m^3 for well aggregated loamy soils, to 1.2 - 2.0 tonnes/m^3 for sands and compacted horizons *(White, 1979).* The bulk density of soils will be influenced by restoration, with root penetration particularly affected if soils become compacted during soil handling operations. The amount of water and nutrients which are available to a plant are influenced by the depth and surface area of rooting system which it can develop *(McLaren & Cameron, 1990).*

Porosity and pore size distribution determine the permeability of the soil and the air to water ratio prevailing and are therefore of considerable importance with regard to soil aeration and drainage regime. The porosity of the soil can be damaged during soil handling operations particularly during storage.

G.6 SOIL CHEMICAL PROPERTIES

Soils supply a range of macro and micronutrients (or trace elements) which are essential for plant growth. Most of theses nutrients are taken up by plant roots from the soil solution. Soils vary greatly in the amount of nutrients they are able to provide in this way. Some soils may be completely lacking in one or more of the nutrients required by plants, and plant growth in these soils suffers accordingly. The composition and concentration of the soil solution is varied and depends on a number of soil properties, such as parent material, fertiliser additions, pH, plant uptake and moisture content.

G.7 SOIL COLOUR, ORGANIC MATTER AND MOTTLING

Colour is the most obvious and easily determined of soil characteristics. Although it has little direct influence on the functioning of the soil a lot can be inferred from soil colour. An indication of the organic matter content of the soil can be deduced from it. Organic matter in the soil arises from the debris of green plants, animal residues and excreta that are deposited on the surface and admixed to a variable extent with the mineral component.

The colour of most soils varies with their moisture content and the basic colour of a soil horizon is normally recorded from the surface of a freshly broken soil aggregate in a field moist state. Some horizons will show mottling, areas of colour different from the overall background colour of the horizon. The most common forms of mottles are rusty coloured ones associated with poorly drained conditions; however, other types of mottles do occur. Since mottling is significant in relation soil moisture regime, it should be carefully noted. The abundance, colours, size and contrast of the mottles and the sharpness of the mottle boundaries are normally recorded.

G.8 SOIL BULK DENSITY

Bulk density measurements are an important indicator of the success of soil handling operations. A baseline measurement of the bulk density of the different soil horizons should be carried out in order for comparisons with post restoration values. Typical bulk densities for undisturbed topsoils are 1.0 to 1.8 tonnes/m^3 depending on texture and condition. Bulk densities increase with depth e.g. compact sandy loam subsoils may have bulk densities approaching 2.0 tonnes/m^3. Coarse textured soils also tend to have lower porosity owing to the close packing of the particles, even though individual pores may be large. The nature of the relationship between texture, bulk density and porosity is given in Table G.3.

TABLE G.3 GENERAL RELATIONSHIP BETWEEN TEXTURE, BULK DENSITY AND POROSITY OF MINERAL SOILS

Textural Class	Bulk Density (tonnes/m^3)	Porosity (%)
Sand	1.55	42
Sandy Loam	1.40	48
Fine Sandy Loam	1.30	51
Loam	1.20	55
Silt Loam	1.15	59
Clay Loam	1.10	59
Clay	1.05	60

Soil pores provide openings for gas exchange, water movement and root penetration. Soil mechanical impedance to root growth and low root oxygen environment due to poor water drainage can reduce crop yield and performance. Impairment of root distribution is usually noted with increasing densities above 1.2 tonnes/m^3. Roots may not penetrate heavy clays with bulk densities above 1.46 tonnes/m^3 and sandy soils with densities above 1.75 tonnes/m^3. Depending on texture, coarse fragment content of soil and plant species, complete impairment of root penetration can occur around 1.8 tonnes/m^3 *(Ramsay, 1986)*.

Soils should be moved only when dry i.e. at moisture content below their plastic limit. However, in temperate climates, subsoils are rarely this dry. It may be beneficial to pre-strip topsoil and grass the subsoil which will encourage drying out by evapotranspiration and exposure.

