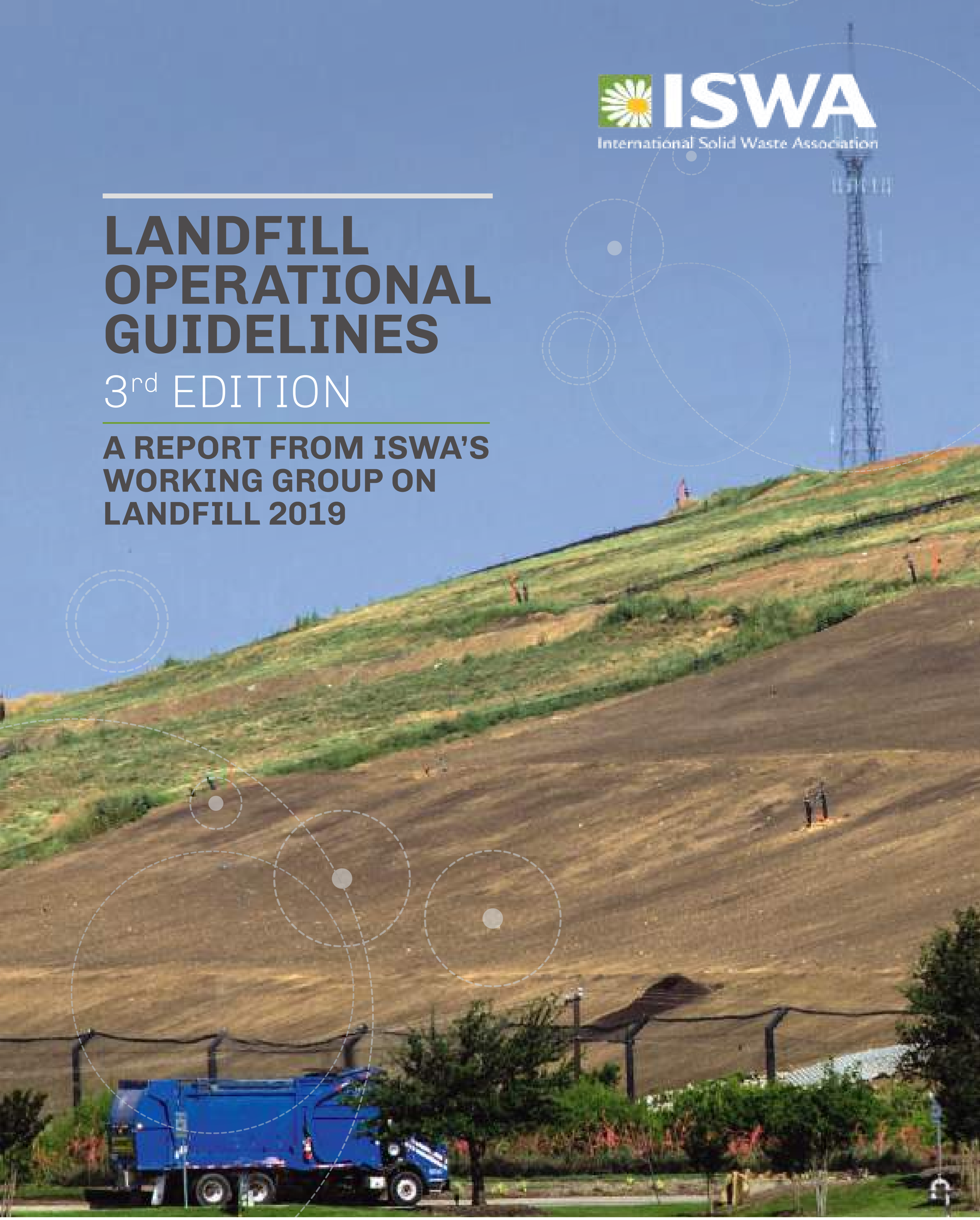

ISWA
International Solid Waste Association

LANDFILL OPERATIONAL GUIDELINES

3rd EDITION

A REPORT FROM ISWA'S WORKING GROUP ON LANDFILL 2019

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FORWARD

The ISWA Working Group on Landfill responded to the urgent need for an up to-date guidance document that can be used to assist those who are operating a sanitary landfill. When a sanitary landfill is carefully designed, constructed, operated, and monitored, it isolates wastes and pollutants from its surrounding environment; both the environment and the public's health is protected.

This document enables lower-income and lower-middle-income countries to transition from open dumping and uncontrolled landfilling to sanitary landfilling operation. Upgrading waste disposal sites into sanitary landfills is the key to improving the people's standard of living. This is the document that can bring such proper waste management practices to those who can benefit most.

In this new edition, we have replaced some of the old and out-of-date photographs with new photographs in certain chapters. In some chapters in the last edition, we added new figures and illustrations to strengthen its technical content, such as Chapter 8 on Waste Compaction and Chapter 9 on Landfill Fires. We also revised the existing chapters at best as we can in attempting to include new technologies and practices, such as Chapter 12 on Leachate Control and Treatment. Furthermore, we added four new chapters, which address important aspects of monitoring a sanitary landfill, basic practice and technologies in landfill mining and biocovers practices, as well as a chapter on closing landfill requirements, methodologies and standards in great details.

While this document may seem like yet another ISWA technical output to be shelved and forgotten, its content is priceless and can have multiplicative effects, instilling drastic change to mitigating greenhouse gas emissions in lower-income and lower-middle-income economies where dumpsites continue to plague communities. I am confident that it will become a useful guidance document in operating a landfill properly and safely. It is the document that we can reference to as we campaign on our Closing Dumpsites initiative and for those who are transitioning from dumpsites into sanitary landfills worldwide. I am proud to use it in promote ISWA's mission of professional and best practices in solid waste management worldwide. It begins with you; I hope you share this document with those in need.

H. James Law
Chair of ISWA Working Group on Landfill (WGL)

Björn Appelqvist
Chair of ISWA Scientific and Technical Committee (STC)

Landfill Operation Guidance, Third Edition, September 2019

MESSAGE FROM ISWA PRESIDENT

While we are working hard on circular economy and resource management and their relevance for modern waste management systems, in ISWA we never forget that there is no waste management system without a final disposal infrastructure capable to safely receive and storage the residual streams.

We also know very well that the importance of sanitary landfills is becoming more crucial for the rapidly urbanised developing world, where the growing waste generation surpasses the capacity of local and regional authorities to deliver waste management infrastructure. It is clear that the developing world requires much more sanitary landfills than there are today as a basic condition that will stimulate the closure of dumpsites and the reduction of their serious health and environmental impacts.

So, I would like to congratulate the ISWA's Sanitary Landfill Working Group for the third version of the operational guidelines document. I had worked myself in one of the previous versions and I know by heart how interesting, practical and solution - oriented those guidelines are. I am sure that the readers of this document will enjoy it and they will use it as a guidance to advance their operations. At the end, we all know that a sanitary landfill is as good as its operations and this document really stimulates integrated, careful and advanced operational techniques.

Antonis Mavropoulos
ISWA President
September 2019

ACKNOWLEDGEMENTS

The Landfill Operational Guidelines were originally developed in 2002 as a short-hand document to assist waste managers with day-to-day operations at a landfill site. Eight years later in 2010, the Guideline's Second Edition, under the initiative of former Chair, Derek Greedy (Chartered Institution of Wastes Management, CIWM, UK), blossomed into a comprehensive document providing the latest, operational practice with some technical guidance.

Today I am proud to say that after nearly ten years from publishing the last edition, we have just completed this new Third Edition with volunteers from the WGL. They are the key document's reviewers and contributors who represent a diverse group of individuals scattered across the globe, 12 countries to be exact. While we may be from different walks of life, the ISWA Working Group on Landfill has united us and we have produced a truly strong, international output that will greatly benefit for those who want to operate their landfills properly and safely in protecting the health of the people living nearby and the environment.

This document will be a very useful operational guidance document as ISWA promotes better waste management practices by closing of dumpsites and transitioning into sanitary landfill operations worldwide.

I wish to acknowledge and extend my gratitude for the contributions and support given by the various members of the Working Group and their associates to the Landfill Operational Guidelines' Third Edition:

Chapter	Main Contributor(s)
Chapter 1: Site Roads	Deji Fawole, SCS Engineers, USA
Chapter 2: The Use of Daily Cover	Hiroyuki Ito, DOWA Eco-System CO. Ltd., Japan
Chapter 3: Bird Control	Derek Greedy, CIWM, UK
Chapter 4: Wheel Cleaning	Monique Kallassy, Veolia, France
Chapter 5: Litter Control	Richard Watson, Delaware Solid Waste Authority, USA
Chapter 6: Vector Control	Derek Greedy, CIWM, UK
Chapter 7: Managing the Working Face	James Law, SCS Engineers, USA
Chapter 8: Waste Compaction	Marcos Elizondo, WCA Waste Corporation, USA
Chapter 9: Landfill Fires	Odile Oberti, Suez, France
Chapter 10: Stormwater and Sediment Control	Dr. Mark Milke, University of Cantebury, Department of Civil and Natural Resources Engineering, New Zealand
Chapter 11: Waste Control at Landfills	Dr. Bharat Bhushan Nagar, IPE GLOBAL LTD., India
Chapter 12: Leachate Control and Treatment	Robert Körner and Frank Natau, WEHRLE Umwelt GmbH, Germany
Chapter 13: Odour Control	Richard Watson, Delaware Solid Waste Authority, USA
Chapter 14: Landfill Gas Management	Yuri Matveev, SEC Biomass, Ukraine
Chapter 15: Site Health Safety and Security	Jacobo Moreno Lampaya, Valoriza Servicios Medioambientales, SACYR Group, Spain
Chapter 16: Landfill Monitoring	Dr. Sahadat Hossain, University of Texas, Arlington, USA
Chapter 17: Landfill Mining	René Møller Rosendal, Danish Waste Solutions, Denmark
Chapter 18: Biocovers	René Møller Rosendal, Danish Waste Solutions, Denmark
Chapter 19: Landfill Closure	Heijo Scharff, Afvalzorg, Netherlands

Furthermore, I would like to extend my deepest appreciation to the ISWA Scientific and Technical Committee and to the reviewers who assisted me and incorporated valuable suggestions for improvements of the penultimate draft:

Mr. Derek Greedy, Former Chair of the Working Group on Landfill, CIWM, UK

Professor Sahadat Hossain, Solid Waste Institute for Sustainability, University of Texas Arlington, USA

Mr. Luis Marinheiro, Former Chair of the Working Group on Landfill, AST Ambiente Environmental Solutions and Services, Lda., Portugal

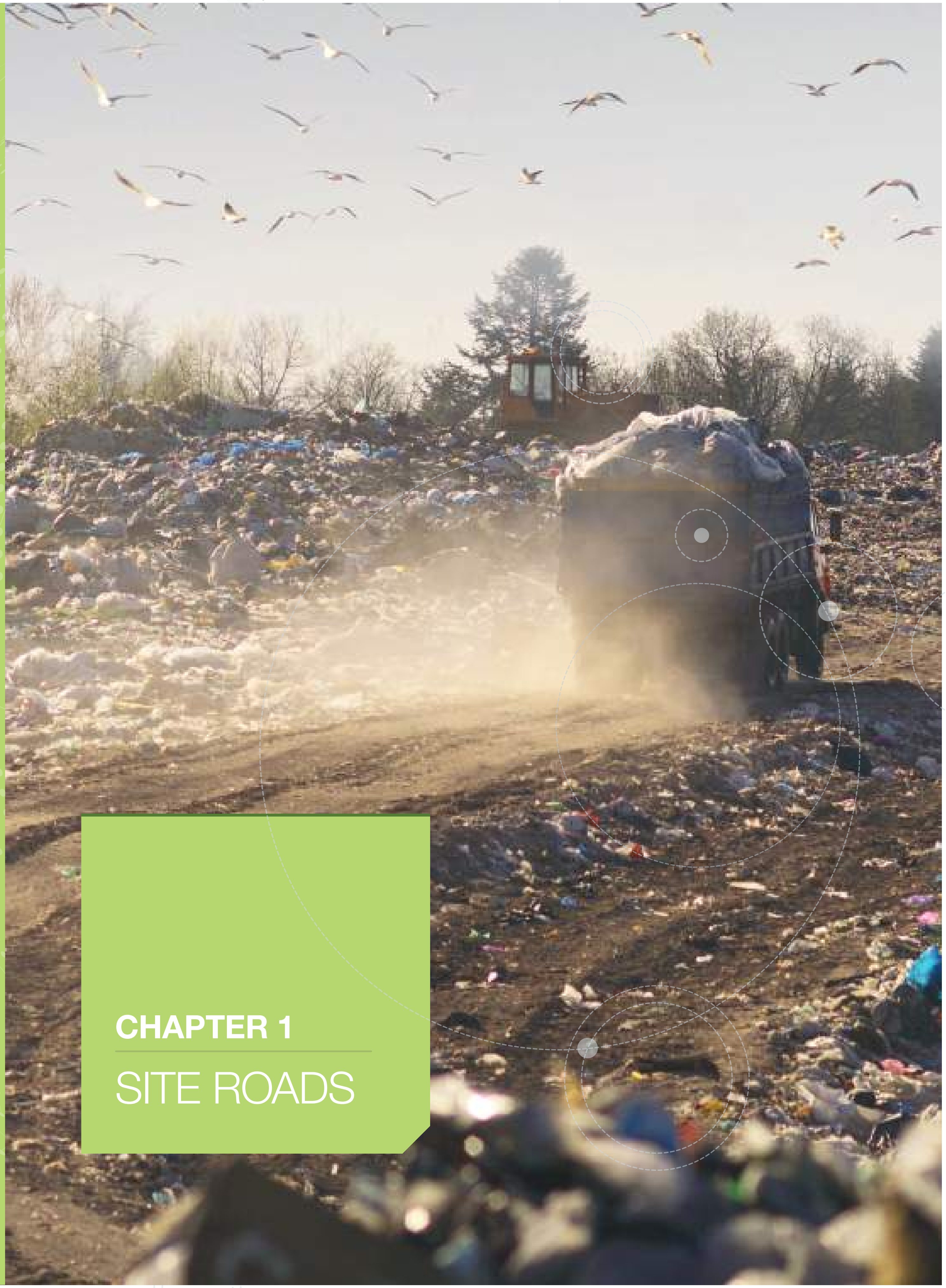
Mr. René Møller Rosendal, Vice Chair of the Working Group on Landfill, CEO of Danish Waste Solutions, Denmark

Finally, I would like to confer my greatest thanks on the staff at the ISWA General Secretariat for their diligent, on-going support, fundraising, coordination, and management of this project:

Ms. Jennifer 'Faa' MacDonald, ISWA Technical Project Manager

Mr. Daniel Purchase, ISWA National Membership and Communications

H. James Law
Chair of Working Group on Landfill
September 2019



CHAPTER 1

SITE ROADS

CHAPTER 1 SITE ROADS

1.1. INTRODUCTION

Road access is a vital part of landfill operation and must be appropriately planned and budgeted for. It is imperative that landfill site roads are adequate for their intended use in providing safe and unhindered access to and from the tipping face at all times to ensure all-weather access. Access for landfill equipment also needs to be considered and often this needs to be on separate roads or equipment tracks.

Figure 1.1. Site approach road

Prevention of damage to vehicles and quick turn-around times are essential in maintaining good customer relations at a landfill site. In addition, maintaining continuous access to the tipping face reduces reliance on emergency tipping areas, and minimises the risk of forced of site closure due to the tipping area becoming inaccessible.

All landfill roads need to be well graded, and kept mud and debris free to the extent practicable, and with adequate drainage. Maintenance must be given high priority as early action in addressing road problems will usually minimise the need for major repairs over the long term.

Use of a graded running course on main site roads is usually essential to ensure all weather access – sometimes waste materials (either as-received or re-processed), can be used for this purpose.

1.2. ROAD TYPES

Landfill roads can be divided into four types:

- Approach roads and entrances (with approach roads usually part of a regional road network)
- Primary Access roads – Internal roads to reception / weighbridge and internal site road junction
- Secondary Access roads – Main internal roads to operational area
- Tertiary Access roads – Temporary roads within the operational area

Where possible, all main access routes should allow for two-way traffic flow. However, where this is not possible the provision of passing bays must be considered and is usually essential at other than very small sites. The design standard for each of these road types will be very different as described below.

