Best Practice Note: Landfarming

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Note

This best practice note is advisory only. It has been prepared to assist contaminated land practitioners in NSW and should be read in conjunction with guidance documents, recognised industry best practice, standards and other technical publications.

The note will be revised from time to time following feedback from stakeholders and readers should ensure they are using the latest version. Regular revision will ensure its ongoing relevance and update best practice as the result of regulator and industry experience.

Comments are welcome via email to upssreg@epa.nsw.gov.au

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1. Introduction

'Landfarming' is a form of bioremediation which, with the proper controls, can be a practical, effective, durable and cost-effective method for treating certain types of contamination in soils. Landfarms are engineered bioremediation systems which generally use tilling or ploughing to reduce contaminant levels biologically. Another well-practised system of bioremediation uses forced air that actively aerates the contaminated mass to encourage bioremediation. Known as 'biopiles', they are discussed further in Appendix I.

The Environment Protection Authority (EPA) has prepared this best practice note to outline what it expects from those who undertake landfarming remediation in NSW. It aims to promote good practice and assist practitioners to comply with the requirements of the *Protection of the Environment Operations Act 1997* (POEO Act), particularly the uncontrolled release of emissions to air, land and water. This note does not provide advice on how or when to use the landfarming process but describes control measures the EPA believes should be applied to minimise environmental impacts from the process. It applies only to temporary and non-commercial operations and does not provide guidance on the control measures required at permanent or commercial landfarms.

When the use of bioremediation technology for remediating soils on a site is being considered, landfarming may not be a suitable option. Consideration should be given to alternatives such as engineered biopiles or moving the soils off-site for treatment at a commercial landfarm/soil treatment facility, such as the soil recycling facility at Cootamundra.

The use of on-site, in-situ, emission-controlled and economical treatment technologies is consistent with the hierarchy for site remediation and/or management in the *National Environment Protection (Assessment of Site Contamination) Measure* (NEPC 2013). Landfarming soil on-site so that it becomes suitable for reuse will minimise the requirement for off-site disposal.

In compiling this note, the EPA reviewed the guidance for the landfarming process currently available. A number of useful information sources are included at the end of this note for the benefit of practitioners. This list is not exhaustive and other guidance may be available.

The EPA recommends the use of these guidelines to avoid breaches of the POEO Act which may result in enforcement action by a regulatory authority.

2. Basic process description

Landfarming is a biological process which uses naturally occurring micro-organisms, such as bacteria and fungi, to eliminate, attenuate or transform polluting or contaminating substances in soils to reduce the risks to human health and the environment (UK EA 2002).

Landfarming is an above-ground, engineered process which involves the spreading of excavated contaminated soils in a thin layer (generally < 0.3 metres) on a suitably prepared surface (UK EA 2002). This is followed by the stimulation of aerobic microbial activity within the soils through aeration and/or the addition of minerals, nutrients and moisture. Other materials such as compost can be added to improve the properties of the substrate. The movement of oxygen through the soil promotes the aerobic degradation of organic chemicals.

Landfarming is a passive form of remediation that generally requires an extended time frame, possibly up to 24 months, depending on a number of factors, including the nature of the contamination, the concentrations of contaminants, types of soil and volume of soil to be remediated (SA EPA 2005).

Landfarming is an established remedial treatment process that has been commercially available for several decades. It is a technique often used at petroleum refineries to remediate tank sludges and contaminated soils and also for treating superficial hydrocarbon-impacted soils typically found at petroleum storage sites.

3. Assessing the suitability of landfarming

When deciding whether landfarming is a suitable remedial option for a particular site, a number of factors need to be assessed and certain criteria met. These should be detailed in a remedial action plan (RAP). A single overriding factor may be enough to make landfarming unsuitable for a site.

Table 1 outlines a number of the factors and respective suitability criteria which should be considered before identifying landfarming as an appropriate remedial option.