APPENDIX H. EQUIPMENT FOR SOIL BULK HANDLING

TABLE H.1 EQUIPMENT FOR SOIL HANDLING OPERATIONS

Lifting	Transport	Placement	Advantages/Disadvantages
Front loader	Dump truck	Light bulldozer or back acting shovel	– available on wheels or tracks with bucket capacity 1 - 2 m^3 – low shovel pressures when lifting soil – loading into trucks by gravity only, which breaks up and may cause mixing of soils – more efficient dealing with deep layers of soil rather than shallow variable soils – front loader does not run over layer being lifted – manoeuvrability limited by turning circle and short reach of bucket causing trafficking on layer below – more suited to subsoil moving rather than topsoil – uses pushing and lifting action
Front shovel	Dump truck	Light bulldozer or back acting shovel mounted on track carriage	– reach of 9 meters – 360^0 turning ability – good flexibility operating from standing position – uses pushing and lifting action
Bulldozer	Bulldozer	Bulldozer	– movement range limited – exerts strong horizontal force on soil, especially near lower part of blade and when working uphill – static ground pressure of 0.25 - 0.5 kg cm^{-2} – can cause compaction even at low ground pressure – uses pushing and lifting action

Lifting	Transport	Placement	Advantages/Disadvantages
Dragline bucket	Dump truck	Light bulldozer or back acting shovel	– use small size dragline bucket – the 360^0 turning ability coupled with the range of the boom makes it possible to lift a wide swath of soil along the face in just one pass of the tracked equipment – minimal damage to the soils – pulling action of machines requires that the machinery must position itself over the soil to be worked
Back-acting shovel	Dump truck	Light bulldozer or back acting shovel	– reach up to 10 meters shovel capacity about 1.5 m^3 – very accurate and mobile – high work rate compensates for low bucket capacity – if working from lower level soil, soil compaction can avoided – pulling action of machines requires that the machinery must position itself over the soil to be worked
Earthscraper	Earthscraper	Earthscraper	– unique as it combines soil lifting, transport and spreading ability in one move – often self-propelled or towed with push from additional dozer – compaction and smearing can be serious – scrapers operate on top of the soil to be moved, so that each filling and emptying operation involves running over the soil moved – empty scrapers may weigh 60 tonnes with loaded weights of 100 tonnes – static ground pressure of around 7 - 8 kg cm^{-2} – scraper cuts have depths of only 15 to 30 cm

Lifting	Transport	Placement	Advantages/Disadvantages
			– earthscrapers should only be used when soils are dry (both top and subsoils) and are at their highest bearing capacity – teeth can be fitted to scraper blade to increase break-out force – detailed planning and strict supervision required
	Dumptrucks		– recognised method of transporting soils from on point to another – dropping soils into the truck body and subsequent tipping to the ground involves no damage to most soils and may help to break up compacted layers – routing of trucks over exposed soil layers must be minimised – by combining trucks with long reach excavators it is possible to avoid running over soil layers during lifting and after spreading – can result in segregation of stony soils

Source: After Ramsay, 1986

APPENDIX I. COMPOSTING

The composting process requires a mix of materials to work most effectively. The basic requirements for successful composting include:

- ratio of carbonaceous material and nitrogenous material in the range of 15:1 to 40:1. If the ratio drops below 15:1 then the process starts to release ammonia and becomes problematic in terms of odours. If the ratio rises to much more than 40:1 , then the process slows down or even stops because there is insufficient nutrient to sustain bacterial growth;

- the compost heap or windrow must have structure created by woody materials (bulking) to allow air and water penetration and CO_2 and vapour release. Lack of structure will cause the material to slump, excluding the air and causing anaerobic degradation with its attendant odours and undesirable leachates;

- controls during windrowing and maturation are critical in determining final product quality; and

- the final quality of the end product is affected by the quality of the input material.

The basic raw material for composting schemes include those listed in Table I.1

TABLE I.1 MATERIAL SUITABLE FOR COMPOSTING

Source of material	Description	Advantages/disadvantages
Household vegetable, fruit and garden waste (VFG)	wastes include vegetable peelings, reject fruit and vegetables, spent cut flowers, grass cuttings, hedge clippings, pruning, weeds, leaves and dead plant material	– only available if collected separately – some plants should be excluded eg. rhubarb leaves have high oxalic acid content – broken slabs, stones, glass should be excluded – small scale composting schemes may not achieve sufficient temperatures to achieve a total kill of seeds and pernicious weeds
Municipal/private parks and landscape wastes or green waste (CGW)	wastes arising from landscaping works such as prunings, loppings, grass etc.	– avoid contamination with litter and non-plant wastes – useful sources of carbon containing structural material required in composting – material requires shredding
Food processing wastes	wastes arising from fruit and vegetable processing plants such as canneries, freezing plants, juice extraction plants etc.	– has high N and water content and is ideal to mix with woody wastes to give a good C:N ratio – these waste are generally of a high quality, uncontaminated by disease and chemical and are perceived as being very suitable for composting – lack of structure in heaps and windrows can cause anaerobic conditions leading to odour release – problem loads require mixing very quickly with woody material and should then be turned and aerated frequently