1.3. SITE APPROACH AND ENTRANCE ROAD

Main site approach road design should be to local highway standards, including road markings and speed limit signs, based on anticipated traffic usage. Drainage with cesspits is desirable to enable both the entry road and adjacent approach roads to be kept clean.

Care must be taken not to under-design the pavement construction as repairs related to pavement failure and pothole development in this crucial area can lead to significant difficulties, particularly if site user vehicles need to queue onto a public highway.

Entrances will typically be bell-mouthed, and sealed with either tarmac or concrete.

A minimum distance into the site of 25m from the entry point is desirable before reducing road configuration to a lower standard. Sufficient distance should be provided between the main entrance and weighbridge to avoid queuing of vehicles outside the gate. Entrance roads are usually provided with kerb and channel, a camber to ditches on either side, or sloped to a ditch running along one side of the road, to enable mud and water to drain to the side of the road.

In order to present a good image at the site entrance, visibility splays should be grassed and/or landscaped, with due regard to any sight distance or other height restrictions applicable, and should be regularly maintained. In addition, site entrance signage must be neat, functional, well-planned and located. A site approach road is shown at Figure 1.1 (page 4).

1.4. PRIMARY ACCESS ROADS

This type of access road typically runs from the site entrance to the site reception facilities and to the egress point of any wheel cleaning measures. It should be paved with either tarmac or concrete, have lane markings and be designed to allow for surface water run-off, either by cambering to ditches on either side, or by sloping to a ditch running along one edge. Appropriate drainage and silt traps (or cesspits) should be provided for litter, debris and sediment control. A primary access road is shown at Figure 1.2.

The road surface must be capable of being regularly watered down and swept. Installing speed humps should be avoided (these can be when wet and in winter), unless required for safety reasons. Speed humps can also make road sweeping difficult and prove to be collection points for mud and debris. However, where speed control is necessary, consideration should be given to chicane-type features to enable cars, but not waste haulage and other heavy vehicles, to manoeuvre around them.

To avoid the need for speed humps, barrier arms can be installed and may be an appropriate solution. Barriers help to control vehicle speed, prevent access to unauthorized vehicles and make it much easier to sweep, clean and maintain the site roads (Figure 1.3) (page 6).

1.5. SECONDARY ACCESS ROADS

Hard-core (gravel) roads, as shown at Figure 1.4 (page 5), can be used to provide secondary access within the site active area. However, due regard should be given to the length of road and the length of time it will be utilized. It may be more economical over the long term, when both construction and maintenance costs are considered, to provide a sealed / paved road for main secondary roads and perimeter access roads.

Hard-core roads should always be properly designed and where roads are formed over waste usually will be underlain with geofabric to facilitate drainage and prevent stone being "punched" into the underlying formation. It is also important to ensure that the road surface is above that of the surrounding area and that there is sufficient cross-fall to promote surface water run-off.

Run-off control (watertable drains) must be provided along the length of the road whenever possible. At the very least, provision must be made for surface water to shed at discrete locations. This is particularly important where the access road is in a cutting, or where safety bunds are required the edge of slopes. Good quality hard-core (road aggregate) is a must for this type of construction. If recycled or recovered gravel is used, material

contaminated with wood, plastic, paper or sharp materials should be rejected. Where practicable, a perimeter access road surrounding the entire site is advantageous.

Figure 1.2. Primary access road

A perimeter access road facilitates maintenance of the site, enhances efficient traffic flow, and renders one-way traffic flow a practical option.

1.6. TERTIARY ACCESS ROADS

This is the final type of access that traverses the active working area and forms a tipping area and by its nature is always formed on waste and temporary in nature.

However, as with secondary access routes, forward planning of operational areas is vital to ensure that maximum use and minimum maintenance of these roads is achieved.

It is important that these roads and tipping areas are sufficiently well constructed as to provide adequate traction for vehicles accessing the working face in all weather conditions. Consideration should be given to the use of any suitable dry waste material, including construction waste (gravel, crushed stone, cinders, crushed concrete, mortar, or bricks), spoil or in certain cases household waste, for working face area access.

Materials, particularly where waste materials are used, should be carefully selected to avoid an increase in puncture risk for road vehicle tyres, and to avoid traction problems in the active manoeuvring area. Lime, cement or asphalt binders may also be used to enhance serviceability of the tertiary access roads.

If gravel aggregate is used, as with secondary prevent the material being "punched" into the underlying waste and to assist in the recovery of the majority of material for re-use when the tipping area is shifted. Grading to provide drainage is not essential, but if it is possible to have the finished surface above waste level, less maintenance will be required. Ruts should be regularly addressed, mud scraped off and drivers encouraged to split their approach in working face apron areas to reduce rut formation. Single-track roads should be avoided by providing a width of at least one-and-a half-tracks.

Compactors and other heavy site mobile plant should avoid crossing or using the tertiary access roads and separate tracks should be provided for machinery that needs to be moved away from the active area for maintenance. The better tertiary access roads are maintained, the greater the corresponding reduction in the impact on other access routes. In particular, the carry-over of mud can be reduced and the effectiveness of wheel-cleaning measures can be improved by keeping tertiary access roads at a good quality level, although weather and the nature of available site road making materials can often impact on this aspect of operation.

Figure 1.3. Barriers at a primary access road

Figure 1.4. Hard-core secondary access road

1.7. CONCLUSIONS

It is important to give vehicle access high priority at any landfill site. Good access roads can contribute significantly to customer satisfaction by reducing vehicle damage and enabling quick turnaround times, as well as reducing site operations costs.

Permanent roads should be designed to support the anticipated volume and loading of vehicular traffic and pedestrians. In all cases, traffic flow patterns should be designed to minimize conflict between pedestrians and vehicles. Entry and exit turns against oncoming vehicles should be avoided as much as possible, and provision of safe site distances should be considered in the layout of roads. The use of one-way traffic patterns can reduce the risk of collisions, while at the same time serving to aid the efficient flow of traffic.

Road maintenance is of fundamental importance and appropriate design is essential to meet service requirements. Rutting and potholes will trap water, which can damage roads and potentially result in the need for major repairs, as well as disrupting face access. Recovered waste or other surplus site materials are often suitable for use in forming temporary site roads, but such materials should be carefully selected to avoid introducing problems with maintenance, or increasing puncture risk to road vehicle tyres.

CHAPTER 2
THE USE OF DAILY COVER

CHAPTER 2 THE USE OF DAILY COVER

2.1. INTRODUCTION

The regular application of daily cover soil (Figure 2.1), or an alternative such as tarpaulins or an artificial (alternate daily cover) material is perhaps the most fundamental control on direct effects arising from waste landfilling. Sites with poor daily cover practices are often subject to bird, odour, vermin, litter, and surface water quality problems.

Figure 2.1. Application of daily cover

The most fundamental control to achieve good landfill performance is to regularly and completely cover the waste and to ensure it remains covered in all areas other than the active face, which should be kept as small as practicable.

2.2. OBJECTIVES OF DAILY COVER

The key objectives of placing daily cover are to:

- Minimise windblown-litter
- Control odours
- Prevent birds from scavenging
- Prevent unauthorised scavenging by humans
- Prevent infestation by flies and vermin
- Reduce the risk of fire
- Provide a pleasing appearance
- Shed surface water and minimise contamination of runoff generating potential leachate out of the landfill

2.3. DISCUSSION

2.3.1. Windblown Litter

Windblown litter is created when waste is deposited and is not controlled by compaction and/or cover soil. The use of modern equipment such as a bulldozer or steel-wheeled compactor ensures that material capable of being windblown is compacted and worked into the waste surface. The regular application of daily cover throughout the day, and completely at the end of the day is a key control over litter at most sites. However, under some conditions (e.g., where a site is windy, where cover soil is in short supply, or where artificial cover methods such as tarpaulins are being used) this may not be enough on its own to provide effective litter control and additional measures to control litter may be needed (see the Guideline for Litter Control).

However, windblown litter can occur simply as a result of poor compaction of the waste, or as a result of weather conditions. Both are issues which can be effectively addressed by the regular application of daily cover soil.

2.3.2. Odour

While the placement of daily soil cover does not provide a completely sealed surface, it is shown to be an effective control on odour. But daily cover alone will not be an effective odour control measure at most sites. However, when combined with a proper cell development sequence, the use of thicker intermediate cover layers and a positive gas extraction system, daily cover provides a vital and effective odour control measure.

2.3.3. Scavenging by Birds

Scavenging by birds, particularly gulls or the like, occurs as the waste is tipped and exposed as a food source is readily available. Prompt compaction and covering of the waste with soil (enhanced by minimising the size of the working face) minimises the availability of the food source. Regular application of a thick layer of soil will reduce the attractiveness of a site as a food supply to gulls and is essential to discourage birds like crows and raptors that tend to dig through the cover to unearth food waste. It is essential to recognise that while closing down the food supply by applying daily cover is an effective control measure, it may take some time for improvements (by way of reduced bird numbers) to be noted at sites where birds are well established due to conditioning of the bird population. In such cases, other control methods may also be needed (refer to Guideline on Bird Control).

2.3.4. Scavenging by Humans

Scavenging by humans occurs at some sites, particularly those in developing countries and where security measures are inadequate in preventing entry to the site at the end of a working day. The application of daily cover, combined with compaction of the waste in accordance with good landfill practice will reduce the ability to access and sort through the waste and make a site less attractive to scavengers. However, daily cover alone will not eliminate scavenging where the waste has a value locally: other methods such as physical destruction prior to landfilling will also be required.

2.3.5. Infestation by Flies and Vermin

Practical experience, supported by experimental work, has demonstrated that the regular placement of cover soil will prevent the emergence of flies. The soil cover layer has to be a minimum of 100mm thick to be effective in this regard. Application of a thick layer of daily cover (200mm minimum) has also been shown to be very effective in controlling rats and other vermin such as feral animals as over a period of time, it simply makes accessing the food source too difficult to be attractive to animals. Insecticides and rodenticides can be an effective supplement to daily cover practices, but are expensive to implement on a large scale and will provide only a short term response if daily cover practices are not kept at a high, consistent level.

2.3.6. Fires

Fires are a concern for the management of any landfills and have been synonymous with open dumps. Fires typically result from poor operational practice, including at open dumps where waste is often deliberately set on fire to create more space.

Daily cover reduces the ingress of air to the waste and hence promotes the onset of anaerobic conditions. It also isolates the waste from the surface and reduces the potential for accidental or deliberate fires being started. Also sources of fire such as smoking or electric sparks must be eliminated from the landfill site because flammable gases like methane may occur due to anaerobic conditions.

2.3.7. Visual Appearance

The use of daily cover always improves the visual appearance of a landfill site. While at some sites visual appearance may only be an issue when the waste surface nears final levels, a neat site free of windblown litter sets the first key impression of the level of management applied at a site and is an essential consideration at a modern, well run landfill site. When viewed from the site boundary with a well-managed, well-compacted, fully covered landfill surface can give a uniform appearance and be aesthetically pleasing to the eye. In this respect, the use of daily cover does enhance site performance and give the public and local community confidence in the operational standards being applied at a site, particularly where neighbours are in relatively close proximity.

2.3.8. Surface Water Control

Daily cover, when loosely placed will have little impact on surface water management. However, as moisture is an essential component for waste degradation many believe it should be allowed to penetrate the waste to speed up the stabilisation process.

As cells are developed, graded areas of daily cover are typically amended with the application of further soil as intermediate cover layers. These thicker soil areas are compacted, graded and sloped to surface water drains to ensure that runoff from larger completed cell areas is not contaminated by waste materials.

Table 2.1. Types of daily covers

Inert	Waste Derived	Artificial / Synthetic
Free draining soils	Paper pulp	Synthetic foams
Non draining soils	Pulped paper	Geotextile matting
Contaminated soils	Shredded wood	Plastic film
Foundry sand	Shredded tyres	Synthetic mesh
Colliery waste	Shredded plastics	Hessian fabric
Quarry waste	Recycling process waste	Tarpaulins
Ash	Shredded green waste	
River silts	Pulverised household waste	
	Compost	

There are clearly advantages and disadvantages from the use of each of these generic cover types as summarized in Tables 2.2, 2.3, 2.4 below.

Table 2.2. Advantages and disadvantages of inert wastes used as daily cover

Advantages	Disadvantages
Ease of application and availability	Consumes void space
Visual appearance	Wheel cleaning often necessary
Non combustible	Potentially dusty
Can be applied using on-site plant	Can be relatively impermeable to leachate and landfill gas
Can be permeable to landfill gas and leachate	Poor traction for certain materials
Good traction quality for some materials	

Figure 2.2. Application of Geotextile Matting

CHAPTER 2 THE USE OF DAILY COVER

For landfills whose locations have monsoon seasons with a lot of rain, proper procedures may be required such as, holding operation during raining and temporary covering with tarpaulin etc, dependent on the site condition.

2.4. DAILY COVER TYPES

The types of daily cover available can be split into three generic material types as shown in Table 2.1.

2.5. DAILY COVER APPLICATION

Ease of application is a factor that needs to be taken in to account when selecting the type of daily cover for use at a particular site. When selecting natural cover soils, it should be noted that dry, friable soil materials are easier to place than wet "sticky" clays. However, each soil type has advantages and disadvantages and the reality is that most sites tend to use whatever is available on site, as effectively as is possible.

The surface upon which the daily cover is applied should be well compacted and free from major ruts and depressions. A poorly compacted and graded waste surface will result in more daily cover being used than is desirable, which will result in a loss of void availability for waste as well as higher disposal cost.

2.6. SOIL USE PLAN

It is important, when using site soils as daily cover, to ensure that the soils are used effectively. A cover soil plan can be developed, as follows:

- Ascertain the volumes of cover used on a day-to-day basis
- Stockpile soil cover close to the active face for ready access
- Ensure the machine operative is aware of the quantity available
- Ensure machine operator prepares the surface to minimise soil use and that previous layers are stripped back and stockpiled for re-use before fresh waste is placed each day
- Record actual volumes used
- Review cover usage regularly
- Amend planned usage to reflect the effectiveness being achieved
- Daily visual check of the entire active area to ensure that it is completely covered at the end of the working day

Advantages	Disadvantages
Utilises a waste stream	Can be ineffective in controlling odours
Permeable to landfill gas and leachate	Processing required
Good running surface	Can attract birds and vermin
Preserves void space for waste	Possible fire hazard
May be biodegradable	Dust can be a problem particularly from shredded wood

Table 2.3. Advantages and disadvantages of wastes derived materials used as daily cover

