MANAGING URBAN STORMWATER

Soils and Construction

Volume 2B Waste landfills

stormwater TRUST

Department of Environment & Climate Change NSW

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Department of **Environment & Climate Change** NSW

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1. Introduction

1.1 Waste landfills

A 'waste landfill' is defined in this publication as any activity that involves the disposal of waste to land, and includes the covering of the buried wastes with soil or other material. Waste landfills therefore involve significant areas of land disturbance and earthworks which require the planning, design, construction and maintenance of effective erosion and sediment-control measures.

Landfills of many scales and types exist across New South Wales, with every city and township typically being serviced by at least one landfill facility. Large cities commonly have a range of specialised landfills suitable for the disposal of specific waste types (e.g. hazardous waste). Waste landfill sites may also host a number of other waste-management-related activities, such as recycling or waste processing.

A range of water-management issues need to be considered at landfill sites, including the use of water for dust suppression, site revegetation etc., the management of leachate from the active filling area and the management of stormwater from within (and sometimes from outside) the landfill site. The specific focus of this publication on erosion and sediment control should therefore be viewed within the broader context of an integrated water-management framework that seeks to minimise the use of water from external sources and prevent or limit the degradation of downstream environments.

1.2 Purpose and scope

The purpose of this publication is to provide guidelines, principles and recommended minimum design standards for good management practice in erosion and sediment control for waste landfills. The target audience for this publication includes those within local government, State government agencies, consulting firms and others in the private sector involved in the planning, design, approval, operation and regulation of waste landfills.

This publication guides the user in applying the principles and practices of erosion and sediment control to landfill operations. These practices and principles were described in volume 1 of *Managing urban stormwater: soils and construction* (Landcom 2004b). This publication should therefore be read and used in conjunction with volume 1.

> Throughout this publication, cross-references to *Managing urban stormwater: soils and construction,* volume 1 (Landcom 2004b) are shown in bold: for example, see **vol. 1**: section 5.3.

A useful additional reference is *The hip pocket handbook* (Landcom 2004a), which is a small field guide for the use of contractors and others responsible for the construction and maintenance of erosion and sediment controls.

The principles of erosion and sediment control on urban development sites described in **vol. 1** are broadly applicable to waste landfills. There are, however, a number of key differences in the extent and manner of land disturbance on landfill sites that warrant special consideration. The urban land development process can expose large areas of land (tens of hectares or more) for a relatively short period measured in months. In contrast, the operational life of waste landfill sites is typically measured in decades.

This publication does not address broader environmental issues associated with waste landfills, such as the related water-quality issue of leachate management and ancillary activities such as waste separation and recycling. Landfills have a range of potential environmental impacts beyond erosion and sedimentation, which should be identified and assessed in the project planning and environmental assessment phase.

1.3 Characteristics of landfill sites and operations

Waste landfill sites involve the disturbance of land for the burial of waste, and a range of related activities (roads, building etc.). Most landfills are designed from the start as landfill sites, while others utilise an existing void (e.g. a quarry or mine site) in which the landfill operation is part of a rehabilitation program.

Landfill sites can be categorised as:

- **Small unsupervised landfill sites** that serve small rural communities. Typically these sites accept less than 2500 tonnes a year of waste. Because of the relatively small volume of waste accepted at these sites they are likely to continue to operate for several decades, but do not normally warrant detailed site planning and management.
- **Larger existing landfill sites** that serve major urban areas. Many older sites may have difficulty meeting contemporary performance standards due to historical decisions relating to location, leachate control and layout. Appendix B provides a sample erosion and sediment control plan (ESCP) for a large landfill.
- **New landfill sites serving urban and metropolitan areas.** When new landfills are proposed, the approvals process requires an extensive process of site selection and landfill design, normally including a detailed environmental impact statement (EIS). The process of site selection and design typically involves detailed analysis of the site characteristics (topography, soils, geology, climate etc.) as well as preparing design plans for the site layout, facility design and management activity that will minimise off-site impacts (see DUAP 1996). The EIS for such sites will commonly include a site-specific draft ESCP. Appendix B indicates the level of detail required in an ESCP for large new landfill sites.

The key features of landfill sites that distinguish the approach to erosion and sediment control from those employed for urban development are:

- the active lifetime of a landfill is often measured in decades rather than months. The design and operation of erosion and sediment control measures should therefore reflect this longer duration
- the soil materials used in the landfill process may be imported to the site over the lifespan of the facility, and may therefore differ from those found at the site. The approach to erosion and sediment control should therefore take account of the possible differences in physical characteristics of imported soil, including erodibility and hydrologic properties.

Many landfill sites accommodate a range of ancillary activities, including separation and processing of recyclable materials (e.g. metals, glass, plastics, green waste). Guidance on the management of environmental issues associated with these ancillary activities is provided in *Environmental protection guidelines: solid waste landfills* (EPA 1996 – currently under review).

1.4 Potential impacts on the water environment

Large-scale disturbance associated with landfill operations has the potential to significantly impact on the surrounding environment through:

- sedimentation of waterways, impacting on river health
- impacts on vegetation, including threatened species.

Erosion, sedimentation and other forms of land degradation should therefore be controlled to minimise any impacts.

1.5 Structure of this publication

Section 2 provides an overview of the regulatory framework for landfill sites

Section 3 outlines an approach to developing an erosion and sediment control strategy at landfills

Section 4 summarises design considerations for operational erosion and sediment control at landfills

Section 5 provides information on landfill site rehabilitation relevant to minimising site erosion

Section 6 provides guidance on applicable erosion and sediment control techniques at landfills

The appendices contain guidance on erosion and sediment control plans (ESCPs) and the selection of erosion and sediment control measures.

2. Statutory requirements

2.1 Overview

A number of State and local regulatory authorities will need to be consulted to ensure activities associated with waste landfills are undertaken in accordance with all necessary statutory requirements.

Several pieces of legislation may need to be considered in the planning and design stages of a landfill site, including the *Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Protection of the Environment Operations Act 1997* (POEO Act). The requirements of these two key pieces of legislation are described below.

Other Acts which may influence aspects of erosion and sediment control are listed below, but are not discussed in any detail in this publication:

- *Water Management Act 2000*
- *Native Vegetation Act 2003*
- *Threatened Species Conservation Act 1995*
- *National Parks and Wildlife Act 1974*
- *Soil Conservation Act 1938*
- *Fisheries Management Act 1984*

A more detailed description of these Acts is presented in **vol. 1**: appendix K.

The information below was current at the date of publication. However, statutory requirements and the roles of government agencies can change over time – proponents should check that this information is current during the planning stage of their project.

2.2 Relevant legislation

2.1.1 Environmental Planning and Assessment Act 1979

The EP&A Act and the Environmental Planning and Assessment Regulation 2000 (EP&A Regulation) specify the planning approval and development consent requirements for waste management facilities or works. Where development consent is required and the development is designated development, as defined for waste management facilities or works under schedule 3 of the EP&A Regulation, an environmental impact statement (EIS) must be lodged with the application. DUAP (1996) provides guidance on the contents of an EIS, including water and management issues to be addressed. Where an EIS is *not* required, a statement of environmental effects (SEE) generally has to be lodged with the application.

2.1.2 Protection of the Environment Operations Act 1997

The POEO Act is the primary piece of NSW pollution control legislation. The Act defines activities that require environment protection licences (schedule 1) and the roles and responsibilities of appropriate regulatory authorities. The Act also prohibits the pollution of waters, except in accordance with an environment protection licence (section 120).

Environment protection licences are issued by the Environment Protection Authority (EPA), part of the Department of Environment and Climate Change (DECC). The EPA is normally the appropriate regulatory authority for:

- activities listed in schedule 1 of the POEO Act for which licences are issued
- activities carried on by a State or public authority (e.g. a council operating a small solid waste landfill)
- other activities in relation to which a licence regulating water pollution is issued.

Local councils are normally the appropriate regulatory authority for other activities (e.g. operations by small to medium businesses and subdivision construction by private developers). Local councils have notice and enforcement powers under the POEO Act for these activities.

Landfill sites are a category of 'waste facilities' as defined under the Act. Landfills above specified thresholds are prescribed in schedule 1, for which an environment protection licence is issued by the EPA. Preparation of a landfill staging plan may be a licence requirement.

The impact on the environment of any pollution likely to be caused by the activity will be considered when determining an application for an environment protection licence. Where an environment protection licence is granted, conditions may include soil and water management requirements to avoid or minimise any potential impacts.

3. Erosion and sediment control strategy

3.1 Management objectives

The goal for erosion and sediment control from a landfill is to ensure that there is no pollution of surface or ground waters. Current best-practice erosion and sediment control techniques are, however, unlikely to achieve this goal, due to the limited effectiveness of most of these techniques. An appropriate management objective is therefore to take all reasonable measures (i.e. implement best-practice) to minimise water-quality impacts from erosion and sedimentation.

Given the limited effectiveness of techniques for retaining eroded sediment, a strong emphasis should be placed on pollution prevention through erosion control, rather than relying on treatment techniques to capture these sediments.

3.2 Management principles

The primary principles for erosion and sediment control are firstly to minimise erosion and then to capture sediment from disturbed areas. This approach emphasises pollution prevention rather than pollution control.

Vol. 1: section 1.6 identifies seven general principles of effective soil and water management for land disturbance associated with urban development. This approach focuses on appropriate site planning, and the installation of appropriate erosion-control and sediment-control measures.

These principles also broadly apply to the planning, design, construction and operation of landfills. They can be paraphrased as follows:

- assess the soil and water implications of a project at the planning stage
- plan for erosion and sediment control during the project's design and before any earthworks begin, including assessment of site constraints
- minimise the area of soil disturbed and exposed to erosion
- conserve topsoil for later site rehabilitation or regeneration
- control water flow from the top of and through the project area by diverting up-slope 'clean' water away from disturbed areas and ensuring concentrated flows are below erosive levels
- rehabilitate disturbed lands quickly
- maintain erosion and control measures appropriately.

These seven principles provide a framework for the application of the specific erosion and sediment control practices described in this publication.

Matters of special consideration for landfills are briefly discussed below, and more detailed design considerations are discussed in section 6.

3.3 Strategic approach

3.3.1 Overview

Effective erosion and sediment control for a landfill requires appropriate activities to be carried out over the life of the landfill, including:

- planning and design
- operations
- closure and rehabilitation.

The principles noted in section 3.2 can be used to guide the development of an erosion and sediment control strategy for a landfill site. The specific strategy adopted will vary depending on the nature and scope of the development, type and sensitivity of receiving environments, and other factors such as the site's rainfall characteristics, soils and topography. It is important that any erosion and sediment control strategy is consistent with, and meets any requirements of, any applicable environment protection licence, development consent or approval conditions.

As with construction sites, the magnitude of erosion problems (and therefore the effort required to control erosion) at landfill sites is proportional to the area of soil exposed to the erosive elements and the duration of that exposure. Landfill sites are characterised by land disturbance operations continuing for years (if not decades) rather than months. Because of this longer period of operation, the management focus should be on site design and the scheduling of rehabilitation to minimise erosion occurring rather than reliance only on temporary works to control erosion and sedimentation.

This longer period of disturbance and the consequent longer operation of many erosion and sediment controls means that a stronger emphasis needs to be put on particular management principles such as:

- erosion control as a pollution prevention strategy
- runoff separation by diverting 'clean' stormwater runoff around the site or away from operational areas
- management and maintenance of long-term controls.

3.3.2 Planning and design strategies

The effectiveness of erosion and sediment controls during the operational and rehabilitation stages can be optimised through effective landfill planning and design. Suitable strategies include:

- designing any drainage systems operating for the life of the landfill so that they do not cause erosion. This may involve scour protection of open drains and energy dissipaters located at drain outlets
- diverting up-slope runoff around the landfill site, where possible, to minimise external runoff flowing to operational areas
- designing the final landfill geometry to create a landform that allows free drainage of surface runoff while minimising erosion. This includes designing an appropriate drainage system that avoids erosion
- landfill staging to minimise the active landfill area exposed at any point in time. This will minimise erosion and the necessary extent and capacity of requisite erosion-control and sediment-control measures
- considering stormwater reuse as part of the overall water-management strategy for the site to avoid or reduce discharge of polluted water. There is commonly a range of non-potable water uses on a landfill site such as dust suppression, moisture control for compaction of clay liners and cover layers, and irrigation of revegetation areas. This may be more cost-effective than treatment of polluted runoff and will also reduce the consumption of other water sources.

Areas on the landfill site where runoff may be polluted by contaminants other than sediment should be provided with separate drainage and treatment facilities, with uncontaminated runoff diverted around these areas. In particular, runoff that comes in contact with wastes (except virgin excavated natural material – VENM) should be managed in the same manner as leachate, rather than as stormwater.

These strategies can be documented in a landfill staging or filling plan. This plan will define the sequence and timing of excavation, landfilling and rehabilitation/revegetation, as well as the location of soil stockpiles and water-control facilities (diversion channels, sedimentation basins etc.) throughout the life of the operation. An integrated water-management strategy for the site should be prepared for medium to large landfills. This should consider the available water sources and uses to minimise potable water consumption and discharges from the site.

3.3.3 Operational phase strategies

Operational activities are likely to vary throughout the life of a landfill site, with erosion and sediment control measures and activities expected to evolve over time. Erosion control at landfill sites should normally comprise the following strategies:

- minimising the extent and duration of land disturbance and promptly revegetating disturbed areas that are not operational (using temporary revegetation if required)
- ensuring both temporary earthworks and permanent land shaping provide a landform which minimises erosion hazard
- promptly stabilising land following shaping (both temporary and permanent)
- designing temporary surface water collection, conveyance and disposal systems in a manner which minimises erosion.

Stormwater should be diverted around active landfill areas where possible to minimise the flow rate and volume of runoff to be handled by the on-site water management facilities. This will enable the facilities to perform more effectively.