Source of material	Description	Advantages/disadvantages
Animal bedding and stable manure	wastes arising from animal bedding containing urine, faeces straw and/or paper	– material on its own can provide the basis for composting – used in the manufacture of mushroom compost – material will compost well but is high in lignin, tends to rely on fungal growth after the thermophilic phase for complete physical breakdown – good mixing with other plant waste tends to speed up the composting process
Pig and poultry manure	wastes arising from intensive agricultural production	– high N content – small amounts added to shredded plant wastes will improve the C:N ratio – too much will give rise to the production of ammonia with associated odour problems
Sewage sludge	usually composted in combination with green wastes, straw, lime, paper or wood chips for bulking	– contains large amounts of organic matter, nitrogen and phosphorus – nutrients are released slowly which enables vegetation to establish without regression – composting radically alters the physical nature of sewage sludge and eliminates many of the objectionable factors such as odours etc. – quality dependent on the quality of the materials used in the mixing – source segregated mixing materials produce good quality compost avoiding contamination with glass, heavy metals and sharp fragments – problems of public acceptability – heavy metal levels need to be analysed – weed contamination during storage – storing the compost outdoor can cause handling problems during application

APPENDIX J. HEDGE MANAGEMENT

General guidelines on planting, growing and managing hedges are given below. Some specialist advice should be sought prior to planting.

- the most common hedgerow species in Ireland include hawthorn, ash, rowan, elder, blackthorn, holly, crab apple, wild privet, hazel, alder, and climbing species such as brambles, dogrose and honeysuckle;

- hedge planting requires the same soil conditions as other planting and usually takes one of two forms, notch planting along the proposed hedge line or the preparation of a trench approximately 300 mm deep and 250-300 mm wide backfilled with the excavated material. In all cases a minimum of 5 two-year transplants (450-600 mm high) per meter run should be planted. Where a dense hedge is required two parallel staggered rows can be planted about 300 mm apart giving a total of 6-10 transplants per meter run;

- all new hedges should be protected against damage by livestock, wildlife or machinery;

- hedges should be managed on a phased basis to encourage diversity in height, stages of growth and form;

- cut/trim hedges in rotation preferably in December, January and February so as to reduce impacts on wildlife. Taller mature trees that form part of the hedge should not be cut; and

- an A-shaped hedge 1.8m to 2.0m high and 2.5m wide at the bottom is generally considered best for wildlife, while a shelter hedge is generally cut taller with straighter sides.

APPENDIX K. TREE ESTABLISHMENT ON LANDFILL SITES

There are four main components of soil condition which affect tree root development, mechanical resistance, aeration, fertility and moisture. Mechanical resistance and soil aeration are the two most important factors in terms of restricting vertical root growth. Roots increase in length because as newly formed cells in the actively growing tissue near the root tip grow, they increase in volume and push the root tip forward. Roots are therefore able to exert a measurable pressure, both axially and radially (maximum root growth pressures for a range of vegetation types are in the range of 0.7 - 2.5 MPa). When soil conditions are unfavourable, root pressures are greatly reduced. Anchorage is also necessary for roots to be able to exert pressure against the soil matrix. With a fine texture soil the root has better anchorage than with a coarse soil provided that the fine textured soil does not saturate.

Recent research findings by Bending and Moffat, 1997 conclude that:

- trees growing on undisturbed forest soils typically have a relatively shallow but wide-spreading root system with lateral roots extending outwards from the trunk to a distance of between 1 and 3 times the tree height. In general, tree roots will extend to 1 to 2 meters below ground level, with about 90% of all roots, including virtually all the larger roots, found in the upper 1m of soil. Extensive lateral roots extend outwards from the trunk to a distance of between 1 and 3 times the tree height. Figure K.1 shows typical root architecture.

- a 1.0m thick clay cap compacted to a bulk density of 1.8 - 1.9 tonnes/m^3, and with a permeability of 1x 10^{-9} m/s, is capable of preventing root penetration; however, it is not known how widely this standard is attained by the waste industry. Limited laboratory work undertaken during the Bending and Moffat trials showed that moisture content exerts an overriding control on density and suggested that it may be difficult to compact some clays to densities needed to prevent root penetration;

- a polyethylene membrane was effective in preventing root penetration, while a geotextile significantly reduced the degree of root penetration into underlying clay;