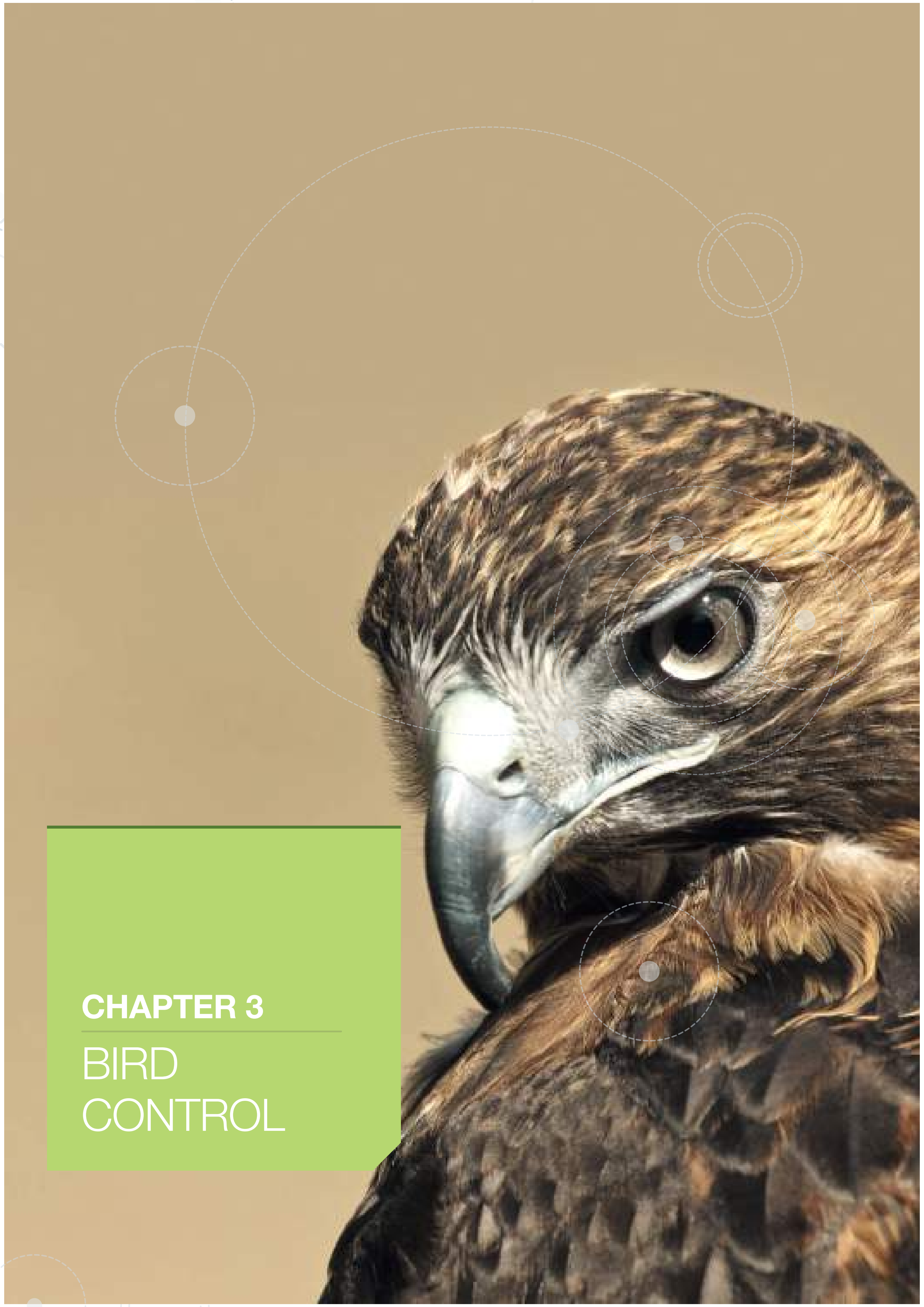
Advantages	Disadvantages
Useful on inclined surface	May not suppress odour
Readily deployed with modifications to existing plant	May not prevent fly infestation
Saves void space	Potential fire risk
Permeable to landfill gas and leachate and biodegradable	Useful as daily cover only
Good visual appearance	Cost
-	Not suitable for trafficked areas
-	Colour
-	Difficult to apply under adverse weather conditions
-	Difficult to apply progressively during the working day

Table 2.4. Advantages and disadvantages of artificial/synthetic materials used as daily cover

2.7. CONCLUSIONS

It is difficult to be prescriptive about what materials should be used for daily cover and the issue must be considered on a site by site basis. However, it is clear that regular and thorough application of daily cover is a fundamental control for effective management of a modern, well-engineered landfill site.

Many of the outcomes achieved by the use of daily cover can be achieved (at least in part) by other means. However, daily cover provides a simple, robust control on many of the key effects of landfilling and generally speaking is an essential requirement at any well managed site.



CHAPTER 3

BIRD CONTROL

CHAPTER 3 BIRD CONTROL

Figure 3.1. Birds at the landfill

3.1. INTRODUCTION

Birds visiting a landfill site do so mainly for food. They are seen as noisy and messy, and commonly they can be carriers of pathogens or they can be the cause of local nuisance through fouling of roofs, roof-water supplies, gardens and public open space. Also, in some instances birds can pose a threat to the safety of aircraft where landfills are located near commercial airports. If birds are given a dependable food supply and a safe environment (suitable resting or roosting areas) their rate of breeding is likely to increase, as it is shown in Figure 3.1 this is likely to attract more birds from a greater distance around the landfill site.

3.2. BACKGROUND

Before bird numbers can be controlled at a landfill, it is important to understand the requirements that birds have and what makes a landfill site attractive to them. All birds have three key drivers: food supply, rest, and the ability to breed. Landfill sites can offer a suitable environment for these, depending on the type of bird.

When a bird infestation issue is to be dealt with, it must take into account that birds can become quickly accustomed to the usual methods of bird control that are used. The method of control must therefore be varied, as required, to provide an effective overall control strategy. If birds can be identified by species it is often possible to use their instinctive and learned behaviour against them to minimise their level of nuisance.

It is possible to keep disturbing accumulations of birds and to progressively remove their food sources, resting and roosting places, until the birds find the landfill site no longer attractive. This process is the key to an effective bird control strategy.

3.3. HIERARCHY OF CONTROLS

- Operational Practices
- Gas Guns
- Heli-kites and Balloons
- Distress Calls
- Signal Pistols and Cartridges
- Falcons and Raptors
- Wires and Screens
- Culling

3.4. OPERATIONAL PRACTICES

Effective management of the working face is the starting point when attempting to reduce bird numbers. The working area should be kept as small as is practicable to reduce the surface area where food might be readily available. All waste that could be a source of food should be compacted and covered with soil on an ongoing basis throughout the day, and completely by the end of each working day, thus removing access to the food source.

Restored areas and non-operational areas of the site are also areas that require attention. It is essential that there are no areas of exposed waste, or areas where water can pond and allow the birds to stand, drink and clean themselves.

Where there are restored areas the grass should be allowed to grow while the landfill site is still operational. The grass should be allowed to grow to a height of at least 225mm, as this will deprive most birds of areas to rest as it makes it difficult for them to land and to take off. Many bird species also fear predators where long grass is present.

3.5. CONTROL METHODS

Once an effective suite of site operational control measures has been put in place, many direct methods of control can be employed. These control measures should be varied on a regular basis to ensure that the birds are continually unsure of the type of danger that they are being exposed to, and hence tend to react by re-locating.

Gas guns (bird scarers) are simple to operate and can be very effective for short periods. Their effectiveness depends upon the gas guns being moved around the site on a regular basis. However, this method of control can become a nuisance to neighbours, particularly if the hours of operation of the equipment fall outside usual business hours.

Heli-kites and balloons can be very effective for 2 or 3 days at a time and again must be moved around the site regularly. If these are left out on site over night during the summer periods in an unsecure area, theft and vandalism may be a problem.

Bird scaring tapes and broadcasting equipment are also available and can be effective when the speakers are mounted onto the compactor.

Again, the use of this type of equipment needs to be varied and used somewhat sparingly to obtain a satisfactory result. It is recommended that when purchasing this type of equipment, the bird distress sounds are purchased in a digital format and used with appropriate equipment as cassette tapes may jam or become scratched and ineffective. The distress call mix needs to be site-specific to be effective.

Signal pistols with bird scaring cartridges can also be used. To use this equipment a firearms certificate may be required, a secure location required for storing pistols and cartridges, as well as specialist training in their use, as is the case with live firearms. As with the gas gun, this control method has the potential to be a nuisance to neighbours.

Falcons and other raptors which are shown at Figure 3.2 (page 14) can be used as an active bird deterrent. Usually this is achieved by contracting a specialist company to fly birds of prey around the site. These can be very effective, but the falconer will need to be fully inducted in the requirements of any Health and Safety policy and should be treated as an external contractor working on site.

CHAPTER 3 BIRD CONTROL


Figure 3.2. Falcons used as bird deterrent

Wires and screens can be used to limit bird flight and discourage birds from settling. The spacing of wires must be such that birds cannot readily fly between them (Figure 3.3). Screens must be close enough to the working area to prevent birds from landing and taking off and this method is only likely to be suitable for larger birds. As a last resort the working area can be completely enclosed, but this can lead to operational problems if the area enclosed is not large enough to allow vehicles to turn or high enough to allow them to tip. However, netting off and achieving an enclosed area does have the added advantage of providing additional litter control.

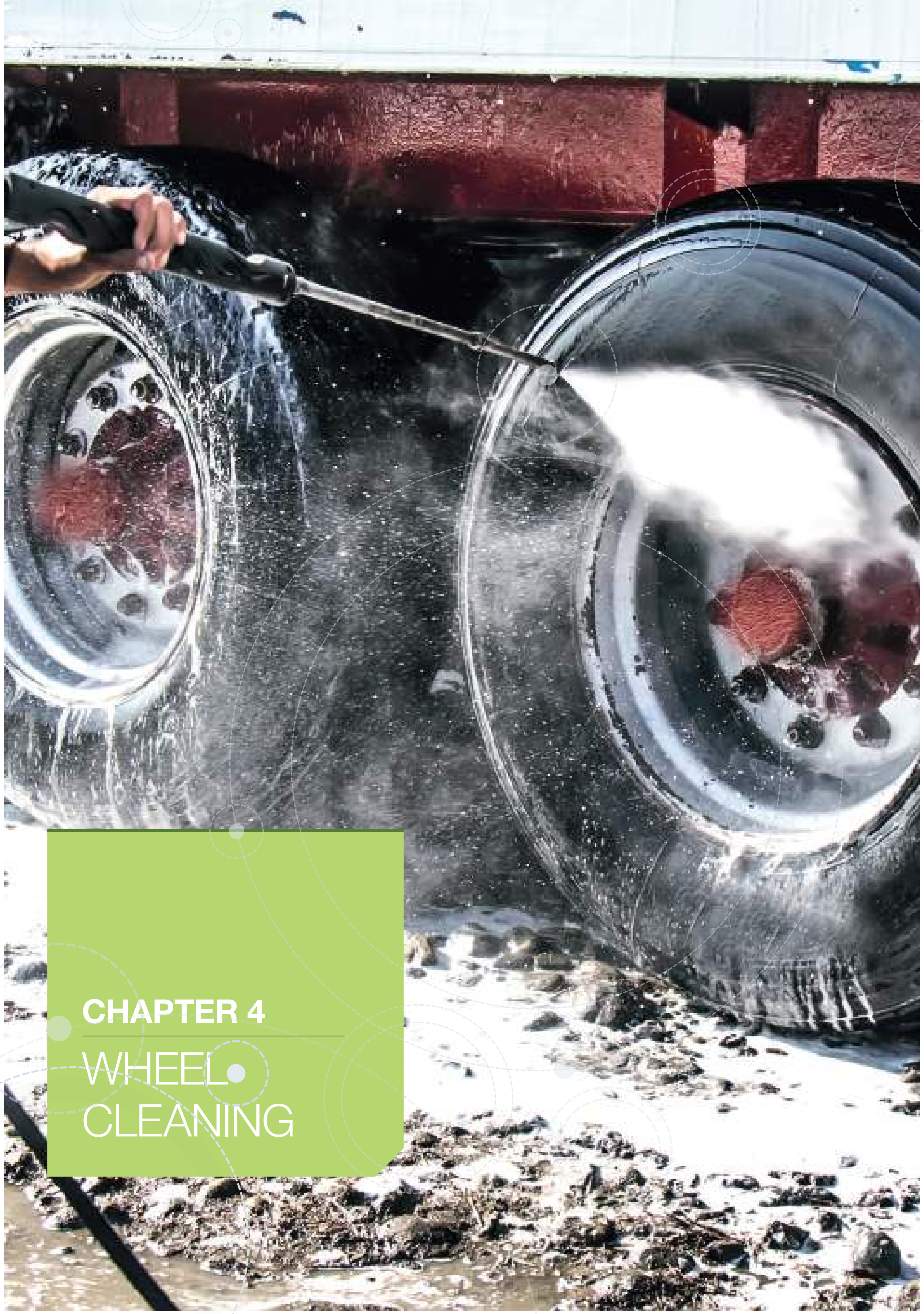
Culling methods for bird control are sometimes not acceptable and may contravene local legislation but may be used as a last resort. Also, public concern over culling methods of control may produce adverse local comment. However, shooting and poisoning may have a role at some sites and can be very effective as some species of birds "learn" from episodes of this and can be so deterred, sometimes in large numbers. Any shooting or poisoning programme should only be undertaken by licensed persons and under strict control. Firearms, ammunition and poisons need to be properly and securely stored on site.

Finally, the latest technology is either a fixed or handheld laser systems which have become more popular because they can be used quietly and in a professional manner, with minimal disturbance and attraction. Laser systems have been shown to change behaviour in some bird species when a constant programme of use is operated. A fixed system has shown to be useful in dispersing birds from flat roof areas by projecting horizontal beams of light across large areas. Smaller handheld systems have proven useful for pest controllers to lift off gulls/corvids from landfill sites.


Figure 3.3 Bird stanch stands hold wires to prevent the inflow of birds

3.6. CONCLUSIONS

The methods described offer guidance on bird control measures that can be employed. To be successful it has been shown that methods of physical bird control or deterrents must be varied on a regular basis. All approaches that work well depend on human presence and human interpretation of the situation, backed by positive and appropriate action. This starts with effective control of the food source by covering the waste effectively and regularly, and thereafter by implementing a hierarchy of measures that ultimately result in the landfill being an unattractive place for bird roosting and breeding. Many species of birds which frequent landfill sites have become used to human presence, so affirmative action is often necessary to get on top of a bird problem. The key to success lies in not allowing birds to establish their presence at a landfill in the first place. However, if birds have established then a site-specific, targeted programme of control methods can usually overcome the problem, although in some cases this can take time to achieve.



CHAPTER 4
WHEEL CLEANING

CHAPTER 4 WHEEL CLEANING

4.1. INTRODUCTION

The arrangements needed at a Landfill to prevent mud or other debris carry over onto public highways are very much site-specific. Where licences or permits are in place, conditions are usually included that are aimed at minimizing the carry over of mud or debris onto the public road network and such conditions are usually enforceable. Carry over of mud onto the highway can also be an offence under local legislation in some situations.

Figure 4.1 Wheelwash Facility

4.2. OPTIONS FOR MINIMIZING NUISANCE

The following opportunities exist for minimising mud and debris carryover and hence nuisance, and enable a hierarchy of controls to be put in place:

- Increasing the length of paved internal site roads (queuing length)
- Using paved access routes
- Mechanical road sweeping
- Wheel spinners (wet or dry)
- Wheel wash facilities (bath or spray)
- Adequately maintaining on site roads
- Use of daily cover

4.3. HIERARCHY OF CONTROLS

The following broad hierarchy of controls is suggested:

- Keep the working area and site access roads as free of mud as possible, and in a good state of repair.
- Use a paved road from the public highway to the site reception facilities and weighbridge, and from any wheel washing facility to the site exit. A longer length of road assists. Note that speed bumps will invariably shake mud from vehicles (even after a wheel wash) and increase the need for road cleaning operations as well as making road cleaning more difficult.
- Adopt mechanical road sweeping (either self-propelled or tractor drawn) is an essential routine maintenance activity on paved roads.
- Apply other vehicle cleaning methods selected to suit site conditions and use them as part of routine operations:

- Shaker bars
- Wheel spinner – dry / wet
- Wheel wash (bath)
- Wheel wash (spray)
- Hand held water lance.

Further configuration is possible with a combination of a wheelwash/shaker bar system (see Figure 4.1). Additionally drying system with air blowers could be installed as well. In general, a wheelwash is preferable to a wheel cleaning arrangement based on shaker bars. The latter tends to deteriorate quickly, is often difficult to clean out.

4.4. DISCUSSION

The carry over of mud or dirty water onto public roads or footpaths is unsightly, can create a nuisance, and can result in accidents. It can also result in problems with regulators, or even prosecution under local laws.

The routine use of an appropriate mix of the techniques described above will be of great benefit in preventing the carry over of mud or other debris onto public roads. For each and every method to be effective, regular use and good maintenance of equipment and support facilities are essential. In some cases, the level of effort that needs to be applied to this aspect of site operations may be influenced by climate, mud or dust and may be strongly seasonal. It is essential that where abatement equipment is available, that it is regularly used. The onus is always on the operator to ensure that the use, maintenance and effectiveness of these control measures is adequate and that these measures are a routine basis part of the landfill operation.

Where wheel-cleaning facilities are provided they must be located as far into the site as is practical in relation to paved site roads in order to minimize the carry over of fine mud or wash water, and to avoid the staining of public roads.

Clear instructions must be provided to ensure that all heavy goods vehicles use the wheel cleaning infrastructure. This requirement can be supplemented by a one way system for vehicles entering and leaving the site.

Contaminated water will emanate from any wheel cleaning equipment during its operation and or cleaning out process. The resulted water should be treated and controlled before any disposal in a watercourses. An oil trap should be provided along with settlement ponds to retain suspended solids. Monitoring for contaminants such as oil and diesel should be undertaken.