The area of the active landfill tipping face should be kept to a minimum in order to minimise the volume of leachate generated from the site. The active tipping face should be protected by a small wall (a ‘bund’) at all times to clearly separate the leachate and stormwater management systems.

Runoff from areas of the landfill which have had daily, intermediate or final cover applied can be diverted to sediment control basins or ponds, provided the runoff does not contain leachate. Ammonia is a distinguishing feature of leachate and an ammonia concentration less than 0.9 mg/L is generally accepted as indicating that the stormwater is leachate-free. Usually several years of monitoring total suspended solids (TSS) and ammonia levels in runoff will be required before direct discharge from the site will be permitted.

Sediment basins and water storages are usually located at the lowest points on the site. They should not be placed on filled areas, to avoid infiltration and resultant excessive leachate generation. Forward planning for the location and size of these facilities is therefore important for effective runoff and sediment control.

Erosion and sediment control measures should be inspected daily (with maintenance and modification as necessary), together with more intense inspection and maintenance regimes during periods of wet weather and wet weather clean-up (see **vol. 1**: chapter 8). Arrangements also need to be made for inspection and maintenance during long weekends and holiday period industry shutdowns (such as Christmas and Easter), particularly if rainfall is predicted or there is predictable seasonal rainfall.

For large landfills, a priority system for repairs and maintenance following large storms should be developed. This should focus on initially restoring controls in areas with high erosion risk which may impact on sensitive receiving environments, followed by restoration of controls in other areas.

Due to the longer operational life of many erosion and sediment control measures relative to urban subdivision construction (outlined in **vol. 1**), additional maintenance effort is often required for long-term controls. For example:

- erosion and sediment control measures should be maintained in a functioning condition until individual areas have been revegetated
- structures for diverting and conveying runoff should be inspected after significant storms so that sediment removal and prompt repairs and/or replacement of damaged works can be undertaken
- inflow points and outflow structures (e.g. riser pipes and spillways) to sediment basins should be inspected after major storms and repaired as necessary.

Access tracks of a basic engineering standard are widely used on landfill sites. Erosion of the tracks is a safety issue as well as a potential water-quality issue. Detailed guidance on erosion and sediment control for access tracks is provided in *Managing urban stormwater: soils and construction* volume 2C*: unsealed roads* (DECC 2008b).

Services such as water mains are often installed as part of a waste landfill's establishment and operations. Detailed guidance on erosion and sediment control for service installation is provided in *Managing urban stormwater: soils and construction* volume 2A*: installation of services* (DECC 2008a).

Monitoring of surface water on and around a landfill site is a vital element in an effective and adaptable water management strategy. Monitoring will indicate the effectiveness of the water treatment system to control sediment discharges, to confirm that leachate is not entering the stormwater system and that regulatory expectations are being met. For larger landfill sites, a robust monitoring regime would include monitoring of any:

- water retention dams
- discharge or overflow from such dams
- discharge or overflow in the local watercourses upstream and downstream of the site.

The monitoring results should be used to refine any erosion and sediment control measures to meet regulatory and operational requirements.

Section 6 contains information on potentially suitable erosion and sediment control techniques for a landfill's operational phase.

3.3.4 Closure and rehabilitation phase strategies

The primary aim of the closure and rehabilitation phase of a landfill is to minimise long-term erosion through effective revegetation. Revegetated areas should be carefully managed for a number of years after the initial rehabilitation works, with intensive management over the first few months. This is to promote rapid vegetation growth and development, and address any problems arising with vegetation establishment.

Guidance on rehabilitation is provided in section 5.

3.4 Documenting the adopted operational strategy

It is important that the strategy for erosion and sediment control is documented so that operational staff and regulatory authorities are aware of the adopted approach to minimising water pollution. The strategy should be documented before the start of land disturbance activities where erosion and sediment controls are needed. The strategy could be documented in an:

- environmental management plan
- landfill staging plan
- water management plan, or
- erosion and sediment control plan.

There is generally no DECC requirement for landfill operators to prepare a specific erosion and sediment control plan, although this is common practice. DECC does, however, expect that there is a document that is current at all times during the operational life of the landfill which details the current erosion and sediment control practices being implemented.

It is recommended that operators consider the scale and nature of their operations and any requirements to provide other plans relating to environmental management when deciding on how to document their erosion and sediment control strategy. For example, a small landfill operator may include erosion and sediment control in an environmental management plan required as a part of development consent conditions, while for a large landfill site an erosion and sediment control plan may be better as a sub-plan of the water management plan. Appendices A and C provide information on erosion and sediment control plans.

It is important that whatever format is adopted allows for the plan to be revised if required to account for monitoring results and to address any implementation problems that may arise.

3.5 Responsibility for strategy implementation

The project principal should ensure that staff or contractor responsibilities for implementing the erosion and sediment control strategy are clearly established and documented. It is recommended that a single person have overall responsibility for supervising the implementation of the strategy, while delegating particular responsibilities. The principal should ensure that all operational staff are aware of the need for effective erosion and sediment controls.

The inspection and maintenance responsibilities for erosion and sediment controls should be devolved across all persons working on the landfill, as well as any environment officers. This avoids the situation where sediment control responsibility is assigned to a single employee or employee category (e.g. environment officer), resulting in other workers (including supervisors) taking little or no interest or responsibility.

3.6 Strategy implementation by contractors

Aspects of landfill operations may be carried out by contractors on behalf of a project principal or client. Both the project principal and any contractor have responsibilities for implementing an effective erosion and sediment control strategy.

The POEO Act (parts 3.4 and 8.5) considers licence holders and occupiers of unlicensed premises to be liable for any breach of a licence condition or pollution caused by any associated person. The occupier of premises is the person (or organisation) who has management or control of the premises. A person associated with the licence holder or occupier of the premises is taken to include an employee, agent, contractor or subcontractor.

Effectively this means that a project principal cannot transfer their obligations under the POEO Act to a contractor. The *EPA prosecution guidelines* (DEC 2004) contains further information on the EPA's approach to selecting an appropriate defendant for a pollution offence and the EPA's views on the responsibility of principals and contractors.

These provisions do not, however, prevent proceedings being taken under the POEO Act against the person who actually caused the pollution (e.g. a contractor who, in the opinion of the appropriate regulatory authority, has been clearly negligent).

The licence holder for a licensed landfill or the occupier of an unlicensed landfill therefore needs to take appropriate steps to ensure that any contractor or subcontractor does not contravene any licence condition or cause unauthorised water pollution. Potential approaches include:

- including details of the contractor's obligations in the contract, along with appropriate contract provisions enabling the principal to direct the contractor or subcontractor to address any potential licence contravention or polluting activities
- providing guidance to the contractor on the procedures to be followed to prevent any licence contravention or polluting activities
- ongoing monitoring of a contractor's activities to identify any potential licence contravention or polluting activities, with prompt directions issued to the contractor to address the inappropriate activities and a follow-up review to see that the actions have been addressed.

4. Landfill site design

4.1 Landfill site assessment

A detailed understanding of the site characteristics that affect soil erosion and sediment discharge is important for both:

- effective planning of erosion and sediment control measures and subsequent management of those measures
- soil and water management of the final landform.

The soil type is important in respect to:

- soil stability and erosion potential
- soil moisture-holding characteristics and runoff volume
- suitability for rehabilitation of the site.

Section 3 and appendix A of **vol. 1** provide descriptions of the soil characteristics, and their constraints and opportunities in relation to erosion and sediment control. Soil testing should be undertaken to characterise the soil materials likely to be exposed to soil erosion during site disturbance.

Where soil is imported to a landfill site for use in activities such as waste cover and landform capping, the worst-case soil stability and erosion potential should be assumed as the default, and erosion and sediment control measures designed accordingly, as set out in section 6.1.

4.2 Final landform

4.2.1 Introduction

The intended final landform is an important initial consideration for operational soil and water management, to ensure that erosion and sediment controls are progressively incorporated as an integral part of the landform's design. The final topography of a landfill site is generally stipulated in the planning consent, the environment protection licence and/or the closure plan approved by the EPA. Several of the key issues for erosion and sediment control measures in the final landform are briefly discussed in the following sections.

4.2.2 Final slope design

The topographical factor with the greatest potential effect on soil erosion at a given location is slope. The impacts of slope angle and length on soil loss are outlined in **vol. 1**: appendix A.

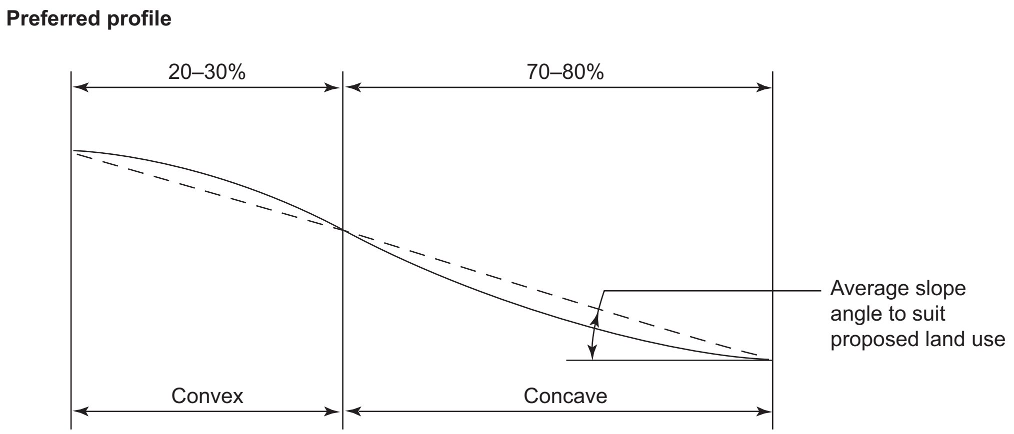
The main soil and water management objective of reshaping is to produce slopes with gradients, lengths and shapes that are not prone to an unacceptable rate of erosion and are capable of conveying runoff from the newly created catchments without risk of erosion and sedimentation. However, for landfills this should be balanced against the need to minimise infiltration and resultant leachate generation. A gradient of five per cent is commonly used to achieve this, but will be dependent on soil type and the climatic characteristics of each site.

Long, steep batters should have benches that are laterally drained, while diversion drains and sediment fences may be used as necessary on steeper slopes to control runoff and trap sediment. Note that benches will need to be maintained and regraded over several years due to the settlement of waste.

Any increase in runoff volume resulting from the final landform can be managed by increasing the depth of flow or by increasing the velocity of flow, although the velocity should only be increased to a point that will not cause erosion. This point can easily be recognised in the field where small rills or scour channels become evident.

Where site constraints prevent the formation of a suitable profile for the final landform, the slope should be formed with a constant angle over its entire length. Consideration should also be given to the formation of a bench in the middle of the slope to create two shorter slopes. Figure 4.1 illustrates these concepts, while table 4.1 provides a guide to optimum spacing between benches for a range of slope angles. Figure 4.2 (overleaf) outlines an alternate approach to bench design. These slope considerations should also influence the landfill staging plan such that the final slope can be designed to minimise erosion potential, and potential exposure of landfilled waste material.

The landfill batters should normally be designed so that the combination of steepness and slope length provide conditions such that, even without any erosion protection actions, the estimated soil loss according to the revised universal soil loss equation (RUSLE) (see **vol. 1**) is soil loss class 5 or less. This amounts to less than 750 tonnes per hectare per year. Note, however, that this figure is simply a benchmark for judging conditions in which excessive erosion is more likely and under which extra erosion protection measures should be undertaken.



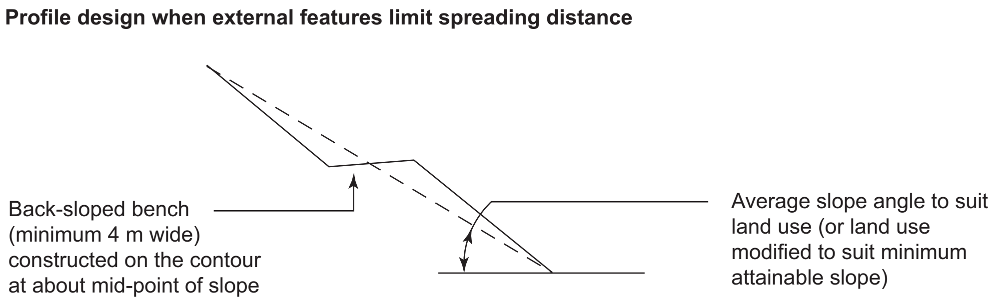


Figure 4.1 Design of slope profiles (Source: Hannan 1995)

Table 4.1 Bench spacing guide

Slope angle	Recommended spacing between benches (metres)
< 6°	Not necessary
< 6°–8°	110
8°–10°	100
10°–12°	80
12°–14	60
14°–18°	40
18°–20°	30
> 20°	Use specialised erosion control measures (e.g. hydromulching or straw mulching)

Source: Hannan (1995)

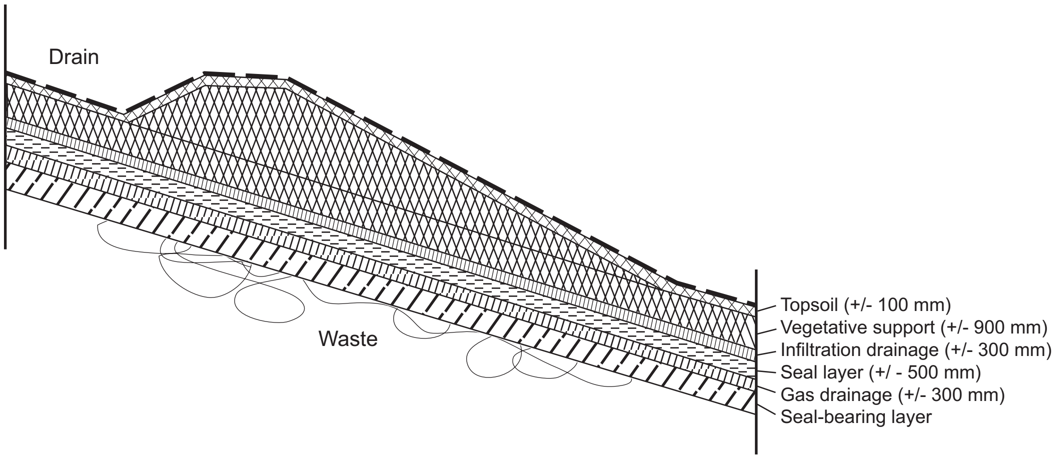


Figure 4.2 Cross-section of a typical berm drain over a landfill area

4.2.3 Final site drainage design

The natural drainage patterns and slope profiles at a site are formed by natural erosion, sedimentation and geological processes over a geological timeframe. The number of drainage channels, their gradient and cross-sectional area are in equilibrium with the catchment area, soil type, slope, rainfall characteristics and vegetation. Any alteration to one of these parameters disturbs the equilibrium and can result in accelerated erosion and/or sedimentation of the drainage channels and downstream waterways.