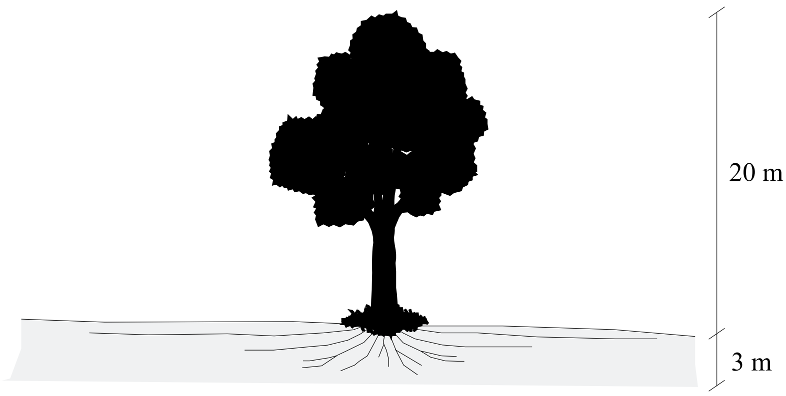
- a synthetic barrier layer should be used in the capping system to augment the effects of the clay cap on areas intended for woodland planting unless it can be shown by physical analysis in the field and laboratory that the recommended requirements for clay densities have been met;

- in all instances where a drainage layer is employed above a clay cap, a water permeable geotextile membrane should be placed above the drainage fill beneath the area to be planted;

- tree roots do not cause desiccation cracking in clay capping because they cannot extract enough moisture from the clay for significant shrinkage to occur;

- trees can be grown successfully on soil forming materials; however, the use of topsoil and subsoils in areas designated for tree planting will enable greater flexibility in species choice and promote significantly better growth. Where available, top and subsoils should always be placed upon soil forming materials to a minimum depth after placement of 200 - 300 mm. The minimum combined thickness of both topsoil and subsoil (which can include a percentage of soil forming materials) should be 1.0 m where a synthetic barrier is used, and 1.5 m in all other instances; and

- the main reasons for poor tree growth on restored landfills are soil compaction (i.e. subsoils and/or topsoils), waterlogging, drought, shallow soils and poor soil quality.



Extensive lateral roots extend outwards from the trunk to a distance of between 1 and 3 times the tree height. Mature trees have typically 99% of their root biomass situated within the top metre of soil

Source: Dobson & Moffat, 1993

FIGURE K.1 ILLUSTRATION OF TYPICAL ROOT ARCHITECTURE (DRAWN TO SCALE)

APPENDIX L. TALL AND MEDIUM TREES SUITABLE FOR LANDFILLS

Tall and medium height trees most likely to tolerate conditions on landfill sites. Species are classified as P-preferred, T-tolerant, S-sensitive to site conditions. *(* indicates native species)*

Species	Height at year 20 (m)	Site Conditions				Remarks
		Moist	Dry	Acidic	Alkaline	
Broadleaves						
Ash * *Fraxinus excelsior*	7	S	P		P,T	likes sheltered, well drained fertile soils
Aspen * *Populus tremula*	8	P,T	S	P,T		grows well on poorer soils, suckers readily and tends to form groves of trees
Beech *Fagus sylvatica*	5		P,T		P,T	shade bearer and casts a dense shade
Common alder * *Alnus glutinosa*	8	P,T	S	P	S	nitrogen fixing, grows well in damp areas, good for wildlife
Downy birch * *Betula pubescens*	8	P,T	S	P,T		tolerates low fertility, acidic and exposed sites
False acacia *Roninia pseudoacacia*	6		P,T	P,T	S	good amenity tree
Grey alder *Alnus incana*	8	P,T	S	P,T	S	nitrogen fixing, will grow well on drier sites
Italian alder *Alnus cordata*	9	P	T		P,T	
Pedunculate oak * *Quercus robur*	5	P	S	P	S	more fertile sites only
Norway maple *Acer plantanoides*	7	P	S		P,T	attractive amenity tree, likes deep, moist, alkaline soils
Red alder *Alnus rubra*	9	P		P,T		nitrogen fixing
Red oak *Quercus rubra*	6	P	S	P,T	S	amenity tree, rich autumn colour
Sessile oak * *Quercus petraea*	5	S	P,T	P,T		tolerate lighter textured soils than pedunculate, high amenity value
Silver birch * *Betula pendula*	9		P,T	P,T	S	fast growing, useful nurse crop, tolerates low fertility