Even where it is considered that the measures that are being undertaken within a site are fully effective, it is both good public relations and usually a permit to license requirement, to carry out a regular programme of road sweeping in the immediate locality. Where there are pedestrian pavements located near the site, it should be noted that these too can become soiled and may need to be regularly swept, or cleaned by water/mechanical means.

4.5. CONCLUSIONS

The operator of a well-managed landfill will routinely devote resources to ensuring that there is minimal impact from the operations on the external road network (Figure 4.2). This will minimise the potential for public complaints, or issues with local regulators. Careful, structured and routine attention to the hierarchy of control methods available will typically result in minimal nuisance from mud and debris from a landfill site and will reflect a professional, well managed landfill operation.

CHAPTER 5
LITTER CONTROL

CHAPTER 5 LITTER CONTROL

5.1. INTRODUCTION

A frequent cause for concern for sanitary landfill management is the control of litter. Litter is unsightly, can result in water pollution and can be a nuisance to surrounding property. In addition, plastic litter can travel large distances via wind and water reaching our oceans. It has accumulated in an alarming amount and causes harm to aquatic life. Hence issues related to wind-blown litter are a common topic at Site Liaison Committee Meetings, during the planning process for new landfills, and with regulators.

Depending on site conditions, litter can be difficult to control and manage. However, in almost all cases there are methods available that can keep the off-site impact of litter to a minimum. A site-specific strategy should be drawn up to manage the impact of litter. Importantly, whatever strategy is introduced, it is noted that this will only be as good as its implementation. To reduce the risk of opposition or complaints from neighbours, effective litter control, achieved via a hierarchy of measures, routinely and thoroughly applied, is an essential site management tool.

5.2. HIERARCHY OF CONTROL MEASURES

A hierarchy of litter control measures is available, based firstly on load containment, load handling and tipping, and moving through to secondary measures such as mobile litter screens, nets and litter picking at site boundaries. Each is expanded on from the overall range of controls that comprises:

- Load control
- Waste handling
- Portable litter screens
- Semi-permanent litter fencing
- Bunds
- Perimeter fencing
- Select tipping areas
- Netted areas
- Designated waste transfer areas
- Methods for handling for lightweight waste
- Restricting operating hours

It is unlikely that any single control measure will be sufficient to combat litter escape at a site, and it is essential to develop and refine an effective set of control measures for each situation. These may also vary with location on the site, or seasonally.

5.3. METHODS OF CONTROL

5.3.1. Load Control

While not strictly a "site-based" control it is common for litter accumulation along principal site access routes due to loss from waste vehicles to be an issue for landfill managers. This can be addressed by applying load and waste acceptance controls to site users. Typically these include measures such as requiring all normal loads to be transported within a fully enclosed collection vehicle or a collection vehicle that is covered with nets or tarpaulins. Dry or dusty loads should also be tarpaulin covered.

Regular inspections should be made of access routes with active litter cleanup as required (often a routine process). Regular inspections should also be made of incoming vehicles to ensure loads are covered, secure and not contributing to litter. The ultimate sanction is to refuse entry to insecure loads or to operators who do not comply with load management requirements.

5.3.2. Waste Handling

Most of the litter lost from landfill sites results from wind acting on the waste at the point of tipping, as well as initial compaction practices. Litter loss at the point of tipping can be minimised by:

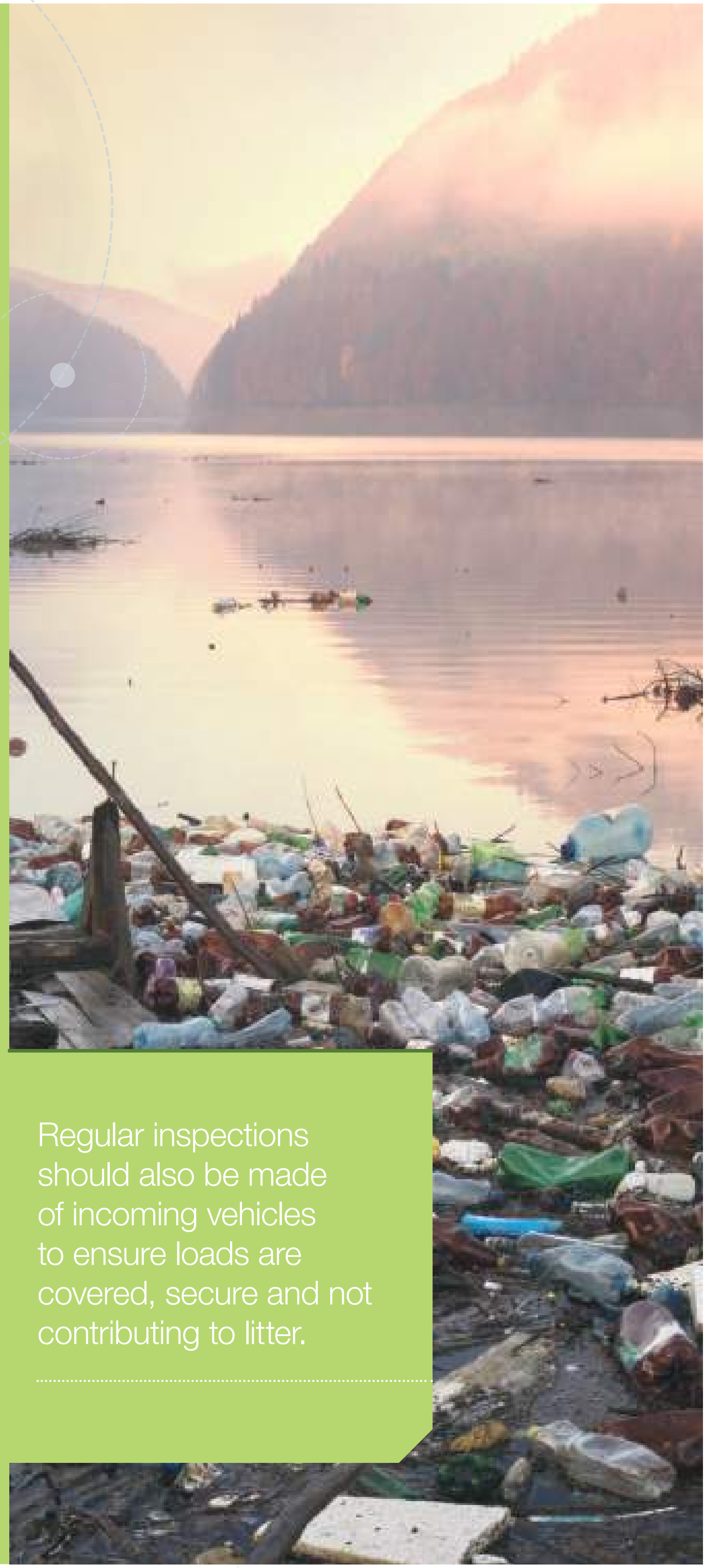
- Carefully assessing the waste type being handled i.e. dense waste is less likely to blow about than uncompacted low density waste such as plastic.
- Not tipping loose waste into the wind.
- Using previously tipped waste to cover and/or provide shelter for more vulnerable (mobile) waste streams.
- Partially compacting loose waste before pushing out.
- Using heavier waste to hold down loose waste.
- Pushing waste out carefully and compact as quickly as practicable.
- Ensuring that the entire waste load is emptied at the tip area, so that no residual waste is left in the collection vehicle which would provide a potential for wind blown litter on the drive out of the facility.
- Keeping the working area as tight as practicable.
- Placing a soil cover over the waste as soon as practical but no later than at the end of the operating day.

5.3.3. Portable Litter Screens

- Use portable litter screens routinely.
- Screens should be placed down-wind and as close to the working face as possible.
- Screens should be of good solid construction and robust enough to withstand handling and relocation by machines (preferably they should be provided with lifting eyes).
- Screens should be cleared frequently to prevent them from becoming overloaded and potentially being blown over.
- Screens need to be moved as frequently as changes in the wind direction dictate.
- Damaged screens should be repaired on a regular basis.

5.3.4. Semi-permanent Litter Fencing

This type of fencing is usually semi-permanent (covering a significant landfill development area through until post-closure). Typically it comprises a metal or nylon chicken wire / fish netting type system and should surround the entire operational area. If it is not practical to surround the entire area, fencing should at the very least cover the downwind side of the common prevailing wind direction.



Regular inspections should also be made of incoming vehicles to ensure loads are covered, secure and not contributing to litter.

A design that has been found effective is to use pole and netting fences with an internal return at the top end to catch litter that collects at and travels up the fence with the wind. This type of fencing is also used to protect restored areas. Again, regular maintenance is essential if such fences are to prove successful.

5.3.5. Bunds

Soil bunds placed downwind of the operational area can also provide good litter control. Under most circumstances, litter rolls along the ground. In this case it will tend to roll over the bund and deposit in the calmer space behind it. The resultant litter has to be regularly removed if the system is to remain effective.

5.3.6. Perimeter Fencing

Perimeter fencing is usually provided mainly for site security, but it can form a last line of defence for litter. However, cranked tops are usually provided which often consist of strands of barbed wire which can trap litter but also make it difficult to remove, so this type of design should be avoided whenever possible. For the same reason, brambles should not be allowed to grow up perimeter fences, or immediately in front of them.

Hedging should not be used as a control measure as it can often be difficult to clear.

5.3.7. Select Tipping Areas

In valley or quarry landfill sites it may be possible to identify different areas within the developed footprint of the site that are out of the wind, hence making it possible to have more than one working area available to cater for differing conditions. Alternative tipping areas should be identified for all sites where there is a problematic prevailing wind direction. On above ground landfill sites, use of tipping areas that are shielded against prevailing winds must be carefully planned as there are typically higher wind gusts as you build upwards.

5.3.8. Netted Areas

Full netting systems that completely enclose the working face area and all loose waste are sometimes required at very windy or exposed sites. These systems can be either portable or permanent. The portable type can be moved to suit changing operations. However, this can be a costly and time-consuming task and is usually only adopted at open sites where other options are not effective.

A permanent netted area has disadvantages related to machine operation and load access. Net systems may also require double handling of waste, which has cost and possible odour implications. However, fully netted systems can be very effective and may be one of the most effective control options available at open, windy sites.

5.3.9. Designated Waste Transfer Areas

At some sites, litter control can be improved by using on-site waste transfer processes such as waste separation and waste containerisation, or baling. Such measures are usually only employed if conditions are particularly adverse and large volumes of one particularly difficult waste type are being handled (e.g., non-recyclable plastic).

5.3.10. Methods for Handling Lightweight Waste

Some lightweight wastes such as plastic (other related non-littering wastes such as ash or sawdust) can also be managed by excavation of a pit into which they can be tipped in a controlled manner and then immediately covered to avoid wind mobilising the wastes.

5.3.11. Restricting Operating Hours

At some sites windy conditions occur at particular times of the day, or seasonally. At such sites, particularly where load control can be managed by containerising waste, or by holding it at transfer facilities, restricting operating hours can be a particularly effective measure for litter control.

Where opening hours can be restricted to morning or evening calm periods for example, or where activities can be suspended entirely on windy days, management of litter potentially can be greatly simplified.

5.4. CONCLUSIONS

A range of management techniques is available for litter control at landfill sites. If carefully and routinely applied there should be few sites where a high level of litter control cannot be achieved. However, there will be occasions where litter problems develop, both on and off-site and litter pickers should be deployed immediately when the windy weather abates to collect the litter. They should start from the furthest most point that litter has reached, and work back to the site boundary and then internally.

It is also good site public relations to have regular litter pickers deployed along the access roads and buffer zones around the site to collect litter whether it comes from the site or not. This engenders a sense of good will with neighbours, which can have significant benefits with regard to community relations.

There are clearly many techniques available to us for collecting litter. Some of the simpler control measures are relatively inexpensive to implement as they relate simply to applying good operational techniques. Other measures can be much more expensive and a hierarchy of measures needs to be developed specific to each site to provide the most effective overall solution recognising that litter control must be given priority in order to avoid visual and environmental contamination problems from landfilling.

CHAPTER 6 VECTOR CONTROL

CHAPTER 6 VECTOR CONTROL

Figure 6.1. Typical rat often found at landfills

6.1. INTRODUCTION

At a landfill "vectors" can include rats and other rodents, foxes, feral cats and dogs, insects, birds and other animals, each of which can carry disease agents and be a threat to public health. Birds require special techniques of control and are addressed in a separate guideline. Each type of vector can live and multiply at a landfill and is potentially of concern to site operators, regulators, public health professionals, and the public. Fortunately, vectors are controllable and should rarely, and even then, only intermittently, be present on a well-controlled landfill.

6.2. BACKGROUND

Vector control involves avoiding vectors from living and becoming established on the landfill by not providing sources of food and water, and/or shelter. The only vectors that should be observed in any significant numbers at a sanitary landfill should be those that happen onto the landfill - they cannot be allowed to establish on the site and so should only be observed intermittently.

6.3. HIERARCHY OF CONTROL

Vectors are controlled by a hierarchy of control methods, all aimed at eliminating vectors to the greatest practical extent. This hierarchy includes:

- Operational Practices
- Monitoring
- Eradication

6.4. OPERATIONAL PRACTICE

The most important control measure used to minimise vector problems at landfills is the application of daily cover. Cover should be present on all solid waste without exception except the tipping face while it is being worked. Daily cover of at least 150mm of lightly compacted soil or similar material or an effective layer of alternate daily cover (ADC) should be applied on finished portions of the daily cell during operations and at the conclusion of daily operations, and not less frequently than once per day. Alternative daily cover materials such as tarpaulins, foams, granular waste, etc, can be effective as vector control after careful site-specific evaluation.

Intermediate cover of 300mm (minimum) compacted soil should be used on all areas not at finished levels, but not to be further landfilled for a period of 30 days or more. Final cover is typically applied as each area is brought to finished level through the operational life of the landfill.

CHAPTER 6 VECTOR CONTROL

There should be no uncontrolled or uncovered (stockpiled) waste, including litter, tyres, brush, domestic appliances, construction/demolition waste or even inert industrial waste within the curtilage of the landfill. The only exception is compactable soil-like inert wastes, such as ash, but even this waste must be graded and compacted to avoid ponding water. Tyres, for example, are known to allow insect breeding due to ponding of water, but can also harbour a variety of other vectors such as rats as shown in Figure 6.1 (page 22).

There should be no ponding water within the curtilage of the landfill except as designed for runoff storage or sedimentation. Sedimentation ponds can, however, aid vector reproduction if not designed and controlled properly to minimise stagnant water, nutrient build-up and plant growth. Finally, the waste must be compacted and graded at reasonable maximum slopes (see the Working Face Guideline) to minimise voids within the waste that can harbour rodents. Rodents and foxes can readily dig into cover soil, but have much more difficulty digging into compacted solid waste.

6.5. MONITORING

Landfill staff should monitor the levels of key vectors daily as part of daily management. The option also exists to contract pest control experts to monitor and control vectors as necessary. Such experts know where to look for evidence of problems and can interpret signs of vector activity. A simple monthly site walk-over can provide a baseline of vector activity so changes can be noted and translated into action. Observations of various droppings, siting, tracks, insect counts, etc are useful indicators of activity. Written reports from regular walk-over assessments should be kept on file so changes that occur, over time, and in response to control measures can be assessed.

On-site personnel can also be trained and given the time to perform monitoring on a regular basis. However, operations staff may not have the expertise, even after training, to monitor vectors efficiently, and may overlook or minimise the importance of monitoring. Appropriate systems and professional support are therefore often an essential management requirement.

6.6. ERADICATION

Eradication of vectors (i.e. where a specific issue is evident beyond the scope of management using routine control measures), is usually best performed by professionals. They have knowledge of the most effective methods available, some of which may not be available to the operator, and are able to choose and implement the best methods. In some cases on-site personnel do carry out eradication (e.g. removing gulls or other birds) as well as using widely available baits, traps (as shown in Figure 6.2) and other techniques.

Figure 6.2. Typical trap that may be used at the landfills

6.7. CONCLUSIONS

Vectors addressed in this Guideline are primarily, insects, rodents and other feral animals. The key basis for control is prompt compaction of all solid waste and the application of compacted soil or other suitable cover, no less frequently than daily. There should be only one working face unless absolutely necessary for waste segregation or operational purposes, and there should be no debris or piles of stockpiled waste outside of the working cell. Ponding of water should be limited to designed sedimentation ponds or water storage lagoons.