The best starting point for designing a drainage pattern is to determine the drainage density and stream ordering that existed on the site prior to landfilling. Drainage density is simply the catchment area (in m^2) divided by the total length (metres) of all stream channels which drain the area. The resultant output is the average catchment per unit length of channel. An example of this relationship is:

Pre-landfill catchment area = 216,000 m^2 (21.6 hectares)

Total length of pre-landfill drainage line = 920 metres

Drainage density = 216,000 m^2 / 920 m = 234 m^2/m

For this example, the pre-landfill drainage density of 234 m^2/m means that every hectare within the catchment is being drained by 43 linear metres of drainage channel (i.e. 10,000 m^2 divided by 234 m^2/m = 43 metres).

The topography after landfilling is unlikely to be identical to that which existed before the landfill. Waste mounding and overburden swell factors will result in a more elevated terrain with the average gradient, from the highest point on the reshaped surface to the final discharge point on adjacent undisturbed land, steeper than prior to landfilling. The original drainage pattern, if reinstated, would therefore no longer be in equilibrium with its surroundings. To overcome this, the pre-landfilling drainage density should be increased in the final landform.

Overall site layout should, where possible, preserve the main natural drainage lines within or through the site. However, 'constructed' drainage lines will be necessary to convey water from landfill areas. Constructed drainage lines on landfill areas should be designed with a low leakage rate to avoid excessive leachate generation, and should be regularly maintained as settlement of waste can alter their grade and integrity.

5. Landfill rehabilitation

5.1 Introduction

Guidance on rehabilitation is in **vol. 1**: appendix G. This section addresses some additional considerations for topsoil management, revegetation and rehabilitation that are important for soil and water management at landfill sites.

The best means of long-term erosion control is through a dense, permanent vegetation cover. However, there is a period between final shaping and topsoiling and the establishment of vegetation, during which the surface is highly susceptible to erosion. Some erosion during this period is almost inevitable, although surrounding land and downstream waterways should not be affected if the soil and water management system is properly designed and maintained.

5.2 Soil management

5.2.1 Soil stripping and stockpiling

Soil stripping and stockpiling, either from on-site or imported soil, is important for soil and water management during both the operational phase and the rehabilitation phase of a landfill site. The stockpiles need to be managed to minimise erosion and loss of valuable topsoil for rehabilitation, and also to ensure the topsoil is maintained in a condition which supports the most rapid stabilisation of the site during rehabilitation.

The following measures should be adopted for soil stripping and stockpiling:

- soils should be stripped in a slightly moist condition (i.e. neither dry or wet) thus reducing deterioration in topsoil quality and dust generation
- topsoil should be stockpiled only when disturbed areas are not available for immediate rehabilitation
- soil stockpiles should be constructed to minimise the stockpile area in a discrete three-metre-high (maximum) pile, with a working face battered down at 30 degrees
- stockpiles should be trimmed, deep ripped to 500 millimetres, immediately sown with permanent pasture species, and fertilised.

It is also important that weeds are managed in pre-stripped areas, to avoid subsequent weed problems during rehabilitation.

Other recommended topsoil and stockpile handling procedures are described in **vol. 1**: section 4.3.2.

5.2.2 Managing stockpile condition

The most common technique used to overcome soil structural problems during stockpiling is to add a layer of topdressing material. Alternatives include:

- the addition of organic mulches to improve soil structure – this will also aid microclimate, germination and infiltration, and reduce runoff and evaporation. Biosolids are an effective soil conditioner
- the application of gypsum to improve surface structure and improve water infiltration. Artificial neutralisation of acidic soils with lime can also assist, but multiple liming applications should not be undertaken to avoid induced nutrient deficiencies.

5.2.3 Topsoil application

The following measures should be considered when applying topsoil during rehabilitation:

- topsoil should be handled at an optimum moisture content to reduce damage to soil structure. This will achieve a higher standard of revegetation and reduce maintenance requirements
- topsoil should be re-spread in the reverse sequence to its removal, so that the organic layer, containing any seed or vegetation, is returned to the surface
- topsoiling should be delayed until as close as possible to the anticipated sowing date
- the final operations of topsoiling, cultivation and sowing should not be commenced until any season of high-intensity storms has passed (e.g. avoid sowing in the middle of summer)
- apply topsoil to a depth of about 40 to 60 mm on lands where the slope exceeds 4:1 (H:V), and at least 75 mm on sites where the slope is less than 4:1 (H:V)
- on completion of the respreading process, leave disturbed lands with a scarified surface to inhibit soil erosion, encourage water infiltration and provide a good basis for plant growth.

5.3 Establishing vegetation

The period of susceptibility and the degree of erosion damage can be reduced by appropriate cultivation and vegetation management methods, as follows:

- selecting vegetation capable of long-term survival and reproduction without the need for watering, mowing, or other intervention (these will usually be naturally occurring native plant species), and without the root system penetrating the landfill cap's infiltration drainage layer and sealing layer (usually not deeper rooted shrubs and trees)
- avoiding the use of fertiliser or irrigation with leachate on areas rehabilitated with native vegetation species – most native vegetation cannot tolerate high nutrient levels
- ensuring that all exposed soil areas likely to remain bare for more than 30 days other then the active landfill area have a temporary cover crop planted to control erosion
- sowing at a time when soil moisture and weather conditions are most favourable to the rapid germination and establishment of vegetation
- including in the seed mixture at least one cover crop species that will grow quickly to provide early groundcover, even if that species will not form part of the final, permanent pasture (e.g. oats or millet)
- cultivating along the contour – a tyned implement, such as a chisel plough or rippers, will create small furrows to retard runoff and promote infiltration for root growth
- limiting cultivation to a depth that avoids disturbance of the landfill capping material
- completing cultivation in a single pass to avoid compaction of the topsoil
- avoiding traffic over the area after cultivation, particularly up and down or diagonally across the slope.

5.4 Ongoing management and maintenance

For a number of years after the initial rehabilitation works, revegetated areas should be carefully managed to promote rapid vegetative growth and development, in order to prevent degeneration after establishment. Degeneration may result either in severe erosion and sedimentation of the site, or replacement of the sown species with weeds. Ongoing management will entail monitoring of regrowth, fertilising as necessary, weed control and re-ripping and re-sowing bare areas.

It is difficult to avoid at least some sheet erosion and minor gully or rill erosion on sloping sites during the first six to eight weeks between sowing and emergence of the new vegetation. The sediment and erosion control measures on the site should be operated and maintained in a proper and efficient condition until the site is stabilised.

Larger bare areas may require re-ripping or some form of cultivation and complete re-sowing. If the topsoil has been completely removed by erosion, it should be replaced prior to cultivating.

All erosion and sediment control measures (e.g. sediment fencing down-slope of soil stockpiles) should be maintained in a functioning condition until individual areas have been revegetated to the point where the C-factor (see **vol. 1**: appendix A) is less than 0.05 (approximately 70 per cent ground cover). See **vol. 1**: chapter 7 for alternative methods of achieving this.

6. Erosion and sediment control techniques

6.1 Applicable techniques from volume 1

Most of the erosion and sediment control techniques described in **vol. 1** are applicable to erosion and sediment control for landfill sites. Appendix C provides a summary of these techniques and guidance on their selection.

The main variation to the techniques described in **vol. 1** relates to the sizing of diversion drains and sediment basins, to account for the longer duration of landfill sites relative to urban subdivision construction. Due to this longer operational life of sediment control measures at landfill sites, higher standards of design and construction should be adopted for water conveyance and storage structures, particularly those that will remain after the operational life of the site.

The recommended minimum design criteria for erosion and sediment control measures on landfill sites are presented in table 6.1. Landfill operators or consent/regulatory authorities may adopt more stringent criteria, particularly if considered warranted by a site-specific environmental impact assessment. Table 6.2 presents the indicative average annual sediment basin overflow (or spill) frequency for the various five-day duration design storms presented in table 6.1 for treating runoff from type F or D soils.

Table 6.1 notes that the minimum basin design criteria can be reduced when enhanced erosion controls are used. If these enhanced controls are implemented, an independent audit of the implementation of enhanced controls should occur at least fortnightly for these sensitive sites. The auditor should be a soil conservationist or an accredited erosion control specialist.

The operation of basins for type F and D soils is described in **vol. 1**: section 6.3.4. This section notes that the basin should be drained or pumped out within the adopted management period (commonly five days) following rainfall. For the purposes of basin management, this requirement refers to rainfall of sufficient depth to result in runoff entering the basin. This rainfall depth will vary depending on the site conditions at the time, particularly the extent of any impervious surfaces (e.g. road pavement) and the extent of any earlier rainfall. For sites at the bulk earthworks stage, where there has not been significant preceding rainfall, rainfall depth of at least 5–10 mm may be needed before runoff commences.

This approach avoids the situation where the basin management period is extended for a further five days following negligible rainfall (e.g. 1 mm). This would result in the basin containing runoff for a longer period, reducing its ability to capture runoff from subsequent storms and hence increasing the spill frequency.

Sediment basins are usually only required for the first two years after the rehabilitation of disturbed areas.

Table 6.1 Recommended minimum design criteria for temporary erosion and sediment control measures at waste landfill sites

	Minimum average recurrence interval (ARI) of design storm event (unless otherwise indicated)							
Duration of disturbance	**< 6 months**		**6–12 months**		**1–3 years**		**> 3 years**	
Sensitivity of receiving environment ('standard' or 'sensitive')[1]	**standard**	**sensitive**	**standard**	**sensitive**	**standard**	**sensitive**	**standard**	**sensitive**
Temporary drainage (erosion) controls[2]								
– designed to have a non-erosive hydraulic capacity to convey	2 yrs	5 yrs	5 yrs	10 yrs	10 yrs	20 yrs	20 yrs	20 yrs
Temporary sediment control measures[3]								
– should be constructed to remain structurally sound in:	2 yrs	5 yrs	5 yrs	10 yrs	10 yrs	20 yrs	20 yrs	20 yrs
Type C sediment retention basin								
– designed to achieve required water quality for flows up to:	0.5 x 1 yr	1 yr	1 yr	2 yrs	1 yr	2 yrs	1 yr	2 yrs
– embankment and spillway designed to be structurally sound in[4]:	10 yrs	20 yrs	20 yrs	50 yrs	50 yrs	100 yrs	50 yrs	100 yrs
Type F or D Sediment retention basin								
– designed to achieve required water quality for storms up to nominated five-day duration percentile event:[5]	75th	80th	80th	85th	80th	85th	90th	95th
– designed to achieve required water quality for storms up to nominated five-day duration percentile event with enhanced erosion controls[6]:	75th	75th	75th	80th	75th	80th	90th	95th
– embankment and spillway designed to be structurally sound in[4]:	10 yrs	20 yrs	20 yrs	50 yrs	50 yrs	100 yrs	50 yrs	100 yrs

1 A 'sensitive' receiving environment is one that has a high conservation value, or supports human uses of water that are particularly sensitive to degraded water quality.
2 e.g. diversion banks, perimeter banks, catch drains, level spreaders, check dams, batter drains and chutes.
3 e.g. sediment fences, stacked rock sediment traps etc. on small catchments where used as a 'last line of defence' (i.e. without a down-slope sediment basin).
4 This is indicative only – consider the risks of basin failure for each basin to determine appropriate spillway design flow.
5 For a five-day management period. Adjustment factors to the five-day volumes for alternate management periods are 85% for two-days, 125% for 10 days and 170% for 20 days.
6 Enhanced erosion controls are described on **vol.1** section 6.3.4(g).

Table 6.2 Indicative average annual sediment basin overflow frequency	
Design storm event	**Average annual overflow frequency**
75th percentile	8–11 spills/year
80th percentile	6–8 spills/year
85th percentile	4–6 spills/year
90th percentile	2–4 spills/year
95th percentile	1–2 spills/year

Adapted from Evans and Peck (2007)

Should the landfill site import soil material for waste cover and capping, or where there is an absence of site-specific data, it is prudent to design erosion and sediment control facilities using the following default soil characteristics (as described in **vol. 1**):

- classification as type D (i.e. dispersive) soil based on texture and dispersibility characteristics
- soil hydrologic group D for purposes of assessing runoff characteristics
- assumed erodibility (K-factor) of 0.05.

Sediment basins should also be designed on the basis of a volumetric runoff coefficient of 0.9 for any impervious areas within the basin's catchment.

6.2 Additional techniques

6.2.1 Pre-treatment basins

Pre-treatment basins may be located immediately upstream of the main sediment basin. They help capture coarser sediment before entry to the main basin. Pre-treatment basins are particularly useful where the main sediment basin also functions as a water storage dam, and is not fully drawn down between storms. Pre-treatment basins should be sized using the design procedures for type C soils as set out in **vol. 1**: section 6.3.

The main requirements for pre-treatment basins are:

- inlet and outlet to be at opposite ends of the basin to provide the maximum flow-path length
- length-to-width ratio should be at least 3:1
- the basin should be capable of being easily accessed and dewatered for cleaning purposes.