Species	Height at year 20 (m)	Site Conditions				Remarks
		Moist	Dry	Acidic	Alkaline	
Broadleaves						
Small-leaved lime *Tillia cordata*	6	P	S		P	
Swedish whitebeam *Sorbus intermedia*	7	S	P		P	tolerant to air pollution, attractive amenity tree
Sycamore *Acer pseudoplatanus*	8	P	T	S	P,T	tolerant to exposure and air pollution, good for wildlife
Conifers						
Corsican pine *Pinus nigra var maritima*	8		P,T	S	P,T	grows well on wide range of soils, used in coastal areas, below 250m O.D
Douglas fir *Pseudotsuga menziesii*	8	P		P		unsuitable in exposed and wet areas, very windthrow susceptible, dislikes dry and limestone areas
European larch *Larix decidua*	8	P	S	P		high amenity and wildlife value, likes drier areas allows under-canopy to develop
Hybrid larch *Larix x eurolepis*	9	P	S	P	S	characteristics between those of EL and JL.
Japanese larch *Larix kaempferi*	9	S	P	S	P,T	high amenity and wildlife value, likes plenty of rainfall
Lodgepole pine *Pinus contorta*	7	P,T	S	T	P	grows well on wet or poor soils
Norway spruce *Picea abies*	9	P	S	P		sensitive to wind exposure
Scots pine * *Pinus sylvestris*	7		P	P,T	S	visually attractive tree, grows well on poor exposed sites
Sitka spruce *Picea sitchensis*	9	P,T		P		most soil types except dry and alkaline

Source: After Bending & Moffat, 1997

APPENDIX M. SMALL TREES SUITABLE FOR LANDFILLS

Small trees most likely to tolerate conditions on restored landfill sites. Species are classified as P-preferred, T-tolerant, S-sensitive to site conditions. *(* indicates native species)*

Species	Height at year 20 (m)	Site Conditions				Remarks
		Moist	Dry	Acidic	Alkaline	
Broadleaves						
Bird cherry * *Prunus padus*	4	P,T	S	S	P	good autumn colour, relatively shorted lived.
Blackthorn* *Prunus spinosa*	3	S	P	S	P	forms dense thickets, good spring and autumn colour
Broom *Cytisus scoparius*	2	S	P,T	P,T	S	visually attractive, good for insects
Buddleia *Buddleia davidii*	2		P	S	P	usually planted in gardens, good for butterflies
Common buckthorn *Rhamnus cathartica*	2	S	P		P	
Crab apple * *Malus* sylvestris	3	P	S	P	S	commonly found in hedgerows
Common dogwood *Cornus sanguinea*	2		P		P,T	
Common elder * *Sambucus nigra*	3	P	S	S	P,T	good food source for wildlife, common on disturbed ground
Hawthorn * *Crataegus monogyna*	4	S	P	S	P	commonly found in hedgerows, attractive tree with white blooms in the spring and deep red haws in autumn
Common privet *Lingustrum vulgare*	3	S	P	S	P	
Common Whitebeam* *Sorbus aria*	6		P,T	S	P,T	tolerant of exposed and coastal sites, attractive amenity tree
Dog rose *Rosa cania*	1.5	S	P	S	P,T	
Field maple *Acer campestre*	5	P	S	P,T		high conservation and landscape value

Species	Height at year 20 (m)	Site Conditions				Remarks
		Moist	Dry	Acidic	Alkaline	
Field rose *Rosa arvensis*	1	S	P	P	S	
Gean* (wild cherry) *Prunus avium*	6	S	P		P	More fertile sites and light demanding tree
Goat willow *Salix caprea*	4	S	P	S	P	associated with damp conditions
Green alder *Alnus viridis*	2	P	S	P	S	
Grey willow *Salix cinerea*	4	P,T	S	S	P	
Guelder rose *Viburnum opoulus*	2	P			P	
Hazel* *Corylus avellana*	3	P	S	S	P	good for wildlife
Holly* *Illex aquifolium*	3	S	P,T	S	P,T	good for wildlife
Rowan * (mountain ash) *Sorbus aucuparia*	6	P,T	T	P,T	S	hardy tree suitable for exposed site, good for wildlife
Sea buckthorn *Hippophae rhamnoides*	2.5		P,T		P,T	visually attractive and planted as sand binder
Spindle tree *Euonymus europaeus*	2.5	P			P	visually attractive
Wayfaring tree *Viburnum lantana*	2.5		P		P	

Source: After Bending & Moffat, 1997

APPENDIX N. TIMING AND METHOD OF TREE PLANTING

The following guidelines should be followed:

- if early tree planting is necessary then close liaison between gas engineers, landscape designers and restoration operators should occur. This will ensure minimal disruption to restored areas and enable access for installation, remedial works and monitoring. It is important to leave sufficient working area around the wellheads;

- trees should be planted when they are dormant, usually between late autumn and early spring (before the end of March). Autumn planting is preferred for broadleaves and some conifers. Care should be taken to avoid damage by frost during planting operations in mid-winter. Planting and subsequent maintenance must be carried out by competent an experienced staff;