Table 1: Factors affecting landfarming suitability

Factor	Suitability criteria
Contaminant types	Landfarming is suitable for the treatment of a variety of organic chemicals including: • benzene, toluene, ethlybenzene and xylenes (BTEX) • total petroleum hydrocarbons (TPH), such as diesels, light lubricating oils, crude oil • polycyclic aromatic hydrocarbons (PAHs), particularly the lower-ringed aromatic lighter compounds, such as naphthalene and phenanthrene • phenolic compounds. Biodegradation rates are generally higher for saturated hydrocarbons followed by mono-aromatic (such as BTEX and phenols) and the lighter polyaromatic hydrocarbons (like the 2-, 3- and 4-ringed PAHs) (UK EA 2002). Long-chain hydrocarbons and those with a higher molecular weight (generally 20 carbon atoms or over) are more resistant to biodegradation, but will still biodegrade. Landfarming is not a suitable treatment method for heavy metals, complex PAHs or chlorinated hydrocarbons and high concentrations of these contaminants in the soil inhibit microbial degradation of the contaminants (UK EA 2002).
Contaminant concentrations	Soils containing TPH concentrations of 8% or more are not generally suitable for landfarming (US EPA 2003), as high concentrations of oil, grease and tar can physically block pore spaces in soils, limiting the mass transfer of nutrients, water and oxygen into the soils and 'smothering' the landfarming process (NPT 2009). The risk of impacts from volatile organic compounds (VOCs) and odours will require control/management (see Section 5 of this practice note).

Factor	Suitability criteria
Volume of contaminated soils	The volume of soils to be treated will affect the treatment area required, treatment time and costs. A small volume of soil with low concentrations of volatile contaminants will present fewer risks to sensitive receptors and therefore probably require less stringent control measures. Large volumes will require wider treatment areas and, depending on the nature of the contamination, more costly control measures.
Site area	A suitably sized treatment area is required to spread the necessary volume of contaminated soils to be landfarmed. Small sites with limited treatment areas are unlikely to be suitable for landfarming soils.
Site topography	Generally relatively flat sites are required for landfarming and sites with steep gradients are not suitable. Topography may also have an effect on emissions.
Local geology	A good understanding of the local geology is important when identifying the sensitivity and whether the area on which the landfarmed material is placed needs to be lined or protected.
Hydrogeology	As with geology, an understanding of the vulnerability of the groundwater as a receptor and pathway is important, as well as the location of nearby groundwater bores, the direction of groundwater flow and baseline conditions.
Meteorology	Wind speed and direction, ambient temperature, rainfall, atmospheric stability and mixing height will all affect how readily landfarming emissions are dispersed in the environment. The frequency of calm conditions and temperature inversion effects are important considerations for the dispersion of emissions to air and also how they may be experienced by the local community as either health impacts and/or odour nuisance.
Distance to sensitive receptors	Landfarming is generally not considered to be suitable in residential areas and the potential impacts to sensitive receptors such as surface waters, bores and humans from an area being landfarmed nearby will need to be adequately assessed when appraising the remedial options. Impacts from dust, odour, vapours, leachates, etc. will all need to be addressed (see Section 5 of this practice note).
Time	Time scales for achieving remediation criteria may vary, depending on a number of the above factors, such as nature and concentration of contamination, clean-up criteria, soil type, volume of soil and size of treatment area, but could be anything between three and 24 months (UK EA 2002).
Cost	The costs of landfarming as a remedial option will depend on a number of the above factors, including the nature and concentration of contaminants, the volume to be treated and area available for treatment, time scales, and the remediation criteria to be achieved. Landfarming should not be considered a cheap remedial option and, depending on the control measures required, it could be costly to do properly.

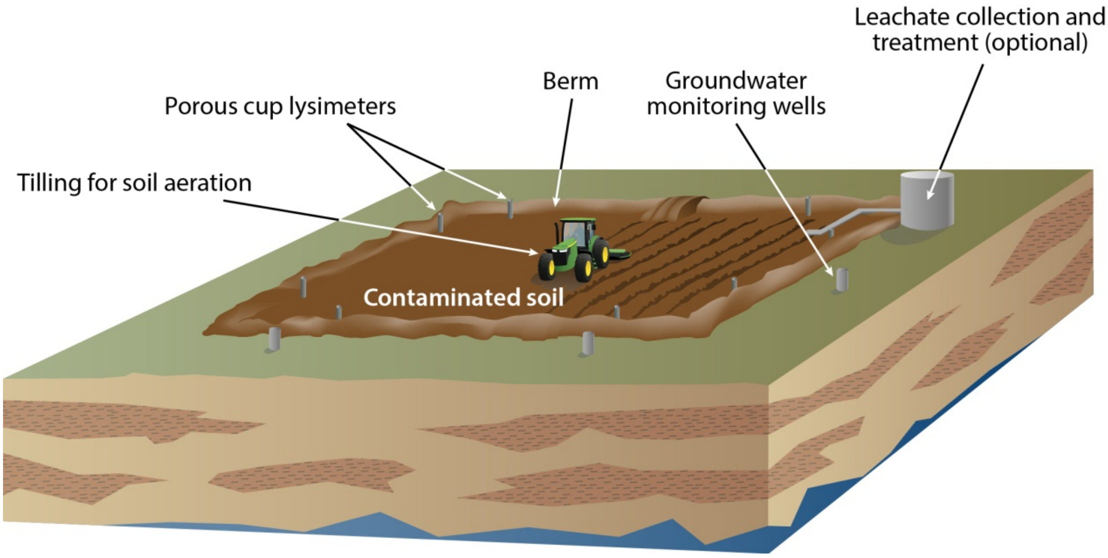
Landfarming may be a suitable remediation option for sites that are remote from residential areas, have soils with low concentrations of volatile compounds and where all potential emissions to air, land or water can be thoroughly managed. Volatilisation will occur, particularly from the shorter chain contaminants, so landfarming as a remedial technique requires measures to be taken that optimise and maximise biodegradation as well as control volatilisation. No offensive odours should be detected at the site boundary.