Pre-treatment basins are not generally mandated by regulatory requirements, but may be implemented to simplify site management practices and reduce the frequency of maintenance required on the main sediment basin.

6.2.2 Reuse of collected runoff

Type F and D sedimentation basins should be drawn down within a specified period following a storm to a level at which the basin can subsequently retain runoff from the next storm (as noted in **vol. 1**). A simple and often cost-effective means of achieving this drawdown is to reuse the water within the site. Depending on the rate at which the collected stormwater can be used within the site, or directed to an additional holding dam, there is likely to be a need, at least on occasions, to discharge the treated stormwater from the site.

On a typical landfill site, runoff water quality following basic treatment (e.g. sedimentation) is generally adequate for uses such as dust suppression, firefighting, and irrigation of rehabilitated areas. The following matters should be considered in developing a reuse strategy for captured stormwater at a landfill site:

- hydraulic loading considerations of the irrigation area
- evapo-transpiration needs of the vegetation on the irrigation area
- water-quality needs for the proposed use (e.g. salinity levels should be considered when irrigating rehabilitation vegetation)
- avoidance of deep drainage into the landfill or increased leachate flows.

Where a sediment basin also functions as a water storage for runoff prior to reuse, the capacity of a basin designed for type D or F soils should normally be the sum of the:

- required settling volume, based on the adopted design storm volume and management period, where inflows will be treated and discharged
- sediment storage volume
- the capacity required for water reuse.

This ensures that sufficient volume is available in the basin to capture runoff from storms up to the design event without overtopping. Such storages should be operated so that the storage is drawn down to the storage zone level within the adopted management period after the end of a storm, such that the basin can subsequently retain runoff from the next rainfall event.

For basins providing storage for reuse, runoff treatment and discharge will not be required where the runoff reused over the adopted basin management period (e.g. five days) is greater than the settling volume. In this situation, the basin's settling volume will be emptied within the basin management period through reuse rather than discharge. The basin will need to be designed with a reuse volume greater than or equal to the settling volume.

The requirements of the *Dam Safety Act 1978* may apply to large water storage dams.

Managing urban stormwater: harvesting and reuse (DEC 2006) provides guidance on stormwater reuse.

6.2.3 Alternate treatment processes

Where the site does not have enough storage capacity to store all runoff for reuse, or the reuse requirements are less than the total runoff, discharge from the site will be necessary. However, the dispersible nature of many clay soils required for landfill cover may mean that runoff into sediment basins on the site will have a high concentration of very fine sediment that exceeds the typical licence limit for stormwater discharges (commonly 50 mg/L total suspended solids), even after extended retention in a sediment basin. Two approaches may be adopted to reduce elevated levels of total suspended solids in captured runoff.

Manual 'batch' treatment within the retention pond using a flocculant

Vol. 1: appendix E identifies potential flocculating agents that may be used in the treatment of sediment-laden stormwater. Gypsum is commonly used at urban construction sites due to its low potential for toxicity (e.g. accidental overdosing) in receiving waterways. Gypsum, however, is not a very effective flocculating agent and high doses are therefore required to ensure that a minimum concentration needed for flocculation is achieved throughout a sediment retention basin. Because of the chemical and labour costs, this approach has limited value as a long-term treatment strategy for landfill sites.

Alternative flocculants may be used at landfill sites, although their use will require appropriate investigation and design to ensure that the treatment system includes suitable safeguards to protect the receiving environment from the potential impact of such chemicals.

Using a purpose-designed treatment system

Vol. 1: appendix E provides details of a simple automatic system for adding flocculant to the inflow into a sediment basin. While such a system could be warranted on smaller sites or sites that have limited opportunity for on-site water reuse, the addition of flocculant to all water entering a sediment basin is likely to be wasteful of chemicals (and therefore incur additional costs), especially in situations where most of the water is to be reused within the landfill site.

Two types of systems may be considered for application at landfill sites:

- a batch treatment system in which a quantity of sediment-laden water is discharged into a separate settlement pond for treatment and subsequent discharge, after settlement
- permanent 'flow-through' treatment systems involving purpose-built or commercial 'off-the-shelf' chemical injection and flocculation facilities, which may include conventional sedimentation and drying beds.

These approaches use conventional water-treatment processes involving the addition of a flocculant, creating conditions for floc growth and then removing the floc by some process (e.g. tangential flow separator or conventional sedimentation in ponds). Although such systems have a significant initial cost, they are likely to be more cost-effective in the long term because of reduced chemical costs, reduced labour and greater reliability of discharge quality. The main design issues that arise with such a treatment system are:

- the chemicals to be used for flocculation (and pH correction if necessary)
- design treatment rate
- any required volume of balancing storage.

It is desirable to have a minimal size treatment plant that operates continually at a steady rate. However, the episodic nature of runoff means that either a large buffering storage is required to allow such a system to operate or that chemicals are dosed in proportion to the inward flow rate. In practice, continuous treatment is unrealistic because of the large buffering storage capacity required. A typical practical design is one which is required to operate for 60 to 240 days per year depending on the rainfall. Such a system may require an 'off-line' balancing storage to allow it to operate in an optimal manner.

For a typical landfill site, water would be taken from a central holding pond into which water from the sediment basins has been transferred. The treatment process can be chemically assisted sedimentation (CAS) that also removes other contaminants depending on the degree to which they are attached (adsorbed) to the surface of suspended solids. As illustrated in Figure 6.1, such a treatment process will usually require provision of facilities for:

- chemical storage and dosing for coagulation (and pH correction if necessary)
- flocculation
- sedimentation
- sludge drying.

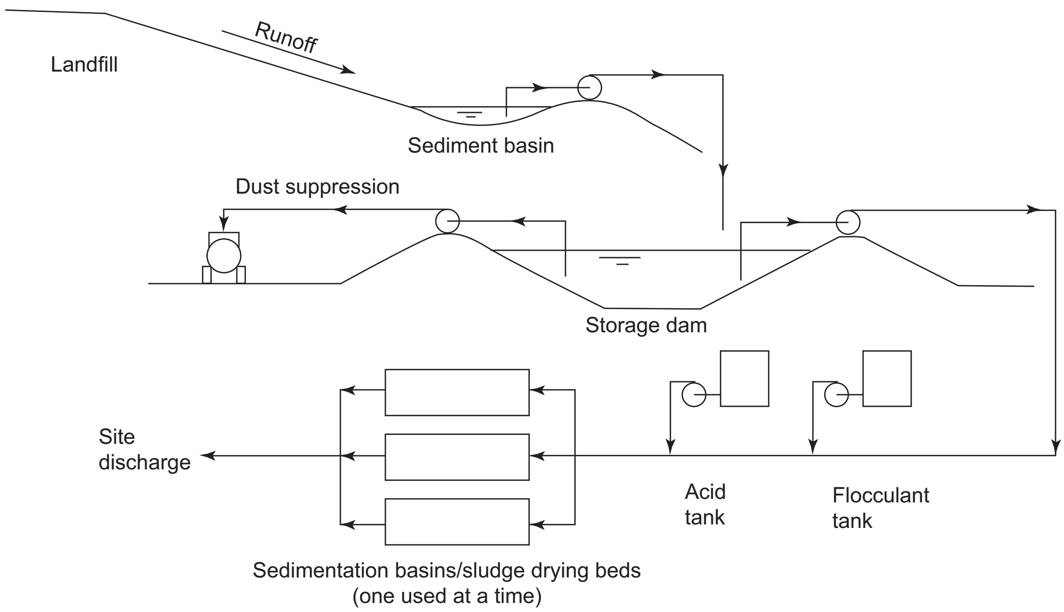


Figure 6.1 Potential arrangement for treatment of stormwater for discharge

6.2.4 Channel lining using rip rap

A preferred method of stabilising the bed of steep channels is using graded durable rip rap (rock) overlying a one-metre-deep base of stabilised and well-compacted material (figure 6.2 overleaf). Rip rap should not be single-sized, but should be a well-graded mixture designed to ensure that all gaps between large rocks are filled with rock of progressively smaller size so that no significant voids occur in the rip-rap blanket. This arrangement means that underlying material can't be washed out and creates an interlocking mass of rock to prevent movement of the rip rap down the channel. Grading recommendations are provided in table 6.3.

Steep waterways requiring rip-rap lining are not recommended in rehabilitation landscape design.

Rock for rip rap should be hard, tough and durable with a crushing strength of at least 25 MPa. The rock should be free of defined cleavage planes and should not be adversely affected by repeated wetting and drying. Rock should preferably be predominantly angular in shape with not more than 25% of rocks, distributed through the gradation, having a length more than twice the breadth and thickness. No rock should have a length exceeding 2.5 times its breadth or thickness.

Where rock fails to meet this specification it may still be used in some cases at the designer's discretion, provided allowance is made in the design for its shortcomings. Care should be taken in attempting to source rock from within the landfill site as site rock may have insufficient durability and strength (e.g. mudstones and shales) and will therefore degrade over a relatively short time.

The use of geotextile filter cloth between the rip rap and the parent material can be considered in certain circumstances. Maximum resistance between the rip rap and the cloth is required. This can be achieved by:

- avoiding preparation of the bank to a smooth and even batter before placing the cloth
- not stretching cloth tightly over the underlying bank
- avoiding cloths with low friction surfaces.

Specialist geotechnical advice should be sought to avoid rock sliding on the filter cloth.

Table 6.3 Rip-rap grading recommendations

Equivalent spherical diameter[1]	Per cent (by weight) of rip rap of smaller size
1.5–2.0 times D_{50}[2]	100%
D_{50}	50%
0.3 D_{50}	10–20%

[1] The diameter of a sphere with an equivalent volume to the individual rock.
[2] D_{50} is the medium rip-rap diameter of the rock mix (i.e. 50% by weight is smaller than this size).

Source: Department of Land and Water Conservation (1999)

Figure 6.2 Rip-rap rock waterways conveying runoff to a sediment basin

6.2.5 Earthworks and stockpiling of soils

Depending on the topography of the site and the overall landfilling approach (e.g. individual cells or gully filling), large stockpiles of soil may need to be created. Some of this material may need to be retained for a number of years until completion of a particular stage of the landfill operation. Because topsoil tends to lose desirable organic matter if stockpiled for extended periods, it is preferable to rotate topsoil material through the stockpile so that it is not retained for longer than 6–12 months.

While the principles of soil stockpile management (as set out in **vol. 1**: chapter 4) apply to landfill sites, the fact that stockpiles on landfill sites tend to be of longer duration than those on urban construction sites means that greater attention should be paid to the main features shown in **vol. 1**: standard drawing 4-1:

- stockpile location should be at least five metres away from concentrated flow
- a diversion bank should be provided on the up-slope side of stockpiles to divert overland flow around the stockpile
- separate stockpiles should be provided for different soils (e.g. topsoil and subsoil)
- soil stockpiles should be constructed along the contour as low long mounds with a maximum side slope of 2:1 (H:V)
- stockpiles should be stabilised to achieve a C-factor of 0.1 (as described in **vol.1**: appendix A) as defined for the revised universal soil loss equation (RUSLE). This can be achieved with a ground cover of 70% from a sterile cover crop. Alternative means of achieving the required level of erosion control include mulches and matting products. The relative erosion control performance and durability of different products are summarised in **vol. 1**: table A3. Cover crops may not be suitable for stockpiles of clay intended to be subsequently used in compacted clay liners or dam embankments
- sediment control fencing should be placed around the lower sides and ends of the stockpile to provide temporary protection while stabilisation takes effect.

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Appendices

Appendix A: Erosion and sediment control plans

The various characteristics of the site and the means of controlling surface erosion and sediment discharge should be documented in an erosion and sediment control plan (ESCP) or other equivalent plan. The ESCP should contain the elements outlined in **vol. 1**: chapter 2. Matters of special importance for landfill ESCPs include :

- a development staging (filling) plan showing progressive development of the landfill and soil stockpile areas and the location of drainage lines and water storage facilities. This staging plan should show progressive development and the location of the site facilities at each major stage
- erosion control and rehabilitation/revegetation schedules for the landfill itself and for soil stockpiles. The erosion control measures should include details of proposed rehabilitation (grass seeding, mulching etc.) as well as any temporary sediment controls such as sediment fences
- water management and sediment control facilities including details of the design principles for all water diversion structures (banks, drains, waterways and special facilities for safely conveying water down steep slopes), and water retention/sediment control structures, including inlet and outlet arrangements
- site management and monitoring arrangements including details of routine maintenance (checking and repair of water conveyance structures after rainfall, removal of sediment from sediment basins etc.) as well as details of water-quality monitoring to be undertaken within the site and at external reference points.

In general, as noted in section 3.4, an ESCP for a small site will include less detail than required for a larger site. In particular, an ESCP for a large site should include details of the design principles for runoff conveyance and water/sediment storage structures as well as details of the temporary stabilisation and permanent revegetation procedures.

These requirements reflect the level of detail required in **vol. 1**: chapter 2 for soil and water management plans (SWMPs) for disturbed areas exceeding 2500 square metres. The term 'soil and water management plan' is not proposed for application at large-scale landfills, however, due to the requirement to address broader water management issues in a landfill management plan.

See appendix B below for an example of an ESCP for a large landfill site.

Appendix B: Sample erosion and sediment control plan for large site

B.1 Introduction

The Flaggy Gully Landfill Project involves the establishment and operation of a putrescibles waste landfill through the filling of a series of bunded cells with solid waste, capping the waste with inert material, and then revegetating the area.

This erosion and sediment control plan (ESCP) outlines the proposed management actions to control water and sediment within the boundaries of the site and thereby minimise any potential off-site impacts from the development.

The ESCP addresses the following issues:

- measures to be adopted for control of erosion and sediment during the life of the project
- sources of and pathways for 'clean' and 'dirty' water
- location and size of water-quality controls
- operation and maintenance requirements
- monitoring and reporting requirements.

Figures and drawings related to this ESCP are contained in attachment 1.