Monitoring and eradication of vectors and pests is usually best performed by specialist firms contracted for that purpose. However, this work can also be performed by on-site personnel, but only if they are given the appropriate training and time allowance such that they can do so, on a routine basis. Monitoring should be performed frequently and as a minimum, monthly monitoring is recommended.

CHAPTER 7

MANAGING THE WORKING FACE

CHAPTER 7 MANAGING THE WORKING FACE

7.1 INTRODUCTION

The working face is the focus of activities at an operating sanitary landfill. It is the area where waste is deposited by trucks, levelled and compacted, and where daily cover is applied. It involves waste transport vehicle movement in a potentially congested area, heavy landfill equipment movement to work on the waste and cover, and personnel to operate equipment and to spot and direct trucks. It is the one location at the landfill where waste is loose, uncontrolled and exposed. It follows that good working face management is critical to achieving a good overall standard of a sanitary landfill operation, and minimised long-term impact.

Conversely, poor working face management has the potential to result in blowing litter and debris, greater potential for accidents, inefficient use of airspace, aesthetic problems, traffic movement problems, uneven or increased long-term waste settlement and vector problems.

7.2. PLACEMENT OF THE FIRST LAYER OF WASTE

7.2.1. General

The first layer of waste placed in a cell is crucial for the landfill operation. This layer needs to be placed as a loose cushion layer, sometimes referred to as a "fluff" layer (Figure 7.1).

This loose first layer is essential in order to avoid damage to the liner and leachate collection system as a result of equipment tracking, or the waste itself penetrating the liner components during initial cell filling. Damage to the base liner system can very easily occur if initial cell filling is not carefully managed and such damage can soon negate good design and construction, and compromise the containment performance of a sanitary landfill.

7.2.2. Construction of the First Layer

The correct procedure for the construction of the first waste layer is as follows:

- The access road to the working face must be constructed from the top of the cell to the bottom in a way that ensures that the landfill vehicles will traffic over soil ramps and not the bottom of the landfill cell.
- At the end of the access road a relatively wide temporary area must be constructed for the manoeuvring of trucks.
- The first trucks must dispose of the waste at the end of the access road or a temporary movement area formed on the landfill base.
- Bulky or hard wastes capable of puncturing the liner must be removed.

Figure 7.1. Placement of the first layer of waste

Figure 7.2. Trucks unloading their waste

- Depending on the waste type, the first waste should be deposited at a vertical layer thickness of at least 50 cm (often up to 1m or more if bagged street collection waste is used), and this layer must not be compacted, so it then constitutes a protection layer to the liner and leachate drainage system.

The above procedure ceases when the whole area of the landfill cell base is covered with waste to a depth of at least 50 cm (1m recommended), so that no landfill equipment can track in close proximity to the liner or the base drainage system of the landfill.

7.3. WORKING FACE MANAGEMENT PROCEDURES

7.3.1. Summary

The key elements of good working face procedure can be summarised as:

- Use the smallest area practicable
- Orderly truck movement and unloading on an all-weather surface
- Work wastes together
- Effective waste placement and compaction
- Maintain working face slope
- Keep working face area well-drained
- Apply and compact soil cover promptly

7.3.2. Use the Smallest Area Practicable

The optimum area of the working face depends on the number of trucks that need to be managed, and on the landfill equipment. Ongoing reviews should be performed in order to regularly adapt the working face size to the expected traffic numbers and total waste input.

An unnecessarily large working face is difficult to control, expensive to run, and unsightly. The exposed waste can lead to vector problems and blowing litter and debris. Also, with a larger face area, landfill equipment has a bigger area to deal with and more cover soil is needed per ton of waste, which in turn reduces landfill airspace utilization and landfill equipment fuel efficiency.

Waste disposal should usually be confined to one operating working face at any time (there are some situations where more than one working face is needed – usually where waste inputs are high at a large site or due to adverse weather conditions). The working face should be only as large as necessary to allow adequate truck movement and unloading space, as well as efficient operation of landfill equipment. In general, the width of the working face should allow approximately 4m of width per truck unit unloading. However, may be impractical to have 4m per truck available at all times if many trucks tend to arrive over a short period, in which case, a balance must be struck between the time spent queuing for the trucks and the width of the working face. The vertical height of the working face should normally be from 2 to 5 meters. Lower working face heights tend to be wasteful of cover, except for small sites. Excessive cell and working heights result in a long working face slope that can be difficult to control, other than at sites where there is a large input of waste.

Figure 7.3. Compaction of the wastes at the landfill

CHAPTER 7 MANAGING THE WORKING FACE

Figure 7.4. Bulky waste

7.3.3. Orderly Truck Movement and Unloading

Traffic patterns should be established and must be obvious to drivers. This may require flags or other markers as well as a "spotter" giving traffic directions. For larger sites it may be necessary to have separate roads to and from the working face for incoming and outgoing trucks. Drivers should wait for instructions before discharging their waste. There must be safety distance between each vehicle of 2-3 meters and each truck should stop at least 2-3 meters away from the working face. There should be sufficient space to allow trucks to unload at the foot or top of the working face as appropriate, and drivers should be encouraged to spend as little time as possible at the working face, as shown at Figures 7.2.

Trucks can potentially unload at the top or bottom of the working face. However, unless dictated by access road arrangements, it is generally better to unload at the bottom where there is better wind protection and the trucks are less visible. This mode of operation also allows landfill equipment to push waste up the working face, which provides more visibility and control, as well as greater compactive effort from landfill equipment. The difficulty with depositing waste at the bottom of the working face is that surface water and muddy conditions occurring during wet weather may hinder truck movement and cause mud-tracking problems. After the waste is deposited, the crew of the truck should ensure that no bins, covers or other equipment is left at the working face before exiting the area.

7.3.4. Work Wastes Together

It is generally best to mix the incoming waste and spread and compact it upon receipt at the working face. The aim is to achieve a homogeneous waste mass within the landfill, resulting in more uniform decomposition, liquid and gas flow, and settlement. One exception is waste that can be used for cover or roads, which is often segregated and stockpiled near the working face for that use. Another exception is if large amounts of a particular waste arrive over a short period, in which case waste placement may be delayed, depending on waste characteristics, until other waste arrives that can be mixed in with the stored waste. Such storage (stockpiling) should be temporary and in any case must not be overnight.

7.3.5. Effective Waste Placement and Compaction

Experience has shown that 3 to 5 passes of heavy equipment over waste placed in 300mm – 500mm loose layers provides the best compaction without unnecessary equipment use and expense. Fewer passes of the compactor result in a lower density of the compacted waste (Figure 7.3). More passes generally provide little additional compaction, but result in significant additional fuel use and wear and tear on equipment. However, a site-specific assessment of compaction performance should always be made as the requirements can vary widely depending on the equipment type and size, and the type of waste being handled.

The optimum waste layer thickness being worked is a function of waste characteristics and equipment size. Waste that is wet and homogeneous with few large items may be compacted in thicker layers without compromising waste density, often with a bulldozer alone. On the other hand, waste containing large items such as appliances or wood may require more passes and thinner layers in order to break and compact it effectively. Similarly, large, heavy equipment such as compactors may be able to work effectively with thicker layers, whereas, smaller bulldozers or compactors may require thinner layers to provide good waste densities.

7.3.6. Maintain Working Face Slope

Steep working face slopes result in poor compaction of the waste, equipment manoeuvrability problems, and may present an equipment stability problem. Conversely, a flat working face, while allowing good compaction of the waste, requires more cover, results in more exposed waste, and can lead to water drainage problems. A slope of between 3 and 10(H) to 1(V) will prove optimal for most landfills. Working at a shallower slope allows compaction equipment to work perpendicular to the incline, allowing more rapid waste control during heavy waste input periods. However, slopes up to a steepness of 3(H) to 1(V) may be appropriate in certain circumstances, particularly with relatively dry waste.

Most of the time, the working slope provides the pattern for the expansion of the next cells of the landfill. In order to avoid using excessive amounts of soil cover material for appropriate slope formation, it is advisable to work very carefully at the beginning of landfill cell development to optimise face management.

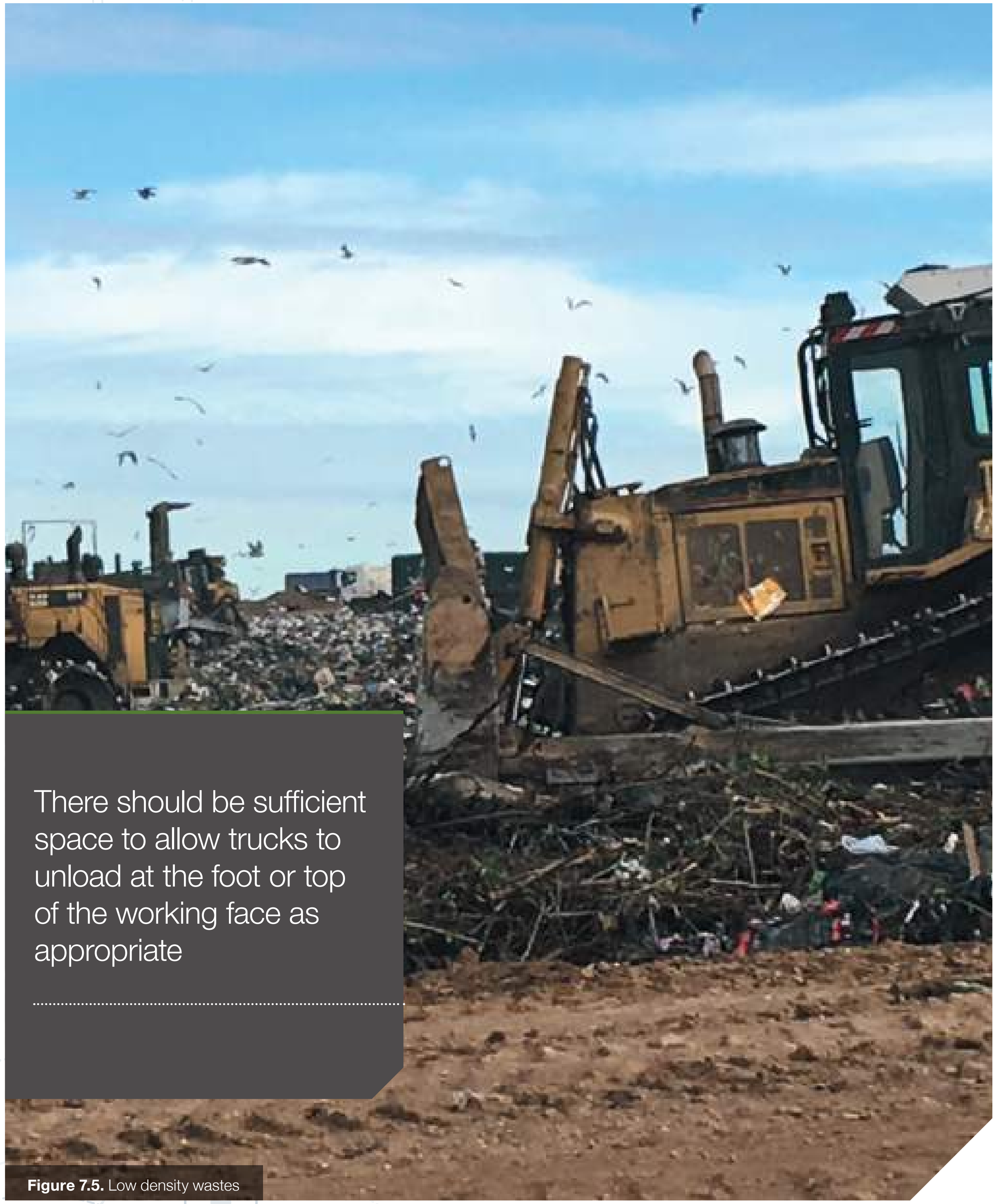
7.3.7. Keep Working Face Area Well-Drained

Water can impede working face activity by slowing truck movement in muddy conditions and can cause traction problems for landfill equipment. It can promote mud-tracking problems and will also attract vectors. A general rule is to avoid flat areas on a landfill and to promote drainage away from the working face and into the waste mass within the operational area at all times.

7.3.8. Apply and Compact Cover Soil Promptly

Cover soil (or appropriate Alternate Daily Cover if used) should be applied to the working face whenever operations are suspended, such as at the end of the working day, or over weekends. In addition, cover should be applied more frequently across the top and to any exposed sides of the daily cells throughout the day if at all possible. All waste should be completely covered with a layer of cover soil (or appropriate alternative cover) at the end of each working day.

It is extremely important to ensure that the traction needs of vehicles are taken into account when applying daily cover. It must be remembered that site users' vehicles are generally designed for road use and not the rough terrain encountered in the active areas of landfill sites.



There should be sufficient space to allow trucks to unload at the foot or top of the working face as appropriate

Figure 7.5. Low density wastes

7.4. Disposal of Specific/Difficult Wastes

Some waste types may need special management at the working face. In these cases the following general procedures should be adopted:

- Bulky waste that is able to be crushed or shredded (e.g. old furniture) should be deposited at the bottom of the working face, so as to be cut and crushed by the bulldozer (Figure 7.4).
- Bulky waste should be spread uniformly at the bottom of the working face and other solid waste should be deposited over the top of it.

- Special wastes that require specific burial (e.g. bagged asbestos, odorous waste, or sewage screenings and sludge) should be directed to an area separate from the main active face where a pit can be excavated in the fresh refuse and the waste deposited into the pit and immediately covered by general waste. This process is generally best handled by separate equipment and at many sites a digger is used for this purpose.
- Low density wastes (e.g. wood and green waste) (Figure 7.5) need specific treatment as they cannot be readily compacted. This type of waste should be pushed into thin layers and covered with general waste to enable efficient compaction of the overall waste mass.

7.5. CHECKLIST

The following checklist can help operators to assess the suitability of their working face and identify possible gaps that have to be covered. Where "No" is ticked in Table 7.1, remedial action must be considered.

ISSUE	YES	NO
Has the working face been designed by taking into account the number of trucks per day?		
Is the slope of the working face in accordance with landfill design and expansion patterns?		
Is there a detailed plan for the disposal of the first layer of waste in order to avoid damage to liner and leachate collection systems?		
Are there clear traffic patterns and instructions for the drivers?		
Do the spotters direct the drivers for tipping and unloading?		
Do vehicles keep a safety distance between them, and from the working face?		
Are there established procedures for removing non-accepted wastes?		
Are there established procedures for the handling of special but difficult and accepted wastes?		
Are the liner system and / or drainage systems around the working face area undamaged?		
Is the compaction appropriate?		
Is the working face appropriately sloped and drained?		
Is the cover applied to the working face properly?		
Is there a system for segregating prohibited wastes?		

Table 7.1. Checklist for the determination of the suitability of working face

7.6. CONCLUSIONS

The working face is the most critical part of any landfill operation. It is the centre of vehicle, equipment and personnel activities; and it is the area where fresh waste is exposed. Hence the standard of the working face operation will affect overall landfill performance, both during operation and well into the future.

Keeping truck and landfill equipment movement orderly, keeping the working face as small as practicable, and operating the working face efficiently to control the waste are all critical to the overall quality of landfill operations. A well operated working face will reduce the impact of the landfill operations and performance, increase acceptance by neighbours and regulators, and result in the efficient utilisation of landfill air space.

CHAPTER 8
WASTE COMPACTION

CHAPTER 8 WASTE COMPACTION

8.1 INTRODUCTION

It is essential at any sanitary landfill that the waste be compacted. First and foremost this will ensure that the available void space is maximized, but effective compaction has a range of other benefits, as follows:

Figure 8.1 Waste Being Compacted by Compactor and Dozer

- Compacted waste provides a stable surface for vehicles to move on and on which to establish access roads and tipping areas
- Compacted waste reduces or prevents differential settlement in the waste mass and can prevent slope failures
- Birds and rodents find it more difficult to dig into the waste to access food
- Compaction helps to reduce wind-blown litter escape from the site surface
- Well compacted waste inhibits and reduces odours and prevents leachate outbreaks
- Well compacted waste reduces risks for fires
- Compaction displaces air and increases the rate of anaerobic conditions which allow for proper generation of methane landfill gas that can be properly collected for beneficial use. Without proper compaction this practice is difficult
- A compacted surface aids stormwater run-off and provides a good base for applying cover soil
- Well compacted waste consumes less airspace which optimizes the landfill operation and use of the landfill disposal area

The factors that influence compaction include the composition of the incoming waste, the equipment used, and how the disposal operations for waste are performed. A thoroughly compacted waste pile is the first sure sign of a well-managed operation.