Landfarming to remove volatile constituents from soils through evaporation (that is, a physical process only) is not acceptable, unless the volatile constituents are captured and treated.

If it cannot be demonstrated that biodegradation will occur, it is not landfarming.

Where there is uncertainty about the effectiveness of landfarming to remediate a particular site, treatability studies should be undertaken to determine whether any reduction in concentration will be due to biochemical processes and not just chemical processes alone, such as volatilisation and photo-decomposition. These studies will also provide important design information required for the success of the landfarm as well as an estimate of the potential time frames for achieving the remedial target concentrations (US EPA 2003). Treatability studies can involve both laboratory and field trials.

Figure 1: Typical landfarming operation



Source: USEPA 1994

4. Landfarming process controls

The process of biodegradation is enhanced by optimising and controlling a number of key environmental parameters, as discussed in this section.

Oxygen

It is crucial to balance the aeration of landfarmed soils so that it is sufficient to promote optimal microbial degradation of contaminants, but low enough to prevent excessive volatilisation of compounds, such as BTEX (UK EA 2002).

Temperature

To promote biological activity which is regulated by soil temperature, temperature should ideally be kept within the range of 10–45°C (US EPA 2003).

pH

pH should ideally range between 6 and 8 to facilitate bacterial growth (UK EA 2002). However pH also has a large effect on the mobility of metals, rate of abiotic transformation of organic waste constituents, soil structure and the availability of nutrients, particularly outside the optimum 6–8 range.

Microbial population density

Microbial population densities in typical soils range from 10^4 to 10^7 colony-forming units per gram (CFU/g). According to US EPA (1994), 'For landfarming to be effective the minimum heterotrophic plate count should be 10^3 CFU/g.' Below this, landfarming may still be effective as long as the existing bacteria are stimulated using nutrients or the soil is amended to increase the bacterial population.

Nutrient balance

Applying additional nutrients, such as manure or complete chemical fertilisers, may be necessary to optimise biodegradation processes as the major nutrients limiting it are nitrogen and phosphorus. Effective biodegradation requires the carbon to nitrogen to phosphorus ratios to be between 100:10:1 and 100:1:0.5 (US EPA 1994). This ratio may be calculated from the soil bulk density and the total hydrocarbon concentration (Environment Canada 2007).

Time

Mixing (aeration) should be performed at regular intervals, such as between one and four weeks, according to site conditions and contamination characteristics. This is designed to limit fungal growth and increase biodegradation rates by enhancing oxygen infiltration, the mixing of hydrocarbons and homogenisation of soils, nutrients, water, air and micro-organisms.

Growth of the microbial population can take time to reach high population numbers and too frequent disturbance of the landfarm bed for aeration may interrupt this. During aeration of the landfarmed materials, some of the more volatile petroleum products will be lost through evaporation, while the remainder will be degraded by microbial action in the shorter term. The heavier, less volatile petroleum products will not evaporate and these products will primarily break down through biodegradation processes over a longer period (US EPA 1994).

Contaminant load

Soils containing TPH concentrations of 8% or more are not generally suitable for landfarming (US EPA 2003). High concentrations of oil, grease and tar can physically block pore spaces in soils, limiting the mass transfer of nutrients, water and oxygen and 'smothering' the landfarm process (NPT 2009).