B.2 Regulatory requirements

The following regulatory requirements have been considered and measures included in the site design and this ESCP to meet the requirements for managing surface water, erosion and sediments for the landfill project:

- for landfill sites that will have a duration of disturbance greater than two years, the sediment basins are to be designed to capture and treat runoff from the 90th percentile, five-day rainfall event
- all water diversion structures are to be designed for a 20-year ARI design storm
- treated discharge waters are not to contain more than 50 mg/L of total suspended solids.

B.3 Project description and staging

The landfill site covers an area of approximately 35 hectares of which up to 10 hectares will be required for soil stockpiles and landfill operations at any one time. The general layout of the site is shown in figure B.1 (page 51). The project has an expected life of about 20 years. The waste will include all general and putrescible waste sourced from the adjoining local council area.

Site works will commence with the establishment of site infrastructure and the excavation of cell 1. All material excavated from cell 1 will be used for site establishment or stockpiled in the designated stockpile area. Following installation of an impermeable HDPE liner and the leachate collection system, waste will be progressively placed in cell 1 commencing from the up-slope side, to create a slightly domed landform that slopes towards the ridge.

Subsoil material will be progressively excavated from cell 2 and used for day cover of wastes placed in cell 1. As sections of cell 1 reach the final landform and the capping layer is installed, topsoil will be taken from the topsoil stockpile, commencing with the oldest soil. This sequence will be repeated progressively throughout the life of the facility with one cell being completed every three years.

During the establishment phase of the project, the construction of the roads, facilities and structures will be completed before any landfilling occurs. The strategy will be to provide temporary erosion control measures where necessary, and to progressively and promptly provide for permanent stabilisation of embankments and channels through revegetation.

An important consideration for the establishment phase has been developing a site layout and staging plan that:

- minimises the area exposed to erosive forces at any point in time
- seeks to establish adequate ground cover as soon as possible after earthworks are completed.

During the establishment phase of the project, temporary erosion control works will be necessary for:

- construction of access roads, sediment basins and clean water diversions
- construction of an office and other facilities
- construction of the soil stockpile area
- excavation of the initial landfill cell
- installation of an impermeable cell lining and a leachate collection system.

Surface water diversion channels will be used, as far as practicable, to:

- divert 'clean' runoff around the operational areas
- direct runoff from soil stockpiles and covered wastes to sediment basins
- minimise the area contributing runoff to the active waste emplacement area and maintain separation between leachate and other runoff sources.

Cells will be a maximum of three hectares each. At any time, only one cell will be actively filled, one will be in the process of final capping and rehabilitation, and one will be in the process of excavation, while a similar area will be used for soil and clay stockpiling. Thus the total area requiring erosion and sediment control will be about 12 hectares. All runoff within these areas that has not been in contact with waste will be directed to the sediment basins.

Ongoing erosion control will be provided through progressively topsoiling and revegetating the completed sections of each landfill cell as soon as practicable after completion of earthworks.

B.4 Site characteristics and constraints

The site is located within the Flaggy Gully catchment, which is part of the larger Blue River catchment. The site (approximately 35 hectares) is on the side of a gently sloping ridge that is surrounded by low undulating forested hills with patches of cleared land. Natural slopes within the area that will be directly affected by the project range up to 20 per cent but are generally around 8–12 per cent.

A small ephemeral watercourse runs through the site and drains into Flaggy Gully which is considered to be a 'slightly to moderately disturbed ecosystem' as described in the *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ 2000). Site topography and drainage is shown in figure B.1.

Based on the relevant soil landscape map, the project area contains elements of the Cedar Hill (ce), Stockrington (sn and sna), and Killingworth (ki) soil landscapes.

The main site characteristics and constraints relating to erosion and sediment control are set out in table B.1 and RUSLE calculations are presented in attachment 2.

Table B.1	Site characteristics and constraints	
Characteristic/constraint	**Data source**	**Value/rating**
Mean annual rainfall	Bureau of Meteorology	877 mm
Mean annual open water evaporation	Bureau of Meteorology	1620 mm
Rainfall zone	Figure 4.9, **vol.1**	7
Rainfall erosivity	Appendix A, **vol. 1**	1550 (R-factor)
Soil erodibility (subsoil)	Laboratory analysis	0.044 (K-factor)
Soil texture classification	Laboratory analysis	D (dispersive)
Soil hydrologic class	Laboratory analysis	D
Existing land gradient	Site survey	8–20%
Potential erosion hazard (existing)	Figure 4.6, **vol.1**	Low
Proposed batter gradient	Landfill design	25%
Calculated soil loss (unprotected batters)	Revised universal soil loss equation (RUSLE)	674 t/ha/year
Soil loss class (unprotected batters)	Table 4.2, **vol.1**	5
Erosion hazard (unprotected batters)	Table 4.2, **vol.1**	High
Proposed landfill surface gradient	Landfill design	3%
Calculated soil loss (unprotected landfill surface)	RUSLE	77 t/ha/year
Soil loss class (unprotected landfill surface)	Table 4.2, **vol.1**	1
Erosion hazard (unprotected landfill surface)	Table 4.2, **vol.1**	Low
90^{th} percentile 5-day rainfall	Table 6.3, **vol.1**	47 mm
Volumetric runoff coefficient (disturbed)	Table F2, **vol.1**	0.89
Peak flow runoff coefficient	Table F3, **vol.1**	0.9
Total site area / disturbed area	Site survey	35 ha / 12 ha
Required sediment settling zone capacity	Calculated	350 m^3/ha
Required sediment storage zone capacity	Calculated (one-year accumulation)	125 m^3/ha

B.5 Principles

The following key principles have been adopted in the design of the Flaggy Gully Landfill Project and the preparation of this ESCP:

- Minimise the area of soil disturbed and exposed to erosion at any point in time.
- Minimise the volume of runoff to be managed by minimising the contributing catchment area that is active at any particular time.
- Conserve topsoil for reuse on the site during rehabilitation/regeneration.
- Progressively and promptly rehabilitate disturbed areas, through:
  - a stable landform topography with minimal slope lengths
  - stable drainage lines
  - establishing groundcover as soon as practicable.
- Divert 'clean' runoff from adjoining lands around landfill and other disturbed areas.
- Keep sources of different quality water separate from each other, including:
  - leachate drainage from the base of the landfill and the immediate area of the active waste placement
  - 'dirty' runoff containing sediment from soil stockpiles and rehabilitated landfill
  - 'clean' runoff from undisturbed areas with no waste-related activities and areas that are fully rehabilitated (with ground cover of at least 70 per cent).
- Reuse or dispose of water on site and thereby ensure:
  - zero discharge of leachate by means of evaporation ponds and/or controlled irrigation onto the landfill
  - reuse of 'dirty' runoff for dust suppression.
- Install and maintain appropriate erosion and sediment controls to ensure that any discharge from the landfill site meets the relevant water-quality limits, including limits contained in relevant guidelines and any limits imposed by specific project approvals as listed below:
  - pH – 6.5 to 7.5
  - total suspended solids (TSS) – 50 mg/L
  - turbidity – 100 NTU
  - ammonia – 0.9 mg/L.
- Monitor water quality in receiving waters and within water bodies on site to ensure that the relevant water-quality limits are being met.

Pollution control strategy for surface water

Each of the four key areas of the site will have separate water management systems designed to cater for the runoff and water-quality characteristics of the particular facility. Details are set out in the following sections. The key elements of the surface water pollution control strategy are as follows:

- All leachate will be directed into leachate ponds for evaporation, re-injection or controlled irrigation onto the landfill area. The entire leachate collection and disposal system will be a 'closed' system which will be protected against the entry of unwanted surface runoff. This will be achieved by bunding of the active landfill area to exclude up-slope runoff and construction of the leachate evaporation ponds with an above-ground berm.
- Runoff from areas that are likely to generate sediment will be directed into designated sediment basins which will be sized so as to meet the sediment basin design

guidelines for type D soils (see Landcom 2004b, *Managing urban stormwater: soils and construction*, volume 1, 4th edition, Sydney – referred to in this document as **vol. 1**). These basins will also provide storage capacity for on-site water supply purposes (dust suppression and compaction of capping layers).

- Runoff from office and access roads will be directed to a small collection pond for trapping oil, sediment and litter. After removal of any oil, litter and sediment, water will be allowed to drain overland to sediment basins.
- Runoff from areas that are unaffected by the development will be allowed to discharge from the site.

B.6 Soil management and sediment control

General instructions

All figures referred to in this ESCP and standard drawings (see **vol. 1**) are to be read in conjunction with the overall landfill management plan and any other plans or written instructions that may be issued by the landfill manager.

Site operators and any contractors will ensure that all soil and water management works are undertaken as instructed in this specification and constructed following the relevant guidelines set out in **vol. 1**.

All subcontractors will be informed of their responsibilities in reducing the potential for soil erosion and pollution to down-slope areas.

Land disturbance

All proposed erosion and sediment control measures will be implemented before clearing and stripping operations, including the installation of sediment fencing down-slope of any areas that do not drain toward the 'dirty' water treatment areas. Sediment fencing will be installed in accordance with **vol. 1**: standard drawing 6-8.

Prior to clearing, the limits of disturbance will be marked by pegs placed at intervals on each side of the disturbed area. All operations will be planned to ensure that there is no damage to any trees outside the limits to be cleared.

Land disturbance will be minimised by clearing the smallest practical area of land ahead of earthworks and leaving this disturbed for the shortest possible time.

Site access roads

Roads will be constructed to ensure surface drainage is optimised and stabilised, thereby reducing roadside erosion and sedimentation. Cross-fall drainage structures and mitre drainage will be implemented for the entire length of the roads. Crowning will generally be implemented on any steeper sections of the roads. Out-fall drainage will be constructed where the road traverses small-fill batter areas, and in-fall drainage will occur where the road traverses larger-fill batter areas. Road runoff will be intercepted at regular intervals to reduce runoff velocity in each mitre drain. Drain spacing will not exceed 50 metres.

Soil management

Separate stripping and management of the various soil layers is to be undertaken as set out below:

- **Layer 1 (0 to 150 mm)** Strip topsoil to a depth of 150 mm. Topsoil stripping should be carried out on all areas that will be disturbed by the development. It should not be necessary to further strip areas that are only to be used for roads, buildings, hardstand areas etc. However, on areas where the disturbance is deeper the subsoil should be stripped as indicated for layers 2 and 3 below.

- **Layer 2 (150 to 750 mm)** Strip subsoil to a depth of 750 mm from the existing surface unless mottled soil is encountered at lesser depths. Stop subsoil stripping if mottled soil is encountered at depths of less than 750 mm below the existing surface. It should be noted, however, that the test pits all showed mottled material to occur at depths generally greater than 750 mm below the existing surface.
- **Layer 3 (remainder of the profile)** Treat as overburden and mix with any weathered rock and bedrock material that might be excavated for the landfill project.

Stripping of topsoil (layer 1) will, as far as practicable, be undertaken when the soil is in a slightly moist condition thus reducing damage to soil structure. The soil materials will not be stripped in wet conditions. The soils to be stripped are generally highly structured, thus excessive handling of the materials, or handling when the soils are wet will be avoided to protect existing soil structure.

During the operational phase of the project, the emphasis will be on maximising the direct transfer of materials and minimising the need for stockpiling of subsoil and clay. However, there will still be a need for an active stockpiling area for storage of topsoil and excess soil and clay.

Stockpiles will be placed in the designated area shown on figure B.1 so as to avoid impediment of the natural drainage line and minimise the likelihood of water ponding against the stockpile. Stockpiles will be managed in accordance with **vol. 1**: standard drawing 4-1. A diversion bank will be constructed on the up-slope side of the stockpile area shown on figure B.1.

Specific requirements for soil stockpile management are set out below:

- Separate stockpiles are to be constructed for topsoil, subsoil and clay at the locations shown on figure B.1.
- A diversion bank will be constructed up-slope of stockpiles in the general location shown on figure B.1 to divert overland flow around the stockpiles. (Specifications for the diversion bank are set out below).
- Loss of soil material from the stockpiles is to be minimised, especially in the period before they are stabilised by means of sediment fences constructed in accordance with standard drawing 6-8 in **vol. 1**.
- The stockpile surfaces should have a generally even surface that is as ‘rough’ as possible, to assist in runoff control and seed retention and germination.
- If stockpiling of topsoil (layer 1) for more than three months is required, a maximum stockpile height of two metres and a batter slope of 2:1 will be maintained to preserve biological viability and reduce soil deterioration.
- Stockpile surfaces should be sown with stabilising plant species as soon as possible after placement. Where stockpile construction is conducted in stages, the stockpile should be progressively stabilised.
- Due to the dispersive nature of the soils, runoff from the stockpile areas will be directed to a sediment basin, preventing untreated runoff from leaving the site.
- To maintain organic matter, the topsoil material (layer 1) will be rotated through the stockpile so that it is not retained for longer than 12 months.
- For any long-term storage of subsoil and clay, the surface of the stockpile will be progressively topsoiled and seeded with stabilising pasture species to minimise erosion.

Water diversion and conveyance

Runoff from areas of the site where soils and vegetation have not been disturbed is considered to be 'clean' runoff. Clean water diversion banks will be required at various stages of the project to divert clean runoff away from disturbed areas and sediment basins (see figure B.5 page 55). The channel bed and side slopes will be stabilised using grasses sown promptly at the completion of earthworks. Additional sediment control measures will be implemented prior to establishment of stabilising vegetation to prevent untreated runoff from leaving the site.

Runoff from disturbed areas of the site will be directed into a number of sediment basins that will be constructed progressively as the landfill cells are constructed. Four types of stormwater diversion and conveyance structures will be required:

- **cross-slope diversion banks** with grades of about one per cent. These banks will be generally constructed in accordance with the typical design for earth bank (low flow) or earth bank (high flow) contained in **vol. 1**: standard drawings 5-5 and 5-6. Dimensions of these drains are set out in table B.2 below
- **down-slope channels** located between cells 1 and 2, and cells 3 and 4 (as shown on figure B.1). Because these channels have slopes of 15 per cent and are permanent fixtures once the landfill operation is complete, they are to be lined with a freeform concrete mattress. Dimensions of these channels are set out in table B.2 below
- **berm drains** that run at grades around one per cent across the steep batters of the landfill. These drains divide the steep batter slopes into three approximately equal-length segments. Dimensions are set out in table B.2 below
- **chutes** constructed from half circle corrugated steel that convey runoff from berm drains on the landfill batters. Dimensions are set out in table B.2 below.