- the density of woodland planting can vary considerably. Close spacing of 1m or less can be used to accelerate canopy closure and thereby create conditions suitable for colonisation (or introduction) of woodland ground flora. Closely spaced trees will also quickly form a dense impermeable barrier. Trees at close spacing will be much more expensive to plant and maintain; however, they may be visually more acceptable. Trees should be planted at a spacing between 1.6 and 1.8 m, and woody shrubs at between 0.8 and 1.2m. This gives a stocking density of 4,500 - 5,000 plants per hectare assuming 10% of the area is allocated for woody shrubs *(Bending and Moffat, 1997);*

- thinning requirement will vary depending on plant spacing, species and intended use. An example of thinning requirements are listed in Table N.1;

TABLE N.1 PLANT SPACING AND THINNING REQUIREMENTS

Planting centres (m)	No. trees /ha	First thinning year after planting
1	10,000	3
1.5	4,444	7 - 10
2.0	2,500	15 - 20
3.6	772	25

- trees can be planted on a simple grid pattern, naturally staggered rows, asymmetrical rows or a more natural random pattern. On areas designated for informal recreation, woodland blocks should have irregular edges with bays and intervening woodland peninsulas;

- bare rooted transplants and cell grown stock should be notch planted and this is generally the preferred method. Figure N.1 illustrates notch planting method for bare rooted transplants. A slot is made in the ground with a spade, and the tree is inserted with its roots spread as widely as possible and the ground firmed around the tree with the heel. Care must be taken to ensure that the tree is planted at the same level as it was in the nursery. Where subsoil ripping has occurred, trees should be planted in the disturbed soil 30 cm to one side of the rip line;

- pit planting should be considered in a situation where soil cultivation is not required and/or on dry sites. Planters can achieve a better spread of roots and can firm plants. This achieves a superior quality of planting leading to higher survival rates. Pit planting is more expensive than notch planting;

- a weed free area of approximately 1m diameter will need to be created at the time of planting around each tree. The tree should be planted in the centre of the band. Complete weed control is inferior to band control. Creating and maintaining a weed-free planting area can be achieved through herbicide use or, through a combination of cultivations and mulching; and

- all areas should be beaten-up i.e. restocked to 100%, in the 2 years following the planting. In commercial forestry any area with 85% stocking at the end of year one is considered fully stocked and no beating up is recommended.