Moisture

Ideal soil moisture content is between 12 and 30% by weight (US EPA 1994) or between 40 and 85% of the field capacity (UK EA 2002 and US EPA 1994). Soils should be moist but not wet as too much moisture restricts the movement of air through them.

Soil texture

Soils (such as clays) that clump together are difficult to aerate and result in low oxygen concentrations (US EPA 1994). The distribution of nutrients and moisture can also be hampered in clayey soils. However the structure of dispersed massive clay soils can be amended by adding soil conditioners, such as gypsum, and bulking agents, such as sawdust. Clumpy soils may also require pre-treatment.

Very coarse soils are not suited to landfarming as they do not retain moisture and nutrients. Volatilisation of compounds occurs more readily from coarse-grained soils than from those with fine grains (Environment Canada 2007). Organic amendment using woodchips, sawdust, straw, hay and animal manure can reduce bulk density and improve soil structure and oxygen infiltration and increase the moisture-holding capacity of sandy soils.

Adding organic materials to soils may adversely affect their geotechnical properties and, if the proposed end use of the soil is for engineering fill, addition of organic materials should be carefully considered.

5. Environmental control measures

Any proposal for landfarming should demonstrate adequate safeguards for the protection of human health and the environment. The potential for uncontrolled emissions of, for example, VOCs, leachates and odours and any other adverse effects from treatment needs to be considered on a site-specific basis according to the nature of the contamination and the conditions of the site (see Section 3, Table 1 of this practice note).

Landfarming sites should not be located in sensitive areas, such as residential.

Consultation with regulatory authorities and nearby owners and occupiers potentially affected by the landfarming activities should occur early in the planning process. NSW planning legislation may require approvals from the local authority, while the EPA may need to approve the undertaking of the works, particularly if the premises operates under an environment protection licence or material is transported, or disposed of, to or from site (see Section 7 of this practice note).

The potential impact on the existing urban fabric, such as the location and position of buildings like multi-storey commercial buildings, should also be considered when planning the positioning of stockpiles, as wind tunnelling may occur which can magnify air pollution problems.

When considering whether landfarming is a suitable remedial option for a site, a number of key issues should be addressed, as discussed in this section.

Control of volatile emissions

Control, capture and treatment of the release to the atmosphere of VOCs using covers, structural enclosures, and abatement techniques may be required under certain conditions if volatile constituents are present in the soils being landfarmed. Emissions should present no health risks and compliance with air quality standards and occupational exposure standards is required. For genotoxic carcinogens, there are no safe levels and emission rates should be reduced to as low as possible.

To ensure compliance with air quality regulations (see Section 6 of this practice note), the air emission controls needed will be determined on a site-specific basis and depend on a number of factors, including the nature of the contaminated material, location of sensitive receptors, etc. (US EPA 1994, Table 2). Equipment such as 'tents' can be used to capture VOCs, which can then be sequestered on activated carbon filters.

Compliance monitoring at the site boundary may be required where the risk of potential emissions is high, as is the sensitivity of receptors. The need for control and treatment measures should be determined during appraisal of the remedial options for the site. If deemed necessary, appropriate vapour treatment technology should specify operational and monitoring parameters, with these detailed in both the RAP and the environmental management plan (EMP).

Control of leachate and stormwater

Appropriate water management systems to control stormwater flow onto and off the landfarmed materials will avoid saturation of the treatment area and the release of leachate. Run-on can be controlled by bunds or ditches which intercept and divert the flow of stormwater away from the landfarmed material (US EPA 1994).

Leachate and run-off can be managed by:

- diversion of water and leachate to a suitably lined retention pond where it can be recycled over the landfarmed materials to maintain moisture content
- on-site treatment which will require either approval from the local authority for discharges to stormwater or a trade waste agreement for disposal to sewer
- being tankered off-site for treatment and disposal.

The site should be graded to allow surface water and leachate to drain. The minimum recommended gradient is 2% so that the final floor-level gradient enables surface water and leachate to drain to a suitably lined retention pond. Leachate retention ponds should be within a bunded area. Heavy rainfall will increase the amount of leachate and covering landfarmed soils will reduce the amount of leachate generated and odours, as well as evaporation from the mass.

To prevent leachate from the landfarmed soils infiltrating the underlying groundwater, the landfarm should be located on a suitable, low-permeability liner. This could be compacted clay or another material with a hydraulic conductivity of equal to or less than 10^{-9} metres per second (Tas DTAE 2006). A suitable depth of sacrificial material must be placed on top of the liner to protect it during tilling and placement and removal of soils (Alaska DEC 2011).