All water diversion and conveyance structures will be constructed to convey the 20-year ARI storm, and in accordance with the principles of **vol. 1**: chapter 5.

Details of the hydraulic design of the various diversion and conveyance drains are set out in attachment 4 and summarised in table B.2.

Table B.2 Design features of the diversion drains

	Clean diversion	Cross-slope	Down-slope	Berm drain	Chute
Design storm ARI (years)	20	20	20	20	20
Catchment area (ha)	11	1.5	3	0.35	1.0
Design discharge (m^3/s)	2.3	0.4	0.7	0.1	0.3
Base width (m)	3.0	1.0	1.0	0.0	0.0
Side slopes (1:X–V:H)	3	3	2	3	U
Water depth (m)	0.5	0.3	0.15	0.3	0.2
Channel depth (m)	0.8	0.5	0.35	0.5	0.5
Channel top width (m)	7.8	4.0	2.4	3.0	1.0
Flow velocity (m/s)	1.0	0.7	3.5	0.6	3.5
Channel lining	Grass	Grass	Concrete	Grass	Steel

Sediment retention basins

Sediment basins will be designed to capture and treat all sediment-laden runoff up to and including the 90th percentile five-day rainfall event.

Runoff from areas that are likely to generate sediment will be directed into designated sediment basins which are sized so as to meet the sediment basin design criteria for type D soils in **vol. 1**, in addition to providing storage capacity for on-site water supply purposes (dust suppression and compaction of capping layers). Details of the design of these basins are provided in attachment 3 and are summarised in table B3.

The sediment basins will be constructed in accordance with the typical design for earth basin – wet (**vol. 1**: standard drawing 6-4).

Sediment basins 1 and 3 will be constructed during site establishment and before the acceptance of waste. Sediment basin 2 will be constructed prior to any earthworks on cell 3.

The downstream slope of the basin embankments will be stabilised though vegetation. Prior to establishment of vegetation, a temporary silt fence will be required along the toe of the embankments. Stabilisation will require that topsoil be spread over the embankment and seeded with pasture. Vegetation establishment must be commenced promptly when construction of the embankment earthworks are complete.

The water storage capacity of the sediment basins will be provided for on-site uses including dust suppression, compaction of capping and irrigation of vegetation for establishment purposes. In accordance with the design principles for type D soils, the water level will be drawn down to the bottom of the settlement zone level within five days of the end any significant rainfall. This will be achieved either by use of water for on-site purposes or by treating the water to achieve less than 50 mg/L of total suspended solids and discharging off-site.

The sediment basins may need to be flocculated to achieve settlement of the suspended sediments. Where necessary, flocculating will be done using gypsum (or equivalent) in accordance with the manual dosing methodology in **vol. 1**: appendix E.

Table B.3 Sediment basin storage size

Component	Basin 1	Basin 2	Basin 3
Settlement zone (m^3)	2550	2850	1260
Sediment storage zone (m^3)	690	1080	310
Water storage zone (m^3)	2000	2000	1000
Total capacity (m^3)	5240	5930	2570

B.7 Final landform

Establishment of final landform

During placement of material, temporary machinery work on batters will be carried out so as to minimise susceptibility to erosion, using techniques such as ‘track walking’ a machine up and down the slope (see **vol. 1**: figure 4.3a).

The final landform will have the following features:

- batter slopes will not exceed a gradient of 50 per cent, and the top surface of the final landform will be approximately three per cent

- berm drains will be constructed across contours every 25 metres of slope length
- the landform will be free draining, with flows directed towards sediment basins and natural drainage channels after areas are fully rehabilitated (with ground cover of at least 70 per cent)
- stable drainage will be constructed to drain water from the landform areas including grass-lined channels and reinforced channel lining on steeper channel sections (see table B.2).

The final landform will then be revegetated as soon as practicable (no more than two weeks) after final capping and placement of topsoil.

Surface preparation for rehabilitation

Thorough site preparation will be undertaken to ensure rapid establishment and growth of vegetation. Topsoil will be spread along the contour of completed batters to minimise erosion by dumping at the top of slopes and grading downwards and across the contour. Once the topsoil is spread, vehicle traffic will be prevented from entering the area.

Gypsum and/or lime may be applied to the final surface using broadcasting machinery immediately prior to sowing. The ameliorants will be incorporated to a nominal depth of 300 mm.

Topsoil that has been stored separately from subsoil material will be re-spread on the surface of the batters and upper surface of the landfill so that the organic layer, containing any seed or vegetation, is returned to the surface.

Topsoil will be spread to a minimum depth of:

- 50 mm on areas where the slope is *more* than 4:1 (H:V)
- 75 mm on areas where the slope is *less* than 4:1 (H:V).

Re-spread topsoil will be levelled to achieve an even surface, avoiding a compacted or an over-smooth finish.

A sterile cover crop (oats and/or Japanese millet) may be applied to assist with initial soil stabilisation and used in different ratios according to the season as shown in **vol. 1**: table 9.4.

Mulch material will generally be applied across the rehabilitated area to stabilise bare soils. Mulches that meet Australian Standard *AS4454-203 composts, soil conditioners, and mulches (unrestricted)* will be preferred.

Vegetation establishment

Revegetation of disturbed areas is an integral component of the site ESCP and, as such, progressive revegetation of disturbed areas will be undertaken as soon as possible after disturbance.

The pasture species mix will generally be in accordance with the specifications in table B.4.

Sowing time Revegetation activities will generally be undertaken in spring and autumn, although opportunistic revegetation will be practised if areas become available for sowing in summer and winter.

Sowing methods After surface soil amelioration and tillage is completed for any given area, revegetation will commence as soon as practicable. The proposed method of sowing will be via conventional spreading using agricultural broadcasting equipment.

Steep slope treatment Slope stabilising techniques such as hydroseeding and straw mulching, will be undertaken on slopes exceeding 18 degrees for enhancement of pasture germination.

Fertiliser application Application will be undertaken simultaneously with both tree and pasture seeding. Maintenance fertilising will be conducted as required. Fertiliser type and application rates will be determined by prior soil analysis.

Table B.4 Pasture species specifications

Species	Rate (kg/ha)	
	Spring/summer	Autumn/winter
Japanese millet	20	5
Ryecorn/oats	5	20
Rhodes grass	10	-
Couch grass	10	-
Wimmera ryegrass	5	10
White clover[1]	8	-
Lucerne[1]	5	-
Sub clover[1]	-	8
Serradella	-	10
Consol	2	-
Starter fertiliser (sowing)	300	300
Maintenance fertiliser (following autumn/spring)	100	100

[1] All legumes will be inoculated and lime-pelleted prior to seeding.

B.8 Management, maintenance and monitoring

Long-term rehabilitation management

The long-term management of the rehabilitated area will require maintenance of the controls to achieve a stable area with a native forest community.

Following adequate establishment of vegetation and stabilisation of the site, runoff from the rehabilitated areas will be diverted away from sediment basins and into natural drainage lines. Alternatively, the sediment basins will be removed from the site. Control structures such as sediment basins and diversion measures will be progressively decommissioned as areas become satisfactorily rehabilitated.

Maintenance

The following operation and maintenance activities will be undertaken in relation to erosion control and water management facilities:

- any sediment control fences will be inspected and, if necessary, repaired/reinstated after any significant rainfall (more than 10 mm in a day)
- diversion drains will be inspected and repaired if necessary after any significant storms that have led to flow in the channels. Grass-lined diversion channels are susceptible

to scour from high-velocity flow and, although the channels have been designed to minimise water velocity, the grass cover will still be susceptible to localised scour around individual grass tussocks or rocks

- sediment-control basins will be inspected after any significant rainfall (more than 10 mm in a day), with particular focus on any sediment build-up and stability outlet structures.

In order to maintain the effectiveness of sediment basins for sediment retention, each basin will be drained down and cleaned within the first year. The frequency of clean-out can be reviewed after the first cleanout.

As part of statutory 'diligence and care' responsibilities, the site manager will keep a log book, making entries at least weekly – immediately before forecast rain and after rainfall. Entries will include:

- the volume and intensity of any rainfall events
- the condition of any soil and water management works
- the condition of vegetation and any need to irrigate
- the need for dust-prevention strategies
- any remedial works to be undertaken.

The log book will be kept on site and made available to any authorised person on request.

Monitoring

To assist with the collection of opportunistic surface-water samples, a collection of appropriate sample bottles will be retained and readily accessible on site. The site manager and his delegate will be trained in the collection, handling and dispatch of water samples for analysis.

Water-quality monitoring at the locations specified in the EPA licence will be undertaken four times a year. This monitoring should occur at approximately three-month intervals but should be adjusted to ensure that at least one (preferably two) samples are taken from the nominated sites during wet weather (more than 10 mm rainfall during the previous day). Monitoring requirements are summarised in table B.5.

During the operation of the site, annual reporting of surface-water quality will be conducted. Changes in water-quality parameters from baseline values will be identified and further assessment will be undertaken.

Monitoring of sediment basins will initially be undertaken at quarterly intervals to check that waste contaminants are not present in surface runoff. Any overflow of surface runoff from sediment basins will be monitored if possible, i.e. if the site is staffed.

<table>
<tr><th colspan="3">Table B.5 Summary of water-quality monitoring requirements</th></tr>
<tr><th>Location</th><th>Frequency of monitoring</th><th>Parameter to be analysed</th></tr>
<tr><td>Sediment basins</td><td rowspan="4">Quarterly</td><td rowspan="5">pH
Electrical conductivity
Total dissolved solids (TDS)
Total suspended solids (TSS)
Turbidity
Calcium – filtered
Magnesium – filtered
Sodium – filtered
Potassium – filtered
Bicarbonate as $CaCO^3$
Sulfate – filtered
Chloride
Ammonia as N
Nitrate as N
Total Kjeldahl nitrogen as N
Total phosphorus as P
Reactive phosphorus as P
Dissolved oxygen</td></tr>
<tr><td>Flaggy Gully downstream of sediment basins</td></tr>
<tr><td>Blue River downstream of confluence with Flaggy Gully</td></tr>
<tr><td>Blue River upstream of the confluence with Flaggy Gully</td></tr>
<tr><td>Sediment basins</td><td>During overflow
(if it occurs)</td></tr>
</table>

Reporting

For each sampling event, water-quality results will be compared against the assessment criteria and any other relevant criteria that may be defined in the project approval and environment protection licence. Any exceedence of criteria will trigger an immediate investigation to determine the cause of the exceedence and preparation of a corrective action plan to re-establish appropriate controls as necessary.

The reporting of all monitoring and measurement data will be undertaken in accordance with the requirements of the development consent, including notification of monitoring or investigation results to external organisations if required. All results will be reported in the annual environmental management report.

Results, including any actual or potential significant off-site impacts on people or the biophysical environment, will also be reported to DECC as soon as practicable after any incident.

Review

It is anticipated that the ESCP will be reviewed at least every five years and updated to take account of operational experience and any changes in the rate of waste delivery or the composition of the wastes delivered to the site.