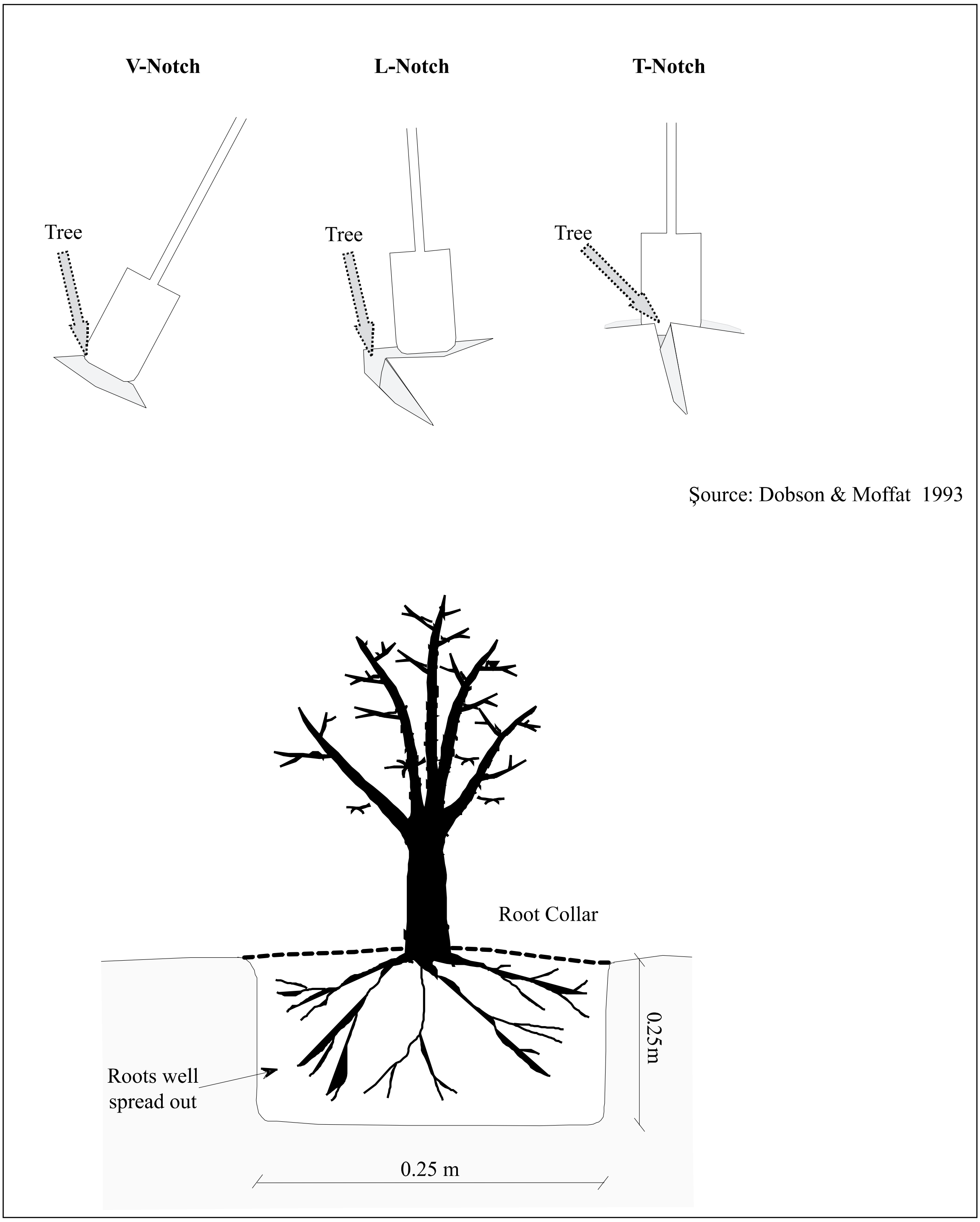


FIGURE N.1 ILLUSTRATION OF NOTCH AND PIT PLANTING

APPENDIX O.
TREE PROTECTION

Trees will require protection from animal damage (rabbits, hares, cattle, sheep, goats etc.). Large woodland blocks can be protected by appropriate stock/rabbit proof fencing. Where small blocks are planted or narrow strips with open areas, fencing of individual blocks or strips is superior to the use of tubes. Individual protective tubes rarely work well on large scale plantings. As well as incubating plants they also incubate a range of pests which are normally not a problem with open planting. Tubes are also expensive and require considerable maintenance. Plants can also be severely damaged by browsing or exposure when they grow above the tops of the tubes.

There are numerous types of individual tree guards on the market and the type chosen will depend on site conditions. Those currently available include:

- spiral rabbit guards - appropriate where rabbits are a problem but do not prevent grazing by livestock and can only be used on whips or larger stock;

- plastic mesh guards - consists of polythene plastic mesh tubes of varying height and diameter and supported by single stake. Provide protection from most animals and can be used on all sizes of stock from seedlings to standards;

- plastic tubes - are split longitudinally and spring in on themselves to form smaller tubes about 50 mm diameter and 200 mm tall. To ensure protection they must be pushed at least 5 mm into the ground; and

- treeshelters - translucent plastic tubes up to 2m high which can be used both as a means of increasing growth rates and providing protection from animals, herbicide drift and ring barking by strimmers. Some concern is expressed that these may encourage trees to become too soft to cope with exposure. Treeshelters should be left around the tree until the shelter naturally disintegrates after 5 to 10 years.

APPENDIX P. GRASS AND WILDFLOWER SPECIES

Table P.1 gives a list of the species of grasses and wildflowers that could be sown either as a pure wildflower stand, or in a mix with grasses to establish a wildflower meadow. The actual species sown will need to be determined on a site by site basis taking into account site conditions, local vegetation and afteruse. Wildflower seeds of Irish origin should be used and for grasses species which are commonly found in Ireland and which are not competitive and are appropriate for meadows and pastures should be used. Specialist advice should be sought in selecting appropriate species to include in the seed mix.