Control of dust

Dust may be generated during the excavation and mixing of the soils. A control hierarchy should firstly prevent the generation of dust, then minimise the source, followed by containment and control if required. Dust may indicate less than optimal moisture conditions in the landfarmed soils and this should be addressed.

Dust and soil erosion control measures may include:

- dust suppressants (such as water, sprays and carts)
- height, location and orientation of windrows
- windbreaks and screens
- covers
- bunds/berms or nets.

Bunds/berms or nets should be constructed around the entire perimeter of the landfarm at a height sufficient to contain the dust and soils.

Real-time particulate (dust) monitoring programs and reactive management plans may be required in situations where the risk of potential emissions is high, as is the sensitivity of receptors. Best management practice must be the guiding principle to prevent or minimise air pollution.

Control of odours

Odours generated during the excavation and mixing of the soils need to be managed at their source. They are difficult to control and measures taken should include best practice and the use of best available control technology to mitigate odour. Control measures may include the use of odour suppressants and foggers and biodegradable foams and/or locating the landfarmed soils in remote areas away from sensitive receptors. There should be no offensive odours at the property boundary and compliance monitoring at the boundary may be required where the risk of potential emissions is high, as is the sensitivity of receptors.

Compliance monitoring may include monitoring of VOCs and subjective odour surveys. Where the mix of VOCs is known, their measured concentration may be translated to an odour concentration by application of odour detection threshold data. The requirement for any control and treatment measures will need to be determined during appraisal of remedial options for the site and, if required, the measures should be detailed in the RAP and EMP.

Other controls

The site should be clearly marked out with appropriate signage to prevent unauthorised public access. Signage should also nominate the appropriate contacts in the event of an incident or emergency.

Regular environmental monitoring will be required to ensure that emission control measures are effective during the operation of the landfarming process.

Where specific control measures are not considered necessary at a site, this decision should be justified by demonstrating in the RAP how emissions from the landfarm will not result in harm to human health or the environment. The requirement for particular control measures will have a considerable influence when assessing the cost-benefits of landfarming as a remedial option and clear commitment to the use of appropriate control measures will be crucial in obtaining statutory approvals for the activity.

6. Landfarming strategy

Before landfarming commences on a site, an appropriate landfarming strategy needs to be developed and implemented. This strategy should be described in the RAP and EMP (if required) for the site and include the following details:

- location and layout plans of the proposed landfarm showing its proximity to sensitive receptors, such as surface water, residences, infrastructure, groundwater bores, etc. and the space available on the site for the landfarming process – generally landfarming needs to be carried out on large isolated sites of over 0.5 hectares
- assessment of the factors to determine the suitability of the proposed landfarm (see Table 1)
- results of a baseline sampling of soils on which the landfarmed soils are to be placed, including sampling methods, frequency, number of samples and analyses
- information on local climatic conditions, including average rainfall, temperature, evaporation, topographic effects, wind strengths and prevailing winds – prevailing winds can dictate the location of the landfarm with reference to nearby sensitive receptors (US EPA 2003)
- details on the materials to be used to construct a low-permeability liner for the base and retention ponds
- air emission control measures and air quality monitoring to be undertaken as included in an Air Quality Management Plan
- details of stormwater, leachate and run-off management, including groundwater and/or surface water monitoring

- requirements for odour control and monitoring, including an estimate of the potential impact of odour
- measures to be taken to control dust and erosion of soils from the landfarmed area
- a proposed soil sampling and analysis program, including the remediation target levels and predicted time scales for completion of the landfarming process
- details of monitoring to be undertaken to allow the optimisation of biodegradation rates during the landfarming process – monitoring should include assessing the reduction in contaminant mass, moisture content and nutrient levels as a minimum, with consideration given to assessing the rates of carbon dioxide production, biodegradation (generation of intermediate products), oxygen, temperature, pH, etc.
- how often the landfarmed soils will be mixed (aerated) and the requirement for the addition of nutrients
- proposed uses of the treated soils and contingency measures should the soils not meet the set target concentrations within the time scales or where unplanned events such as failure of equipment occur – note any materials removed from the site will be characterised as waste and must be dealt with in accordance with the NSW Government's framework for managing wastes
- proposed community consultation, including details of how complaints will be handled
- signage proposed at the site, including contact details for receiving complaints
- how access to the area of landfarming will be restricted to any non-authorised personnel.