Figure 8.2 Waste Being Pushed Uphill

Figure 8.3 Waste Being Pushed Downhill

Figure 8.4 Waste Being Pushed on Flat or Level Area

8.2 COMPACTION METHODS

Managing incoming waste at landfills for disposal can present multiple challenges including how to properly setup the work face to allow for the best waste compaction practices. Compaction methods can include working the waste pushing “up hill”, pushing “down hill” or working on “flat or level” area. As the fill progression in a landfill takes place, there will be a need to implement each of these fill operating practices.

8.2.1 Pushing “Up Hill”

This operating practice is commonly used as pushing up allows to walk over the waste and break it/shred it better as it is being pushed and spread. Pushing up hill also allows to control the size of the work face area as it is easier to keep it more compact. The disadvantages with this method is that the equipment has to work harder as it is climbing fill slopes all the time and pushing waste loads up hill, therefore using more fuel. The equipment tends to sink more in the waste and increases the wear on equipment and maintenance and operating costs.

8.2.2 Pushing “Down Hill”

This operating practice is easier on equipment as units are pushing loads down hill, using the help from gravity manage loads. Equipment operating costs and wear are lower. Some disadvantages with this method is that work face disposal area tends to spread more as it is harder to control down slope pushing; waste compaction can have worst performance as waste can tend to roll over or cascade downward not allowing for proper spreading and walking for good compaction.

8.2.3 Pushing on “Flat or Level” Area

This method is the most efficient to achieve higher compaction of waste (full load for equipment unit and wheels/tracks puts downward force on the waste mass) and puts less strain on equipment, therefore having lower fuel usage and equipment operating costs. This method is hard to execute all the time due to the changes in fill sequence as the landfill gets filled. It also requires more equipment operators training for them to work on properly setting the work face to perform waste disposal operations on flat, level areas.

Regardless of which compaction method is used, the top deck of the work face area should be finished with a gradual slope to aid surface water run off following cover placement. Compacted slopes should, where possible, be diverted towards internal drainage paths as leachate will preferentially follow these layers. It is better to have waste slopes directed into the waste mass to reduce the possibility of leachate build up and to minimize the potential for leachate breakout from the compacted waste face.

8.3 COMPACTION TECHNIQUES

The dozer or compactor, as it pushes the waste to its final point of disposal, will mix, track over, and crush or shred the waste. Once crushed/shredded and in place, the compactor or dozer should pass over the waste a number of times, but as a minimum three to four passes is typically used to achieve effective compaction.

The optimum amount of compaction is controlled by a number of variables, including the nature of the waste,the type of machinery used, and the compaction operating techniques employed.

Good compaction operating techniques include 1) adequate layer thickness, 2) three to four wheel passes, and 3) adequate wheel coverage.

8.3.1 Layer Thickness

The waste should be spread in layers targeted at no more than 300mm-400mm in compacted thickness as much as it can be practical. Employing this discipline ensures optimum compaction is exhorted by the compactor wheels or dozer tracks on the layered waste. This layering practice should be employed regardless of the fill method (i.e. “up hill”, “down hill’ or “flat or level”) being employed. The technical information below is from Caterpillar literature and studies done to measure optimum landfill compaction practices.

4-WHEEL COVERAGE

Straight up & down	Side step	Compacts all material
- Move off face at ends	- One wheel width	- 220” (18’4”)
- Reverse in same tracks	- Make turn off of face	- 4x55” wheels

220” (55” wheels x4)

Figure 8.7 Wheel Coverage Pattern

8.3.2 Wheel Passes

Following proper spreading of layered waste, in order to achieve good optimum compaction, there has to be three to four wheel/tracks passes over the layered waste. Conducting these number of wheel passes ensures the waste is not only properly layered but also properly walked to achieve good compaction. The technical information represented below is form Caterpillar literature and shows the improved performance by doing this practice. At the same time it represents that by exceeding the number of passes beyond the four passes, the gain is minimum and it would only increase equipment operating costs.

8.3.3 Wheel Coverage

It is best for the compactor to work in a pattern to ensure a consistent degree of compaction. This can be achieved by making the first machine pass at one side of the working face (say left to right), making an up and back machine pass, moving over one wheel width, making two up and back machine passes, moving over one wheel width, making 2 more machine passes up and back, and so on until the entire working face has been run over by the machine 4 times. This process is, however, dependent on the nature of the waste being compacted and the geometry of the working area. Waste with a high organic and moisture content (e.g. sludge waste) will likely require less than 4 machine passes to optimize compaction.

The following checklist can be used to help landfill managers and equipment operators monitor their daily compaction techniques in an effort to set an operating discipline that can improve landfill compaction.

8.4 COMPACTION MEASUREMENTS

A high waste density should always be targeted and this should be checked by regular surveys using airspace geometry (allowing for settlement) and waste intake tonnage data. Densities of > 0.85 t/m³ should be readily achievable with modern equipment. Densities less than 0.6 – 0.7 t/m³ significantly reduce landfill efficiency and will increase the risk of landfill fires.

The following template can be implemented and used to complete waste density calculations to measure compaction efficiency at landfill operations. Density calculations can be performed on a quarterly, semi-annual or at a minimum on annual basis. The table and graph provided in the report below can also be used to tack compaction performance over time.

If inbound scales are not available at landfills, the compaction efficiency can be measured by using regular surveys using airspace geometry and by tracking waste intake data based on incoming trucks metric capacity. When compaction is measured this way, a compaction ratio from in place airspace utilized (in cubic meters) is compared to the waste intake gate cubic meters received during that same period.

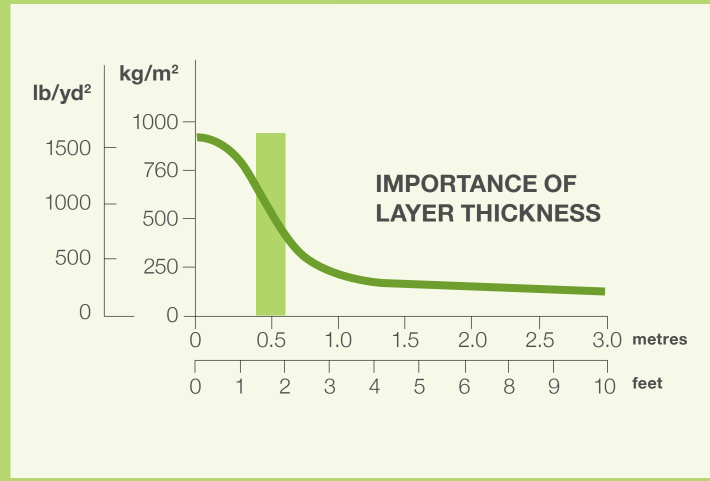


Figure 8.5 Optimum Compaction and Waste Layer Thickness

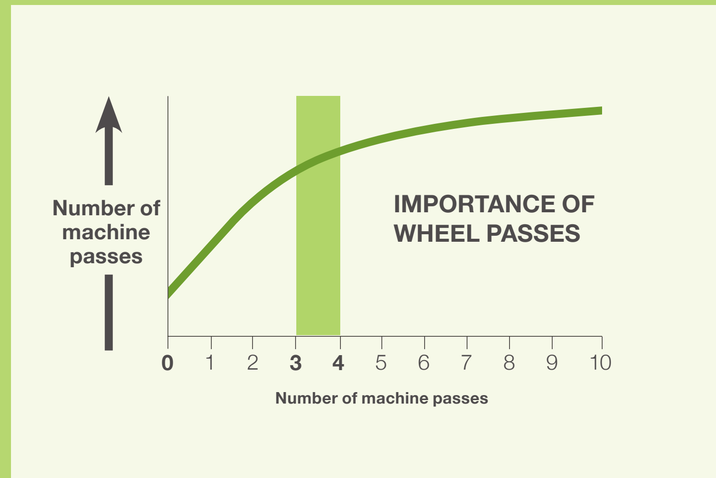


Figure 8.6 Compaction and Number of Passes

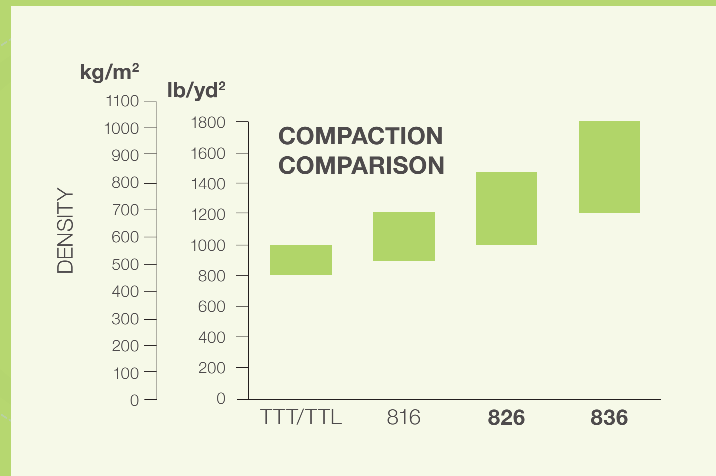


Figure 8.8 Compaction Performance Comparison – Track Type Dozers vs. Compactors

Track Type Tractors
800 to 1000 lbs/yd^3
474.62 kg/m3-593.28 kg/m^3

Landfill Compactors
900 to 1800 lbs/yd^3
533.95 kg/m3-1067.90 kg/m^3

Figure 8.9 Dozer vs. Landfill Compactor – Compaction Efficiency

Table 8.1 Checklist for Proper Waste Compaction Technique

Table 8.2 Annual Density Calculations

This measurement is not as accurate as a density calculation having scales in place, but it does provide a reasonable compaction measurement to determine compaction efficiency at a landfill facility.

8.5 EQUIPMENT

8.5.1 Landfill Compactors

Waste acceptance rates at the working face should be controlled so as to ensure that there is no excessive build up of waste in the working area. This will enable the compactor/dozer to deal with the waste as it arrives. However, at most landfills waste typically arrives at an uneven rate throughout the day, with several peak periods. The site operator must either scale his equipment fleet to meet these peak periods or, to save on machinery costs; there can be some controlled stockpiling of waste in a designated area which can then be dealt with between peak periods that same day. This way a smaller machine fleet can often still meet the waste handling needs of a site.

Compaction is typically achieved using a bulldozer or a landfill waste compactor, as shown in Figure 8.1. A landfill compactor is preferred as it will provide better compaction of waste and in turn it will have lower operating and maintenance cost than a bull dozer in this application. Waste compactors can achieve relatively high waste densities and can result in efficient airspace utilization.

8.5.2 Bulldozers

Bulldozers are track type tractors that have a lower weight and exert a lower force on the waste surface area. Landfill compactors are designed to work in the waste, have a higher weight and exert a higher force on the waste mass as it has metal wheels with cleats.

However, in some situations – for example at tropical landfills where the waste is often relatively wet and site conditions can also be very wet, a heavy bulldozer may be used to provide the spreading and compaction of waste due to the high moisture waste. The term “compactor” in this section of the manual refers to the use of either a landfill compactor, or a bulldozer, or a combination of the two, as applicable.

8.6 CONCLUSIONS

Well compacted waste is an essential component of good management of a landfill. Compaction methods presented in this chapter should be learned and implemented to optimize the landfill operation for good compaction performance which will ensure a good operation is carried at the work face. The compaction techniques presented here should be thought to landfill managers and operators to learn the basic principles needed to execute daily to ensure good compaction is performed. And lastly, the proper selection of equipment to use for the landfill operation is important so that the landfill operating staff has adequate equipment to perform proper waste disposal operations and achieve good compaction.

CHAPTER 9
LANDFILL FIRES

9.1. INTRODUCTION

One generally accepted definition of combustion or fire is a process involving rapid oxidation of material at elevated temperatures accompanied by the evolution of heated gaseous products of combustion, and the emission of visible and invisible radiation. The key word that sets combustion apart from other forms of oxidation is the word "rapid".

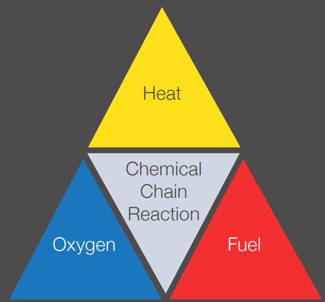
Fire is one of the more serious risks that a landfill will face through its life. Fires are common at dumpsites, but serious fires are relatively infrequent at well-managed landfills. Landfill fires as shown at Figure 9.1, can cause serious damage to the infrastructure of a landfill and can be a major hazard for site staff. Additionally, landfill fires can create significant problems (in terms of health, air quality and social acceptance) with the surrounding community. See Table 9.1 below.

Materials that are landfilled can be the source of both surface and subsurface fires and waste typically has a high fuel energy value. Regional landfills can represent a huge stockpile of flammable material. Understanding landfill fires requires consideration of the fire triangle: fuel, air, and ignition source.

Combustible materials are in the waste such as paper, plastics, textile, represent the main fuel but also hazardous waste mixed in co-disposal (oil, paint, solvent, bottle of gas) are forbidden but existing in the dumpsite with no control at the entrance.

Ignition source carries on site (e.g. hot ash), smouldering material, sparks, spontaneous combustion chemical reaction, recovery material on site by the waste picker who recovers the metal of the electrical cables by firing the plastic sheaths, smoking on site or even arson.

Oxygen is usually present in the waste when deposited and subsists in case of bad conditions of compaction, or it can be drawn in through the surface, large surfaces without inert material for covering is usually observed in dumpsite.



Hazard	Low severity	High severity
Uncontrolled gas and smoke emission	Additional on-site health and safety precautions required. Additional off-site receptor gas risk assessment (chronic effects)	Fire Service required. Nearby housing evacuated
Rapid settlement	Settlement causes seals around gas infrastructure to fail	Plant falls into underground cavity causing injury/death
Damage to landfill liner	Reduce lifespan	Immediate loss of integrity
Additional site management	Extra staff required to address subsurface fire issues and liaison with authorities.	Emergency response including 24 hours supervision and public relations/media management
Uncontrolled chemical reaction	Considerable additional on-site health and safety required. Additional off-site receptor gas risk assessment (acute effects)	Explosion

Table 9.1 Hazard of Fire

9.2. CHARACTERIZATION OF A FIRE

Fires at landfills can be classified into four categories, corresponding to the level of alert:

Level 1 Alerts: Small fires occurring on the landfill property, but not actually involving landfilled waste, compost or stockpiled recyclables, e.g. car fires, bin fires, equipment fires, office fires.

Level 2 Alerts: Small waste fires that can be contained by on-site resources within 24 hours and fully extinguished within 48 hours. Level 2 fires will typically involve less than 200 m^3 of burning material.

Level 3 Alerts: Medium size waste fires or large fires at compost facilities that can be contained in less than one week and that can be fully extinguished in less than two weeks. Typically, 200 to 5,000 m3 of waste material is involved.

Level 4 Alerts: Large or deep seated landfill fires that require more than two weeks to contain typically involving more than 5,000 m^3 of burning waste.

9.3. IMMEDIATE ACTIONS

Fires at Level 2 or 3 alert level have the potential to turn into a Level 3 or 4 fire if an immediate and effective response plan is not applied. This is the reason why quick recognition and spotting of fires is essential. The prevention of the escalation of a fire is related to the delineation of flammable waste, the application of immediate soil cover, and the potential for access and immediate excavation of the landfill slopes.

It is very important also, in the case of a Level 4 fire, to have ensured exact spotting of the fire as well as an assessment of the current and potential extent it could attain. Spotting should be linked to mobilization of fire-fighting resources from the outset.

In any case, the first actions that must be taken at a landfill, during a fire of level 2 or above are:

- Shut-off of the landfill gas collection and management system (if present).
- Water services must be available for firefighting, including treated leachate if available.
- Standby electricity generators should be available for use, in case of power failure.