Attachment 1 Figures

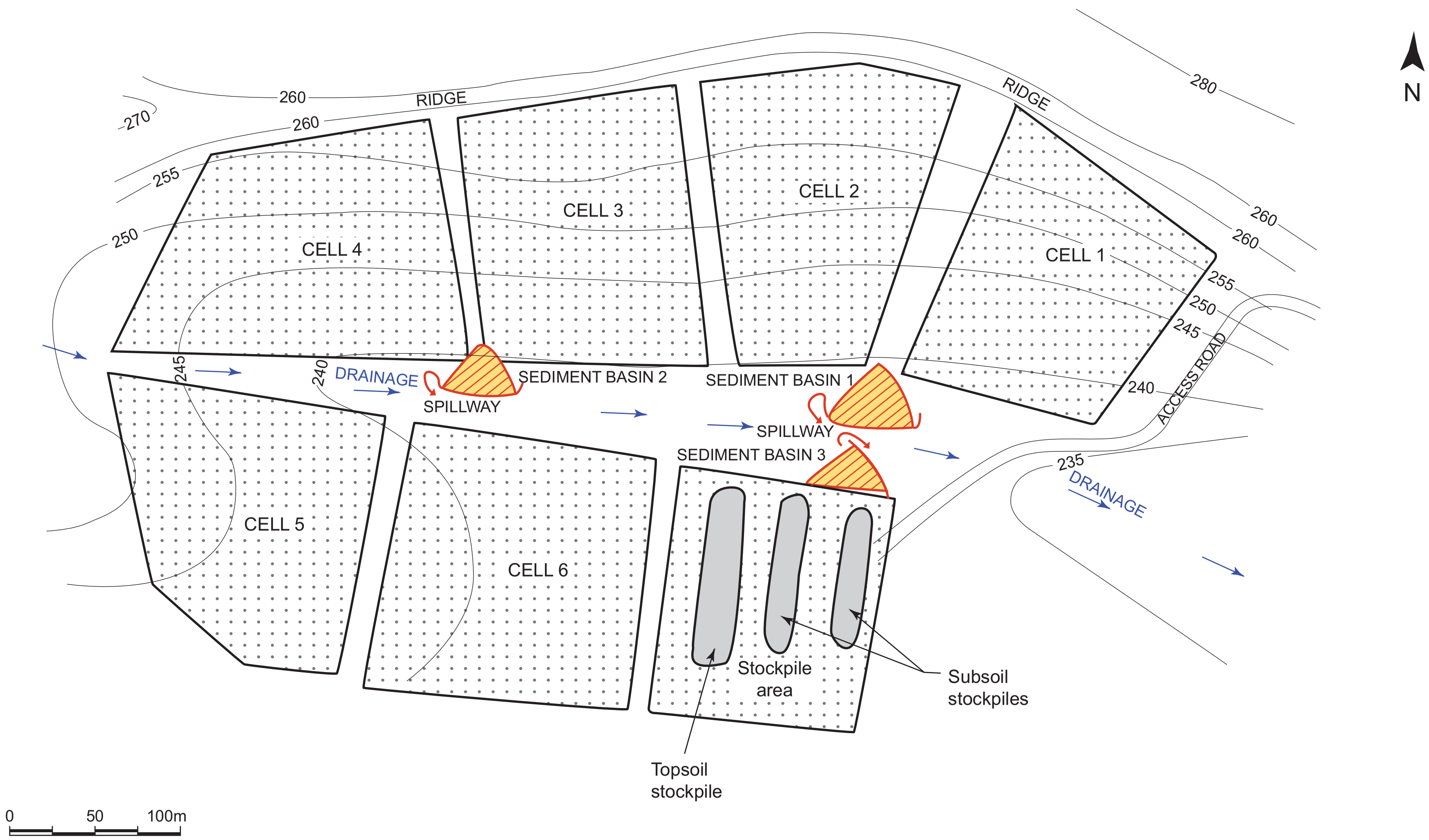


Figure B.1 Site layout plan

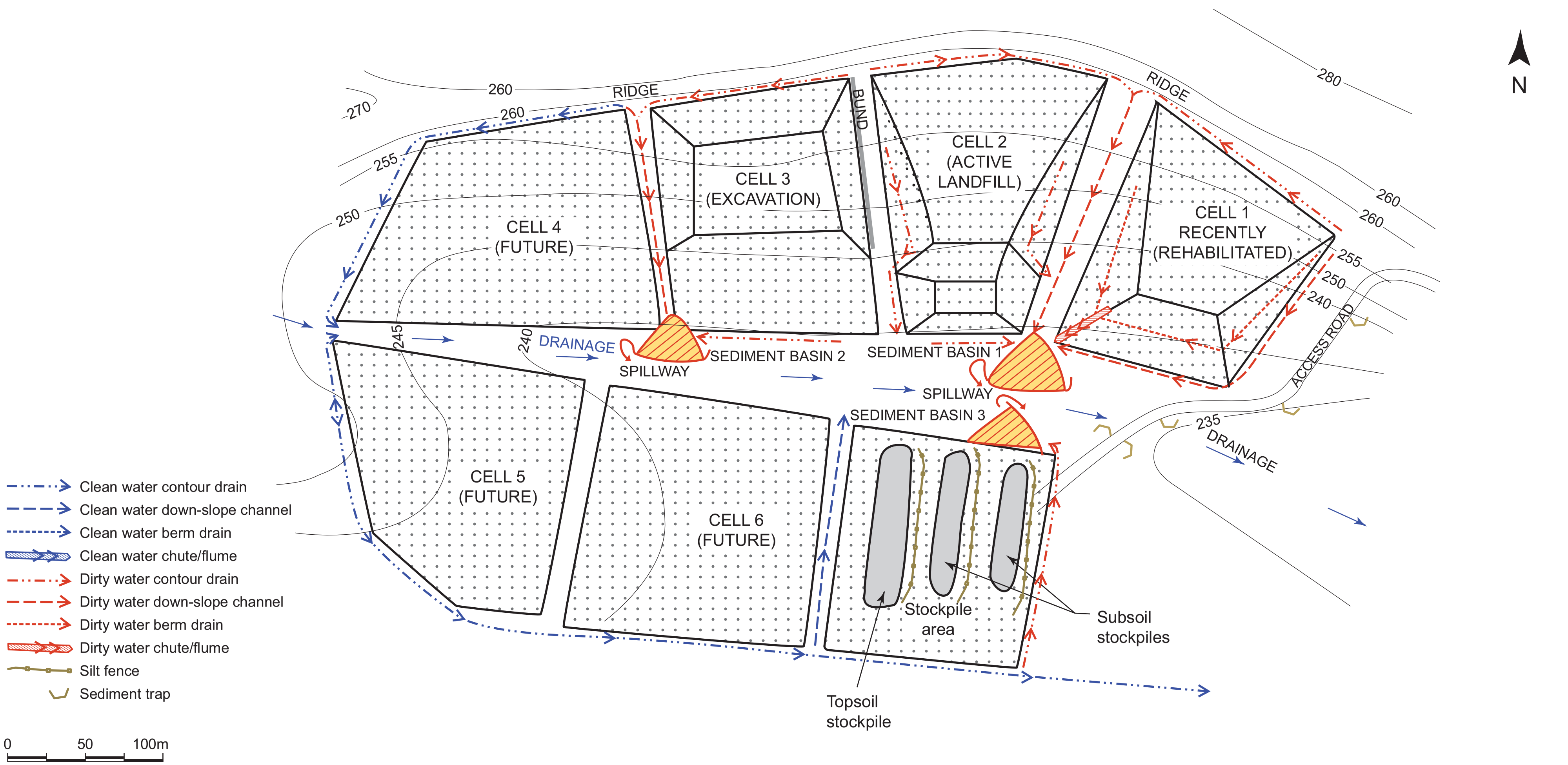


Figure B.2 Site layout and drainage plan – year 5

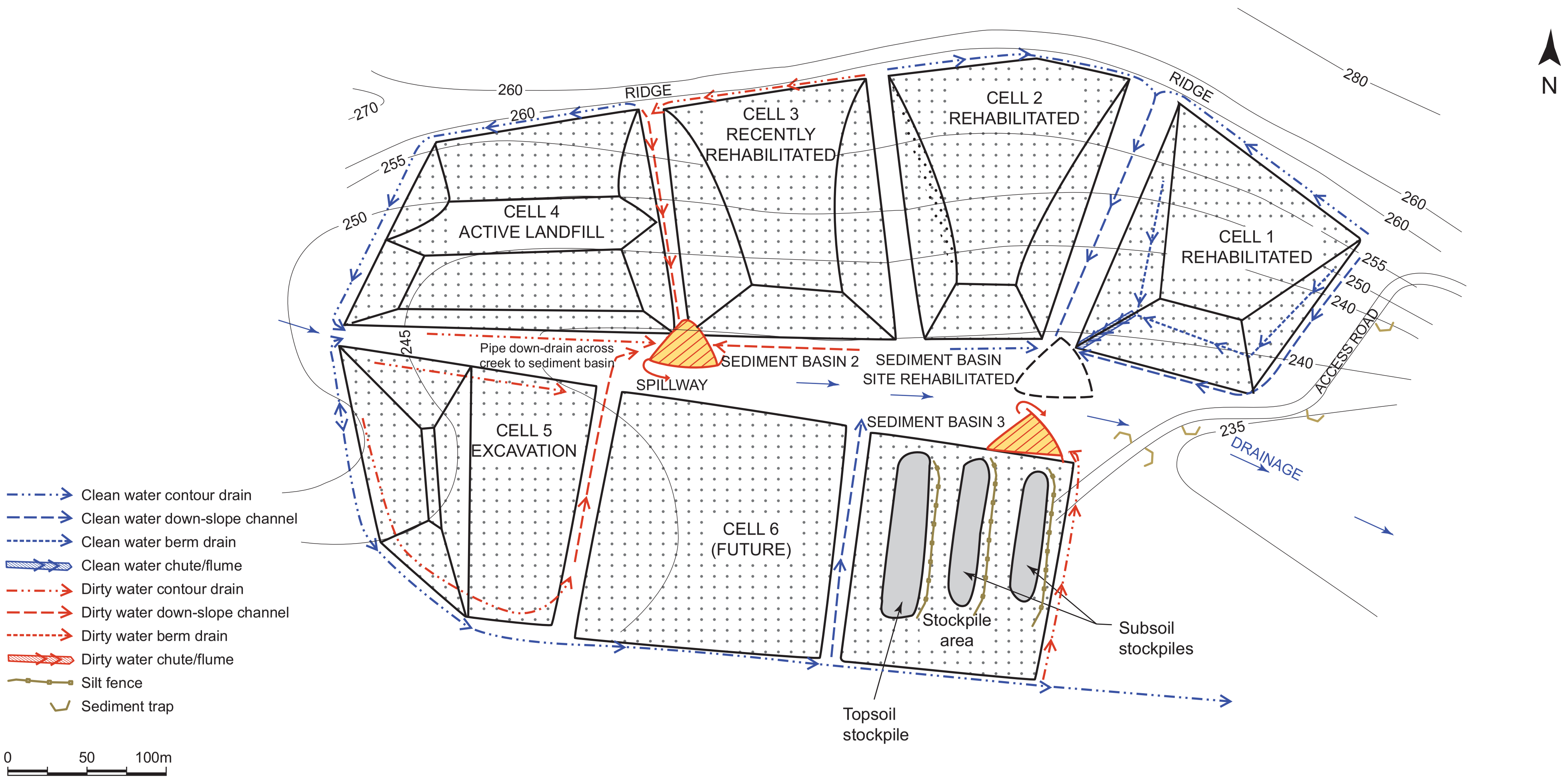


Figure B.3 Site layout and drainage plan – year 10

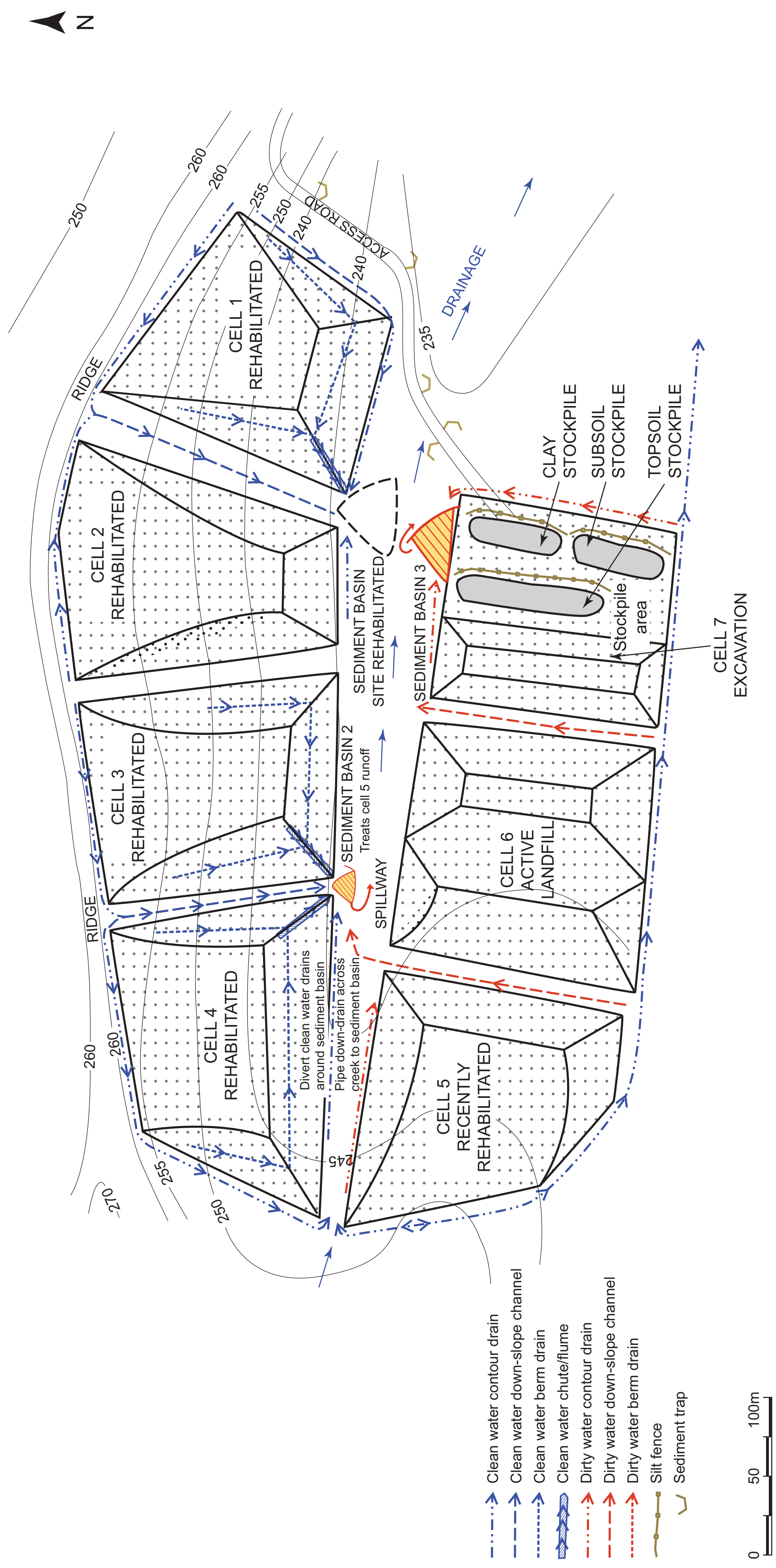
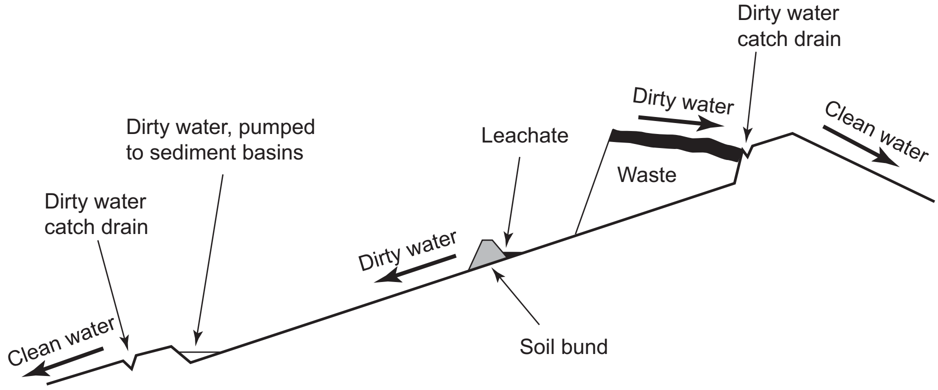
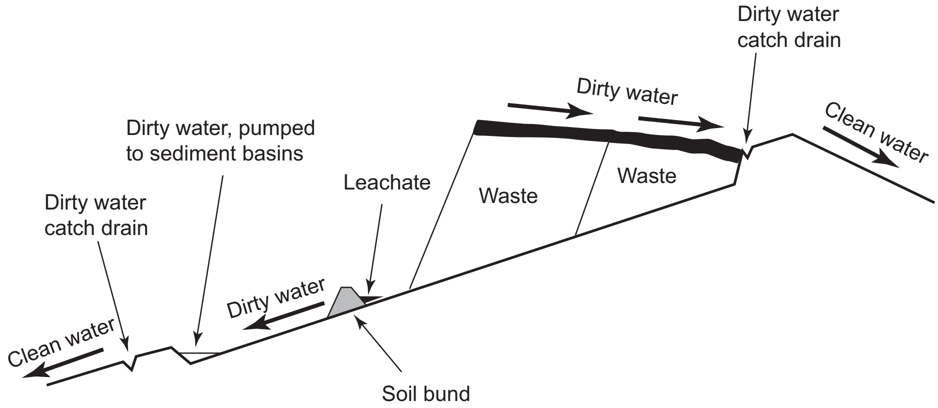