TABLE P.1 LIST OF GRASS SPECIES AND WILDFLOWERS

Grasses for meadows and pastures	**Common name**	***Scientific Name***
	Brown bent	*Agrostis canina*
	Cocksfoot	*Dactylis glomerta*
	Common bent (or brown bent	*Agrostis tenius*
	Crested Dog’s-tail	*Cynosurus cristatus*
	Meadow fescue	*Festuca pratensis*
	Meadow foxtail	*Alopecurus pratensis*
	Rough stalked meadow grass	*Poa trivalisis*
	Smooth stalked meadow grass	*Poa pratensis*
	Sweet vernal grass	*Anthoxanthum odoratum*
	Timothy grass	*Phleum pratense*
Wild Flowers		
	Birdsfoot trefoil	*Lotus corniculatus*
	Bladder campion	*Silene vulgaris*
	Black meddick	*Medicago lulpulina*
	Bulbous buttercup	*Ranunculus bulbosus*
	Burnet saxifrage	*Primpinella saxifraga*
	Cowslip	*Primula veris*
	Common vetch	*Vicia sativa*
	Dandelion	*Traxacum officinale*
	Field scabious	*Knautia arvensis*
	Greater knapweed	*Centaurea scabiosa*
	Hawkbits	Leontodon spp.
	Kidney vetch	*Anthyllis vulneraria*
	Lesser knapweed	*Centaurea nigra*
	Lady’s bedstraw	*Galium verum*
	Lady’s smock	*Cardamine pratensis*
	Marjoram	*Origanum vulgare*
	Meadow buttercup	*Ranunculus acris*
	Meadow sweet	*Filipendula vulgaris*
	Ox-eye Daisy	*Chrysanthemum segetum*
	Ragged robin	*Lychnis flos-cuculi*
	Red clover	*Trifolium pratense*
	Ribworth plantain	*Plantago lanceolata*
	Self heal	*Prunella vulgaris*
	Sorrell	*Rumex acetosa*
	St Johns wort	*Hypericum perforatum*
	White Campion	*Melandrium noctiflorum*
	Wild carrot	*Dancus carota*
	Yarrow	*Achillea millefolium*
	Yellow Rattle	*Rhinanthus crista-galli*

APPENDIX Q. LIST OF SPECIES FOR WETLANDS AND PONDS

TABLE Q.1 LIST OF SPECIES APPROPRIATE FOR WETLANDS AND PONDS

Vegetational Zone	*Scientific name*	Common name
Aquatics	*Callitriche spp.*	Starwort
	Elodea canadenis	*Canadian waterweed
	Hydrocharis morus-ranae	Frog-bit
	Lemna spp.	Duckweeds
	Myriophyllum spp.	Water milfoils
	Nymphaea spp.	*Water-lily
	Potamogeton spp.	Pondweeds
	Ranunculus aquatilis	Water crowfoot
	Zannichellia palustris	Horned pondweed
Marginal/Emergents and fringing	*Angelica sylvestris*	Wild angelica
	Caltha paustris	Marsh marigold
	Cardamine pratensis	Lady's smock
	Chrysanthemum segetum	Ox-eye daisy
	Eupatorium cannabinum	Hemp agrimony
	Filipendula vulgaris	Meadow sweet
	Geum rivale	Water avens
	Iris pseudacorus	Yellow Flag Iris
	Juncus spp	Rushes
	Lotus uliginosus	Greater trefoil
	Lychinus flos-cuculi	Ragged robin
	Lysimachia vulgaris	Yellow loosestrife
	Lythrum salicaria	Purple loosestrife
	Mentha aquatica	Water mint
	Narthecium ossifragum	Bog asphodel
	Phalaris arundinacea	Reed-grass
	Phragmites communis	*Reed
	Polygonum amphibium	*Amphibious bistort
	Pulicaria dysenterica	Common fleabane
	Rhinanthus crista-galli	Yellow rattle
	Sparganium erectum	*Bur reed
	Sagittaria sagittifolia	Arrowhead
	Scripus lacustris	Bulrush
	Typha latifolia	False bulrush
	Typha angustifolia	*Lesser bulrush
Grasses	*Agrostis stolonifera*	Creeping bent-grass
	Alopecurus geniculatus	Marsh Fox-tail
	Alopecurus pratensis	Meadow Fox-tail
	Anthoxanthum odoratum	Sweet Vernal-grass
	Cynosurus cristatus	Crested Dog's-tail
	Deschampsia cespitosa	Tufted-hair-grass
	Poa trivalisis	Rough meadow-grass
Trees	*Alnus spp.*	Alders
	Betula spp.	Birch
	Quercus spp.	Oak
	Salix spp.	*Willows

** indicates species that may become invasive and therefore may require control*

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Urban Wastewater Discharges in Ireland; *A Report for 1996-1997 (1999)*	IR£10/€12.70
Handbook on Urban Wastewater Treatment Regulations. *(1996)*	IR£15/€19.05
Waste Water Treatment Manual *Preliminary Treatment. (1995)*	IR£15/€19.05
Wastewater Treatment Manual *Primary, Secondary & Tertiary Treatment (1997)*	IR£15/€19.05
National Waste Database - *Report for 1995. (1996)*	IR£15/€19.05
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