The following actions need to be taken in the case of a landfill fire of level 2 or above:

- Immediate spotting of the fire
- Call to the fire department

Figure 9.1 Fire at the landfill

Figure 9.2 Protective Equipment to be used in the vicinity of a fire

- Characterization of the fire - choice of alert level
- Appointment of an incident commander
- Application of communication plan
- Selection of the most appropriate firefighting equipment
- Activation of alternative working face
- Monitoring of the air emissions and the course of the fire
- Application of the communication plan for the local community
- Application of the evacuation plan for residential areas if necessary
- Use of soil reserves
- Use of health and safety equipment by staff (Figure 9.2)

Temperature	Landfill Conditions
< 55° C	Normal Landfill Temperature
55 – 60° C	Elevated Biological Activity
60 – 70° C	Abnormally Elevated Biological Activity
> 70° C	Likelihood of Landfill Fire

Table 9.2 The relation between landfill conditions and temperature

CO concentration (ppm)	Fire Indication
0 – 25	No Fire Indication
25 – 100	Possible Fire in Area
100 – 500	Potential Smouldering Nearby
500 – 1000	Fire or Exothermic Reaction Likely
> 1000	Fire in Area

Table 9.3 The relation between CO concentrations and fire at the landfill

9.4. Extinguishment Methods

The approach taken to extinguishing a landfill fire depends on the type of fire. Selection may be dependent on the wind direction and intensity, the location of the flammable materials and the ability to mobilise personnel, fire department equipment and the potential for impact on local communities.

9.4.1. Water Application

Although water is an effective firefighting agent for near surface fires, ensuring that water reaches a deep-seated fire can be problematic. Water tends to flow along paths of least resistance in the waste such as through poorly compacted pockets. This process of channelling can result in significant short-circuiting, and inability of the water to reach the active burn zone at depth. Water does not readily penetrate cover layers composed of low permeability soils, especially if the cover has been compacted by vehicular traffic.

In situations where soil cover is present at surface or at depth, surface application of water is often ineffective. However, stripping of the soil cover should never be considered because it will facilitate air entry, which will accelerate the burn. To deliver water beneath cover soils, the preferred approach is to inject water into wells or other available injection points.

Wells can be quickly drilled with a 150 to 300 mm diameter auger rig. Well screens can be dropped into the boreholes to keep them open. Water can then be deployed into the injection wells from tank trucks or pumped in directly if a fire hydrant or water body is located nearby.

Large volumes of water may be required as 5000 litres of water is required to absorb the energy released by the full combustion of 1 tonne of garbage. The use of foam and surfactants can reduce this volume markedly.

The firefighting team has to consider that the use of large amount of water for the extinguishing of a fire can produce large amounts of leachate, which may possibly, overload the leachate treatment facility or require temporary containment or ponding.

Application of a large volume of water could accelerate the instability of waste body, especially if there is a poor compaction of waste (cohesion = 0) and a steep slope without good geotechnical conditions of stability (< 18° for slope is the starting point of instability)

9.4.2. Excavate and Overhaul

For deep-seated fires, where water application may not be an effective fire-fighting tool the most appropriate method for extinguishing the fire is often to excavate and "overhaul" the waste. The first step in controlling a fire in such way, is the filling of parallel trenches previously excavated by the landfill operator. Next, smother the fire zone with a 2 to 3 m thick lift of refuse or soil and smooth (overhaul) the landfill surface. These actions reduce the amount of air fanning the burn, reduce the rate of burn and the amount of smoke that the fire emits, and make the landfill surface a safer work environment.

9.4.3. Oxygen Suppression

By limiting the amount of oxygen within the burn zone it is possible to extinguish a landfill fire over time, but this is usually a slow process. This method is similar to excavating and overhauling, since it is based on the isolation of the burning section of waste from the rest of the landfill. Isolation is achieved by excavating around the burning mass, until inflammable material (usually soil or rock) is found. The excavated trench is filled with low permeability material in order to limit the flow of oxygen through the burning waste mass.

After applying this method, long term temperature and gas monitoring data needs to be collected in order to determine whether the selected method was effective or not. Also, the collection of the monitoring data indicates when the fire is extinguished and the materials from the trenches can be removed in order to fill them with waste.

9.5. MONITORING AND PREVENTION

9.5.1. Temperature Monitoring

Monitoring of landfill internal temperature is very useful for establishing the risk of or extent of a fire, but only if the temperature is measured at depth. The best way to collect temperature measurements (and gas composition samples) is to drill a number of monitoring wells in and around the suspected fire zone. Air rotary rigs should not be considered since injection of large quantities of air could accelerate the fire and possibly trigger a methane explosion. In any event safety equipment, including respirators and ventilation fans, must be used by workers during such work.

To keep the holes open, the monitoring wells should be cased, preferably with slotted steel casing. Thermistors can then be lowered down the holes to measure temperatures at various depths (e.g. 5 m intervals) within the waste. To prevent convective currents between the various temperature intervals, the installation of foam baffles on the thermistor strings is recommended. A multi-channel read out box is used to measure temperatures at surface, as shown at Figure 9.3.

Temperature monitoring has proven to be a very useful procedure in prevention of landfill fires as well as in monitoring to confirm that the fire has been extinguished. In Table 9.2, the relation of landfill conditions and temperature is presented (see page 40).

9.5.2. Gas Composition Monitoring

Monitoring of gas composition provides very useful insight fire conditions at depth and the success of firefighting measures. Parameters that must be measured at various times include methane, oxygen, carbon monoxide and hydrogen sulphide. Of those four gases, the carbon monoxide is the most useful indicator of a subsurface fire. In Table 9.3, an empirical scale is presented that assists to the assessment of fire conditions in demolition landfills (see left).

The presence of oxygen at concentrations above 1% provides an indication that existing oxygen intrusion barriers (i.e. soil or membrane covers) are not effective in keeping oxygen out and that additional soil cover is required. But until 5% of oxygen, it is not a real issue for the activation of fire condition. On the other hand, a build-up of methane to levels in excess of 40% is a positive indicator that oxygen is being successfully excluded and the biological regime is reverting to cooler anaerobic conditions.

During a landfill fire, sub-surface oxygen levels within the burn area are typically in the range of 15-21% oxygen. As firefighting and capping efforts progress, oxygen levels drop consistently and when the fire is extinguished the oxygen levels typically drop below 1%.

9.5.3. Leachate Management

Application of large quantities of water will invariably produce leachate. In many cases when extinguishing landfill fires, leachate management has proven to be a significant issue.

To minimize the environmental impacts of leachate, recirculation of firefighting water should be considered on projects where large volumes of water are used. Recirculation requires that leachate should be directed into settling ponds, preferably including filtration, and booster pumps may need to be brought on line to enable recirculated water to augment water supplies from nearby fire hydrants.

The use of foams and surfactants can greatly reduce the use of water for fire control and hence reduce the potential leachate problem.

9.5.4. Smoke and Odour Smoke

Smoke is often the first definitive evidence of a fire. In most recent fires the smoke has been seen for the first time when the gas abstraction system has been turned off for routine maintenance.

Smoke, acrid, or 'cooking' odours should also be investigated if there is no visual evidence. Smokey aromas in the leachate have also been observed to correlate with a sub-surface fire.

Steam on cold days has often been misconstrued as smoke. If condensation on a cold upturned bottle isn't conclusive (condensation meaning that the visible vapour cloud is steam), the definitive method of distinguishing between steam and smoke is to take a sample and look at it under a microscope. Smoke contains soot particles, while steam contains water droplets. Steam dissipates rapidly in the environment, while smoke dissipates more slowly.

Smoke detectors are not a viable method of detecting smoke because they are also sensitive to moisture. Most gas emissions from a landfill (even smoky ones) contain moisture.

9.5.5. Abnormal Settlement

Perhaps the most common association with sub-surface fires is rapid or abnormal settlement. Abnormal settlement must be treated with caution because it is caused removal of structural integrity at depth – if there are large sub-surface voids then there is a risk of major collapse at surface. Rapid cylindrical settlement (bomb craters) that appear over a 2 week period was described in one case study. It is reported that the shape and size of the settlement depends on depth of fire, with deeper fires producing a small deep crater and shallow fires producing a shallow settlement over a larger area.

However, it is important to note that settlement is a normal feature of landfills and greater settlement around wells is normal because the waste around these features is not compacted during waste placement (assuming the wells are built up at the same time as the waste). A dusty and cracking cap surrounded by a moist or normal cap can be an indication of higher temperatures below, as can vegetation die back.

9.5.6. Fire Prevention and Control Plan

The first prevention action is follow the good practices to operate the landfill. But also, it is very important for every landfill to have an established and maintained fire prevention and control plan. In this plan, essential issues related to the landfill must be included such as site characteristics, Fire Fighting Resources, Landfill Fire Alert Levels, Incident Command Structure, Fire Response Actions and Responsibilities, Fire Fighting Methods, Landfill Fire Risk Reduction Strategies, Personal Protective Equipment etc. All site personnel need to be aware of the plan, and trained in its application.

CHAPTER 9 LANDFILL FIRES

BUILDINGS	YES	NO
Workplace clean and orderly		
Emergency exit signs properly illuminated		
Fire alarms and fire extinguishers are visible and accessible		
Stairway doors are kept closed unless equipped with automatic closing device		
Appropriate vertical clearance is maintained below all sprinkler heads		
Fire extinguishers are serviced annually		
Corridors and stairways are kept free of obstructions and not used for storage		
The roads that lead to the buildings are clear and accessible to the fire engine		

TRAINING	YES	NO
There is a specific training program for fire prevention & extinguishment		
New employees are given basic fire training		
Job-specific fire training held for employees on a regular basis		
Personnel familiar with applicable Material Fire Data Sheets		
All personnel familiar with emergency evacuation plan		
Training documentation current and accessible		
The guests of the landfill are informed that have to follow the staff's instructions		

LANDFILL	YES	NO
There is a sufficient stockpile of earth close to the working face		
There is on site available equipment to move earth		
Alternative working face has been planned		
There is adequate supply of water under pressure for fire-fighting purposes		
There is a water storage tank for fire-fighting purposes		
Fire-fighting equipment is readily available		
Record-keeping procedures for all fires		
Electricity generators are available for use		
There is suitable access road for the fire engine to reach the working face and the burning mass		
All the equipment maintenance procedures are followed		
All flammable materials are stored properly		
The most dangerous locations of the landfill for fire, are signed properly		
The emergency telephone numbers (fire department, hospitals, police etc) are displayed in approachable places		
There is an adequate network of lightning conductors for protection from lightning strike		

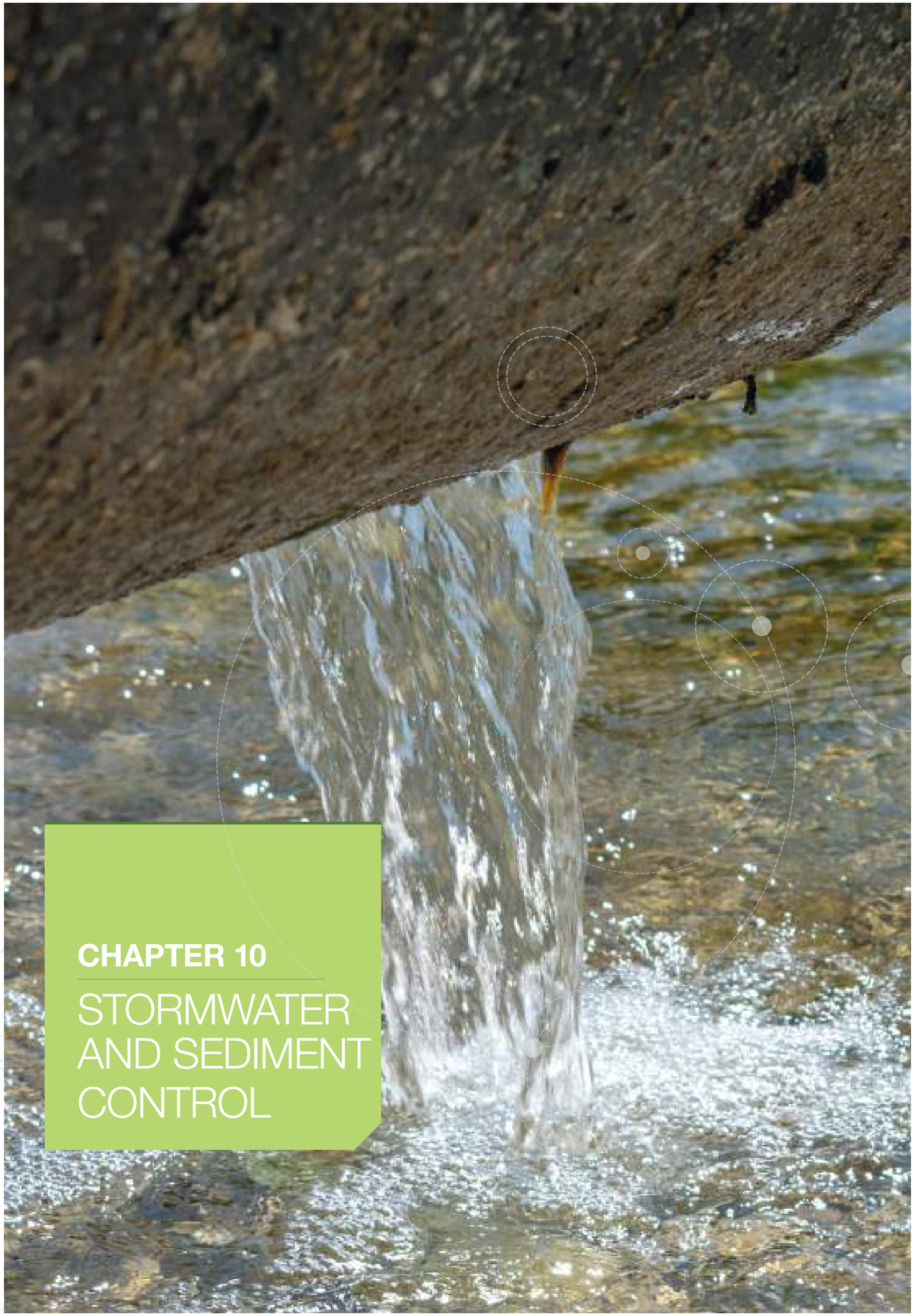
Table 9.4 Checklist for monitoring landfill area

9.6. Checklist to Prevent the Landfill Fire and Consequences of any Fire

The following checklist can help operators to assess their readiness to handle a landfill fire and identify possible gaps that have to be covered. Where "no's" are ticked in the Table 9.4 remedial action must be considered.

9.7. CONCLUSIONS

Landfill fires are an ongoing, complex global concern as they pose a threat to the environment and human health through the hazardous chemical compounds they emit specially in dumpsites in the developing countries where landfills are located within residential quarters. They are usually caused deliberately or by spontaneous combustion of decomposing waste involving methane from landfill gas. They are prevalent in the dry season due to hotter temperatures in this period, when there is a greater chance of spontaneous combustion occurring. The danger and level of toxicity of the pollutants emitted depend on the length of exposure to them and the type of material that is burning. It is therefore necessary to study these fires and their potential effects on human health. Effective landfill management by the operators is necessary to prevent the occurrence of these harmful fires.



CHAPTER 10
STORMWATER AND SEDIMENT CONTROL

CHAPTER 10 STORMWATER AND SEDIMENT CONTROL

10.1. INTRODUCTION

Landfills are engineering structures that generally result in a new landform being developed as a valley infill or mound. Invariably this occurs within a surface water catchment and the Landfill needs to be designed to cater for rainfall and stormwater runoff during development, filling and for the permanent condition following closure.

With few exceptions, landfills are also significant earthworks projects. Landfill development typically requires earthworks for cell formation including in many cases, the placement of components such as compacted clay liners. In addition, operations generally require the placement of soil cover layers and final cap - typically also comprising soil materials. All such materials have the potential to generate sediment during rainfall events that result in runoff and this sediment can impact on downstream waterways if not adequately controlled.

Poor control of stormwater can have very significant impacts not only on receiving waters downstream of the site (e.g., due to entrained litter, sediment and chemical contaminants), but also on the practicality and cost of site operations. Better stormwater management often leads to less leachate needing treatment.

Providing adequate surface water drainage is therefore a critical component of any Landfill facility design and in many situations is a key driver of overall facility design.