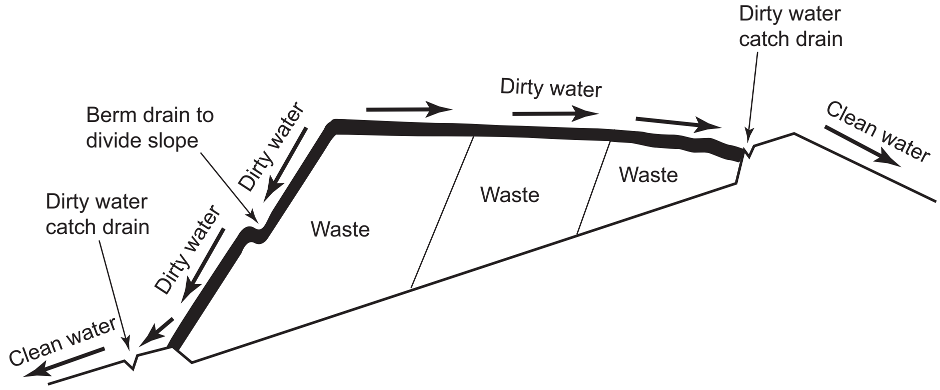
Figure B.4 Site layout and drainage plan – year 15



Initial emplacement



Mid-stage emplacement



Final emplacement

Schematic / not to scale

Figure B.5 Site water management details

Attachment 2

RUSLE analysis for Flaggy Gully site						
Characteristic		**Existing site**	**Landfill surface**		**Landfill batters**	
			bare	**rehab.**	**bare**	**rehab.**
Rainfall erosivity	R	1550	1550	1550	1550	1550
Soil erodibility	K	0.044	0.044	0.044	0.044	0.044
Slope (%)	S	12%	3%	3%	25%	25%
Slope length (m)	L	250	150	150	60	20
LS factor	LS	8.28	0.87	0.87	7.6	3.23
Erosion control practice factor	P	0.8	1.3	0.8	1.3	0.8
Ground cover factor	C	0.10	1.00	0.10	1.00	0.10
Average annual soil loss (t/ha)	A	45	77	5	674	18
Soil loss class		1	1	1	5	1
Erosion hazard		very low	very low	very low	high	very low

Attachment 3

Sediment basin capacity							
Sediment basin	**Design criteria**	**Landfill stage**	**Catchment area (ha)**	**Settling zone (m^3)**	**Sediment zone[1] (m^3)**	**Total volume (m^3)**	**Max volume (ML)**
Sediment basin 1	Type D	C1 Active	3.6	1506	513	2019	3.2
	(5-day 90%-ile)	C1 Pt rehab C2 Active	7.3	2554	687	3241	
		C2 Pt rehab	3.7	1035	192	1226	
Sediment basin 2	Type D	C3 Active	3.6	1506	704	2210	3.9
	(5-day 90%-ile)	C3 Pt rehab C4 Active	8	2847	1075	3922	
		C4 Pt rehab, C5 Active	8	2736	743	3479	
		C5 Pt rehab, C6 Active	7.4	2596	502	3099	
Sediment basin 3	Type D	C7 Active	3	1255	307	1562	1.6
	(5-day 90%-ile)	C7 Pt rehab	3	839	112	950	

[1] Sediment zone designed for 12-month soil loss.

Attachment 4

Diversion banks

	Clean diversion	Cross slope	Down slope	Berm drain	Chute
Design storm ARI (years)	20	20	20	20	20
Catchment area (ha)	11	1.5	3	0.35	1.0
Time of concentration (mins)	21	10	16	6	8
Rainfall intensity (mm/h)	83	116	97	135	127
Runoff coefficient	0.9	0.9	0.9	0.9	0.9
Design discharge (m^3/s)	2.3	0.4	0.7	0.1	0.3
Channel slope (%)	1%	1%	15%	1%	32%
Mannings (n)	0.05	0.05	0.02	0.05	0.02
Base width (m)	3.0	1.0	1.0	0.0	0.0
Side slopes (1:X – V:H)	3	3	2	3	U
Water depth (m)	0.5	0.3	0.15	0.3	0.2
Freeboard (m)	0.3	0.2	0.2	0.2	0.3
Channel depth (m)	0.8	0.5	0.35	0.5	0.5
Channel top width (m)	7.8	4.0	2.4	3.0	1.0
Flow velocity (m/s)	1.0	0.7	3.5	0.6	3.5
Channel lining	Grass	Grass	Concrete	Grass	Steel

Appendix C: Selection of control measures

This appendix, based on an approach developed by the Queensland Department of Mains Roads, provides a step-by-step guide to the selection of erosion and sediment control measures.

The steps involve:

- identifying the problem – erosion or sedimentation – to be managed (see figure C.1)
- where the problem is erosion, identifying whether it is caused by raindrop impact or concentrated flow
- where the problem is sedimentation, identifying if sediment is conveyed by sheet or concentrated flow
- selecting the appropriate techniques (see table C.1) depending on the identified specific nature of the problem.

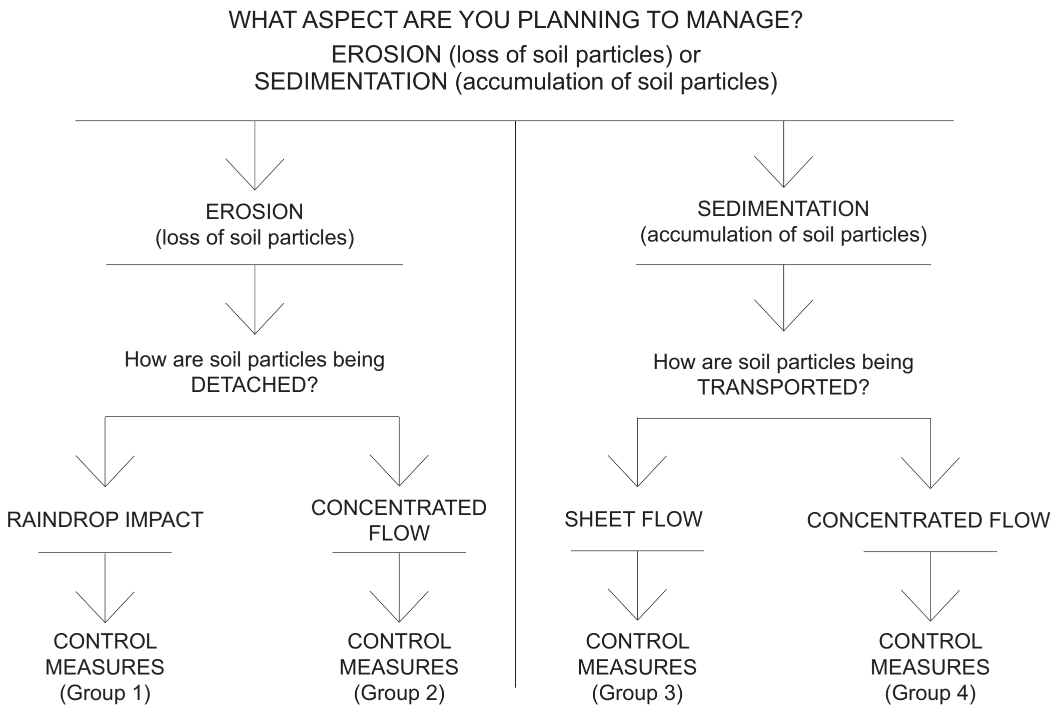


Figure C.1 A step-by-step decision-support flowchart for selection of erosion and sediment control measures (modified from Soilcon Pty Ltd and used with permission)

Table C.1 Group 1 – Erosion control RAINDROP IMPACT

Vegetation

- temporary vegetation (cover crop only)
- permanent vegetation – introduced (exotic) pasture species or native (endemic) species
- refer to **vol. 1**: sections 4.3.2, 7.1 and 7.2; appendices A6 and G

Batter blankets

- vegetation promotion blankets
- vegetation suppression blankets
- needle-punched geotextile membrane
- builder's plastic membrane
- refer to **vol. 1**: section 5.4.2; SD5-2; appendices A6 and D

Soil surface mulching

- hydromulch or hydraulic bonded-fibre matrix
- blown straw, hay, crop residue, with bitumen tack
- tub-ground or chipped organic mulch
- brush-matting
- rock or gravel mulch
- refer to **vol. 1**: section 7.4; figure 7.3; appendices A6 and D

Geocellular containment systems

- Non-woven geotextile type material
- Polypropylene material (perforated and non-perforated)
- refer to **vol. 1**: section 5.4.2; SD5-3; appendix D

Surface roughening

- roughening parallel to contour
- contour ripping or scarifying
- 'track walking'
- refer to **vol. 1**: section 4.3.2; figures 4.3(a) and (b)

Geobinders

- organic tackifiers
- co-polymer emulsions
- bitumen emulsion
- cementitious products
- refer to **vol. 1**: section 7.1.2; appendices A6 and D

Table C.1	Group 2 – Erosion control CONCENTRATED WATER FLOW
Up-slope diversions • excavated channel-type bank • backpush-type bank or windrow • catch drains • shoulder dyke • refer to **vol. 1**: section 5.4.4; SD5-5 and SD5-6	
Mid-slope diversions • berms and benches • temporary diversions (at cut/fill line) • cross banks • refer to **vol. 1**: section 4.3.1; figure 4.2; appendix A4	
Soft armour channels • trapezoidal or parabolic shape • consider channel grade and maximum permissible velocity • establish vegetative ground cover • standard (un-reinforced) or re-inforced turf • biodegradable erosion control mat (temporary) or synthetic erosion control mat (permanent) • refer to **vol. 1**: sections 5.4.3, 7.3; SD5-7; appendix D	
Hard armour channels • loose rock • rock-filled wire mattresses • articulating concrete block systems • grouted rock • cast in-situ concrete • builder's plastic lining or geotextile lining • refer to **vol. 1**: section 5.4.4; table 5.2; figure 5.4; appendix D	
In-stream diversions • temporary coffer dams • water-filled structures • temporary lined channel (stream diversion) • refer to **vol. 1**: section 5.3.5; appendix I	

Table C.1	Group 2 – Erosion control CONCENTRATED FLOW (cont'd)
Check dams • stacked rock • sandbags and geotextile sausages • straw bales • logs • proprietary products • refer to **vol. 1**: section 5.4.3; SD5-4; figures 5.3(a) and (b)	
Batter drains • concrete (pre-cast or on-site) • half 'armco' pipe • sandbags • rock-filled wire mattresses • loose-rock rip rap • builder's plastic or geotextile lined chutes • refer to **vol. 1**: section 5.4.4; appendix D	
Grade control structures and flumes • gully pits and field inlets • sandbag drop structures • rock-filled wire gabions and mattress structures • driven sheet piling • concrete chutes • inclined pipe spillways • builder's plastic-lined chutes	
Outlet dissipation structures • loose-rock rip-rap aprons • rock-filled wire mattresses • roughness elements • hydraulic jump-type structures • impact-type structures • refer to **vol. 1**: section 5.4.5; figures 5.8, 5.9, 5.10, 5.11 and SC5-8	
Revetments and retaining walls • rip rap • rock-filled wire gabions and mattresses	

Table C.1	Group 3 – Sediment control SHEET FLOWS
Vegetative buffers • well established sward with good groundcover • refer to **vol. 1**: section 6.3.8; table 6.4; SD6-13; appendix G	
Sediment barriers/filters • sediment fences • vegetation, brush, rock or gravel windrows • straw bale barriers • refer to **vol. 1**: section 6.3.7; SD6-7 and SD6-8; figure 6.10; appendix D	
Site exit points • shaker ramps • rock aprons • wheel wash systems • refer to **vol. 1**: section 6.3.9; SD6-14	

Table C.1	Group 4 – Sediment control CONCENTRATED FLOWS
Sediment curtains / turbidity barriers • floating geotextile • proprietary polypropylene products • temporary coffer dams • water-filled structures • refer to **vol. 1**: section 6.3.7; SD6-10; appendix D	
Sediment traps • stacked rock/timber with geotextile • excavated sumps • straw bale or sand bag structures • gully pit, field inlet and kerb inlets • refer to **vol. 1**: section 6.3.6, figure 6.11; SD6-11 and SD6-12	
Sediment retention basins • Type C (riser type) basin • Type F (extended settling) basins • Type D (flocculation) basins • refer to **vol. 1**: sections 6.3.3, 6.3.4 and 6.3.5; SD6-3 and SD6-4; appendices E and J	

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