7. Legislative requirements

All landfarming activities must be carried out in accordance with applicable provisions of *State Environmental Planning Policy 55: Remediation of Land* and conducted in a manner that prevents or minimises the emission of dust, odour and noise from the site.

All activities must comply with applicable NSW environmental legislation with particular reference, where relevant, to:

- *Protection of the Environmental Operations Act 1997*
- Protection of the Environment Operations (Clean Air) Regulation 2010
- *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (DEC 2005)
- *Approved Methods for the Sampling and Analysis of Air Pollutants in NSW* (DEC 2007)
- *Technical Framework: Assessment and Management of Odour from Stationary Sources in NSW* (DEC 2006a)
- *Technical Notes: Assessment and Management of Odour from Stationary Sources in NSW* (DEC 2006b)

Waste generated or stored at the site must be assessed and classified in accordance with the *Waste Classification Guidelines: Part 1 – Classifying Waste* (DECCW 2009).

Any waste transported from the site that is required by the Protection of the Environment (Waste) Regulation 2005 to be tracked must be recorded using the EPA's on-line tracking system or an alternative system approved in writing by the EPA.

8. Validation

The time frame for landfarming is site-specific: treatment is complete when the remedial target levels have been achieved for the specified use of the soils and there is confirmation that the chemicals of concern no longer present a risk of harm to human health or the environment.

The number of samples collected and analysed for the validation of landfarmed soil should be adequate to provide a statistically reliable result (EPA 1995), taking into account the intended use of the soils (SA EPA 2005). After removal of the landfarmed soils, the underlying area should be validated to confirm that contamination has not migrated vertically through the underlying liner (Tas DTAE 2006).

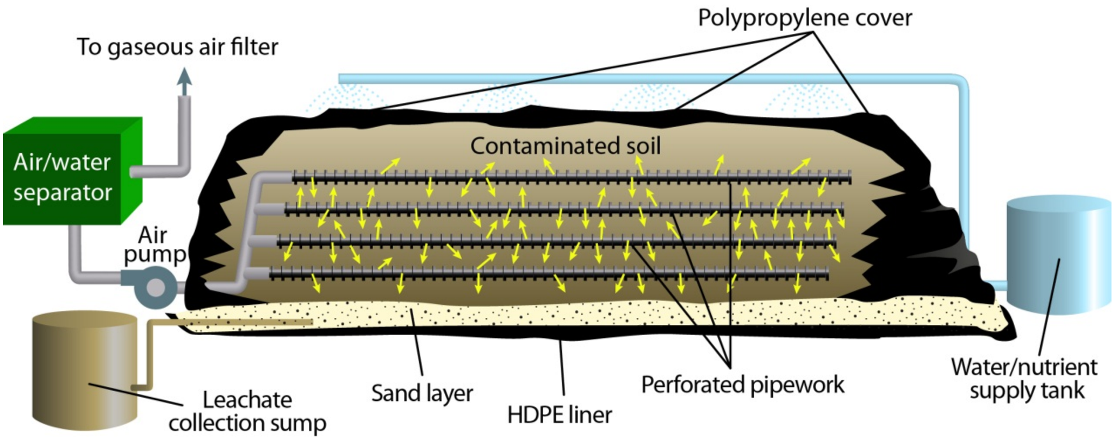
Information on the landfarming process, including monitoring data for air, odour and leachate, etc. collected during the landfarming process and validation results of landfarmed soils and underlying soils, should be described in a validation report for each site. The report should also include records of measures that were taken to optimise biodegradation of the contaminated soils and control volatilisation, including details of any laboratory and field trials.

Appendix I: Biopiles

'Biopiles' – also known as biocells, bioheaps and biomounds – are similar to landfarms in that they are both above-ground, engineered systems that use oxygen to stimulate the growth and reproduction of aerobic bacteria which, in turn, degrade the contaminants adsorbed to soil.

While landfarms are aerated by tilling, biopiles tend to be aerated by forcing air to move by injection or extraction through slotted or perforated piping placed throughout the pile (US EPA 2011), as shown in Figure 2.

Figure 2: Schematic of a biopile



Source: UK EA 2002

Biopiles should be considered an alternative to landfarms, especially on sites near sensitive receptors, as emissions can be more easily controlled.

References and further reading

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