10.2. FUNCTIONS OF SURFACE DRAINAGE SYSTEMS

Landfills are typically subject to stormwater running on or towards the footprint from the surrounding catchment, and also generate runoff from completed cell areas. All runoff, particularly from earthworks areas that are not stabilised by vegetation, has the potential to generate sediment. Poor stormwater management can also degrade a landfill's geotechnical components such as batters, toe bunds, or anchor trenches for geosynthetics. Poor stormwater management can impede good landfill operations by, for example, damaging roads. Runoff from active areas (where waste is being disposed, or in areas where waste is poorly controlled) has the potential to also become contaminated by organic and inorganic materials from the waste itself, and by leachate reaching surface water drains. Runoff from inactive areas where there is re-exposed waste or litter can also lead to contaminated runoff. Significant contamination of runoff from the site can lead to contamination, ultimately, of surface water bodies and even groundwater.

The design of a Landfill stormwater system therefore has a number of critical functions:

- Safely conveying surface run-on and runoff from the landfill and associated catchment to the discharge point for the site
- Ensuring landfill operations not compromised by poor surface drainage
- Ensuring landfill construction not compromised by poor surface drainage
- Minimising leachate generation by preventing surface water from entering the waste mass (to the extent practicable)
- Avoiding contamination of surface breakouts and surface flows
- Minimising soil loss and erosion from borrow sources and completed landfill areas
- Controlling sediment discharge and surface water contamination
- Providing water storage for site use and firefighting (typically as an adjunct to sediment control using detention ponds)

10.3. KEY DESIGN ELEMENTS

10.3.1. Overview

At most landfills, the surface drainage system has a number of key elements. Working upstream from the receiving water/discharge point these are:

- Stormwater detention/sedimentation/ storage ponds
- Primary drainage systems
- Secondary drainage systems
- Tertiary (temporary) drainage systems
- Supplementary systems such as pumping and diversion drains
- Landfill cap drainage

10.3.2. Stormwater Detention/ Sedimentation/Storage Ponds

Generally the principal design objective is to directly bypass and discharge (without treatment) clean runoff from any surrounding undisturbed catchment areas. At valley fill sites high level cut-off drains formed of stable permanent materials (grassed channels, concrete or riprap-lined channels) can sometimes be used to divert clean runoff right around the facility area. However, in almost cases significant clean water diversion may not be possible during the operating life of the landfill because runoff from the disturbed site area and parts of the contributing catchment may not be able to be practically separated. Such runoff will contain sediment and will under most flow conditions, require detention and settling processes in a stormwater (sediment) pond prior to discharge. Local guidelines or regulations often govern stormwater pond design. The key features normally required are:

- Ability to store runoff from moderate storm events for gravity settlement, sedimentation using chemicals (where required and appropriate) and slow discharge (usually via a siphon or other decant structure targeting the upper clear water zone)
- Ability to safely bypass overflows during larger events (service and emergency spillways)
- Provision of a deep water zone for sedimentation (sediment forebay) with machine access for de-silting
- A controlled slow release outlet (decant outlet)
- Flow and water quality monitoring facilities
- Storage zones (on or off line) for surface water storage (where required)

Typical design criteria for sediment ponds are:

- Emergency spillway: Probable Maximum Flood flow
- Service spillway: 1 in 50 to 1 in 100 year event
- Full range decant time: Several weeks typically
- Storm storage: 1 or 2 year critical event where practical

10.3.3. Primary Drainage Systems

Primary drainage systems can comprise both natural streams and channels and the engineered drains that form the permanent external drainage to the Landfill (that is outside the footprint).

Design requirements for primary (permanent) drainage vary greatly from location to location and are typically governed by factors such as local design regulations, site licence requirements, climatic conditions and local materials and construction methods.

Typical designs may include:

- Shotcrete and concrete-lined channels (including with energy dissipation)
- Rock-lined trapezoidal channels
- Broad, low gradient grassed channels
- Piped culverts and drains

Normally open channel structures are used for primary drainage to optimise flow capacity and to reduce the risk of blockage.

Typical design criteria for primary drainage systems at landfills are:

- Ability to convey 1 in 100 year flow within normal flow zone (with freeboard).

At flows beyond the design capacity of the system localised flooding can be expected. However, the selection of a return period of 1 in 100 years ensures that the risk of significant inundation and adverse effect on the Landfill during the typical life of a landfill facility (20-50 years) is relatively low.

To lessen the chance for disastrous outcomes, consideration should be given to secondary flow paths in the case of flows beyond design capacity. For example, overflow could be designed to flow along repairable roads or through soil borrow areas, rather than over completed waste, or through soil structures that hold waste in place.

10.3.4. Secondary Drainage

Secondary drainage comprises subsidiary channels, structures, piped drains, road culverts, mechanised pumping systems etc. that are either semi-permanent, or permanent. Typically such features are associated with major phases of Landfill development, related to cells, benches, or waste lifts, and are expected to have a required service life of 5-20 years. However, secondary drainage also includes the permanent drainage on the final cap. Such systems are usually designed to provide a balance of construction cost and risk. Under storm events more severe than the selected design life it is expected that such drainage systems may suffer drainage and require repair and reinstatement. There is also the potential for impact on the Landfill operations area (for example due to secondary drain overflow into an inactive cell).

At landfills where geomembrane cover systems are used, or where significant areas of sidewall geomembrane will remain exposed for periods of time, there is the potential for large volumes of runoff. This runoff occurs quickly and can impact on landfill operations and leachate volumes in a major way if not controlled. In such situations the use of surface gutter drains or side-slope drains (generally formed of the geomembrane material itself) is essential.

Design requirements for secondary drains may be specified in the Landfill licence, but are often determined on a site-specific basis considering climate, timing, risk and cost. Typically adopted design criteria are for such drains to be designed to convey the 1 in 5 to 1 in 10 year flow, with sizing for the maximum temporary catchment area that contributes to a particular drain.

10.3.5. Tertiary (temporary) Drainage Systems

Such systems relate to active areas, earthworks areas and areas that are being capped and rehabilitated up until the point where permanent conditions are reached. Design is usually site-specific, often based on local soil conservation/sediment control guidelines and on short-term experience gained on site for local drainage management.

10.3.6. Active Area Drainage

Drainage in the active area where waste is being disposed of, needs to be carefully managed. Any rainfall or surface water contacting waste must be treated as leachate, so minimising this water volume is a key driver for design and operations. Runoff from such areas to the secondary drainage system needs to be avoided until intermediate cover is placed.

Features of active area drainage include:

- Slope surfaces inwards to a low point draining into the waste
- Provide ample slope to keep the tipping area from flooding
- Minimise the active area and hence stormwater ingress into the waste mass
- Apply intermediate cover regularly, and as soon as practicable to promote maximum "clean" runoff (albeit that the sediment component needs to be treated for a period of time)

10.3.7. Landfill Cap Drainage

Landfill cap drainage is implemented progressively as the landfill is capped and rehabilitated. Timing, settlement, cap construction method and contour are all key determinants of the final cap drainage configuration.

Ultimately the cap drains are permanent secondary drainage features on the site and hence need to be:

- Durable
- Require minimal maintenance
- Able to accommodate ongoing settlement

Often the rate of and extent of settlement dictates the programme for establishing permanent cap drainage. For this reason a staged approach is often taken with drains formed and lined temporarily, and then re-levelled and permanently lined or vegetated when the bulk of landfill settlement has occurred.

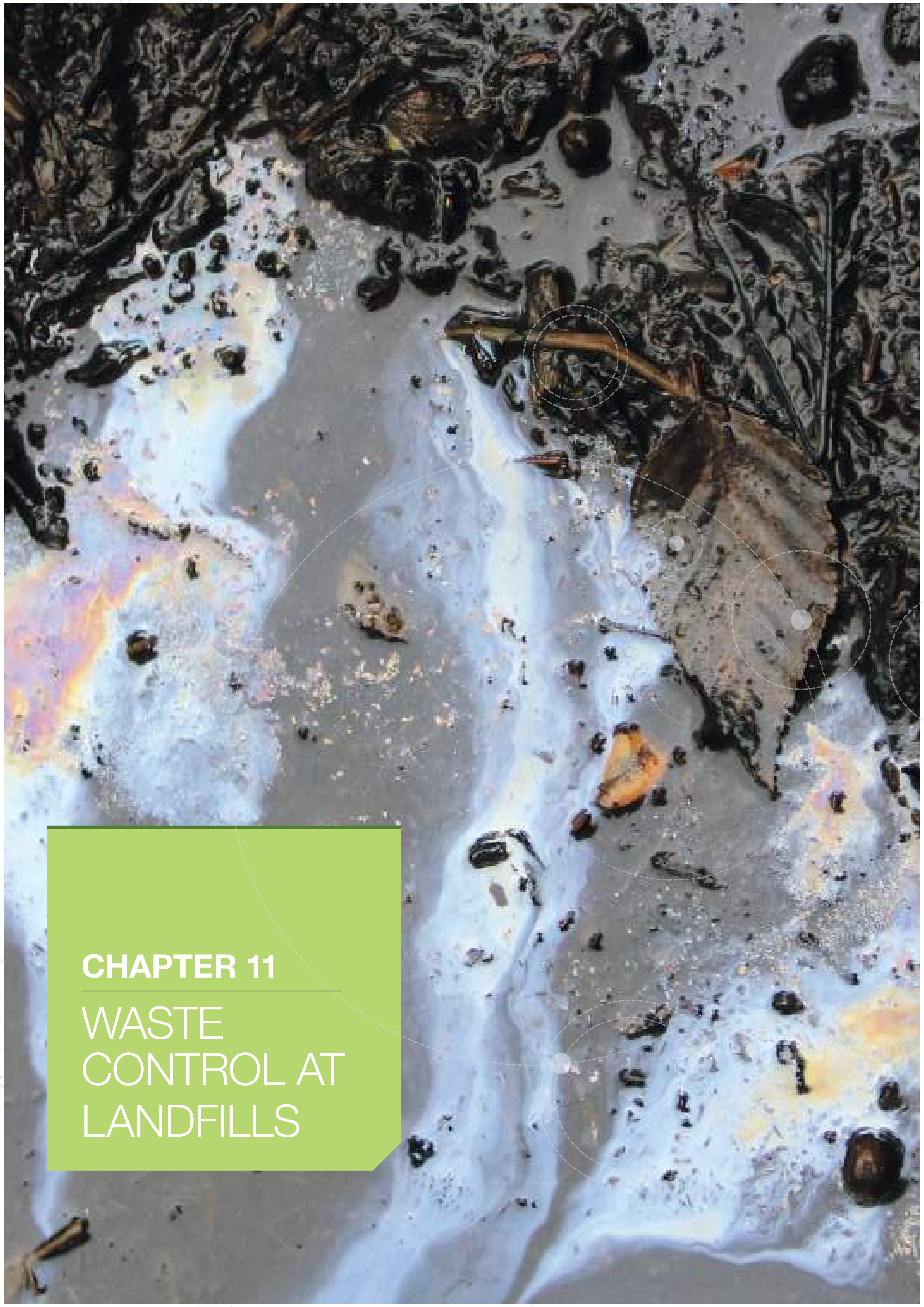
Special cap drain configurations are adopted in areas of high rainfall or where exposed geomembrane caps are used. These can comprise site-specific designs such as masonry lined channels with energy dissipation and outfall structures, corrugated steel flumes, or geomembrane gutters and channels. All such features require careful detailing and site-specific design.

10.4. CONCLUSIONS

The design of the stormwater drainage system at a landfill is key to optimising operations, managing the risk of flood damage and avoiding adverse effects offsite due to sediment, leachate and waste contamination in site runoff. The design of stormwater system needs to consider both the permanent (completed) landform as well as the range of intermediate conditions that will occur.

A main (primary) drainage system needs to be configured to safely convey flows from the catchment within which the facility is sited in order to maintain the integrity of the facility over the long term. Further secondary and tertiary drainage features are designed for smaller contributory flows, for predominantly interim conditions, and generally carry a higher design risk to avoid over-design and excessive construction cost. The exception is the final cap drainage which ultimately becomes a permanent feature of the site following closure and hence needs to be conservatively sized and detailed. Other site-specific features are generally employed to minimise surface water ingress to active areas, silt generation, downstream flooding, and sediment and contamination in stormwater flows.

Combined with an effective Landfill liner (barrier) system and good operational practices, effective surface water control based on sound design and detailing is one of the most important environmental control features at any modern Landfill site. Stormwater system design shortcomings can quickly become evident in severe climates or rain events, especially sites where rainfall is routinely high or monsoonal. This has the potential to compromise facility operation, result in large quantities of leachate needing to be dealt with, add cost, and cause downstream environmental impacts. Careful design of the stormwater management system is therefore a key aspect of any Landfill development.



CHAPTER 11
WASTE CONTROL AT LANDFILLS

CHAPTER 11 WASTE CONTROL AT LANDFILLS

11.1. INTRODUCTION

11.1.1. Definitions

Control of waste accepted into a Landfill requires the use of protocols to routinely screen waste inflow and / or criteria to assess the admissibility of waste for handling and disposal. These criteria are aimed at determining whether particular waste should be accepted or rejected. All acceptable wastes are classified as permitted waste and those rejected are classified as prohibited waste in relation to the operating criteria for the facility.

Figure 11.1 Site roads reaching to landfill

Figure 11.2 Entrance to a sanitary landfill

Prohibited wastes can include specified waste categories such as tyres, sludge depending upon the type of facility-whether hazardous or non-hazardous and that have not been dewatered, recyclable materials or hazardous waste. Other associated controls may include the specification of maximum allowable water content in sludge, and maximum allowable amounts of permissible waste diversions per annum for specific waste categories.

Waste control processes for a Landfill should be considered during the risk assessment process, before the development of operational procedures. The reason for this is that the permitted waste definition will affect the quantity and quality of leachate and landfill gas generation and composition, and are also likely to affect the specifics of the containment system design and landfill development configuration. Therefore waste control protocols and related implementation procedures need to be established before any design and risk assessment can be conducted for a particular facility.

Waste control processes are also important in recording information about waste types that are subject to control, including:

- Establishing accurate information about deposited waste (quantities, timing)
- Recording the location of waste placement and issues around the potential environmental risk of the facility
- Details of generation point of waste to be deposited
- Waste manifest details including its detailed physic-chemical characterization studies
- Toxic chemical leachate procedure studies results with respect to its landfilling

11.1.2. Control Processes

Control processes such as pre-determined waste acceptance criteria are usually statutory, or facility-specific – sometimes both. Statutory criteria may include reference to facility permit conditions, national waste management policies (e.g., related to hazardous waste), statutory guidelines and procedures, preparing waste manifest details and other legal instruments related to management of waste depending upon specificity of its category, with focus on its management.

These criteria are usually implemented jointly by both the facility operator and regulators.

Facility operators control waste acceptance and landfilling permits, which often detail operational procedures, guidelines, and other procedures to be adopted by a facility. The regulators are focussed upon achieving compliance of policies and technical guidelines, upon which the permissions have been issued to establish the landfill facility and acceptance of waste category for its disposal. The fundamental objective of such control methods is to ensure adequate:

- Pollution control
- Operational and public safety
- Information management
- Optimisation of facility capacity
- Compliance of regulatory framework, under which permission has been granted to facility
- Compliance of applicable environmental health and safety protocols

11.1.3. Control Infrastructure

The primary means of facility control is achieved by controlling access and entry points. Access to a landfill is always via a site road (Figure 11.1), usually with a gatehouse and weighbridge. The close circuit TV Camera are also provided for better and effective supervision with option for remote controlled access control. The perimeter of the landfill is usually delineated and secured by natural or artificial features such as ditches, dykes, or secure wire perimeter fences. The site entry point is typically either continuously manned during the hours of opening (sometimes 24 hour security is also warranted), or may be automated where a high degree of upstream waste control is possible (applies to some transfer stations and to container-based waste transfer systems).

11.1.4. Levels of Control

The degree of facility control achieved can be classified as a series of levels:

a. Level 0: Uncontrolled

This occurs where the facility has no secure barriers to entry, which means that both users and other parties such as stray dumpers or scavengers can access the site without control. Such facilities does not have any defined physical boundaries delineation and are vulnerable to receipt of all types of waste, leading to chaos and unsafe operation. They contribute to environmental degradation as all types of wastes can end up in the facility and such sites are essentially "uncontrolled tip sites. Such sites are characterized by presence of smoke, uncontrolled leachate release and any anticipated fire hazards due to dumping of incompatible waste with varying physical, chemical and biological properties. Such a level of operation is not consistent with modern sanitary landfill practice.

b. Level 1: Basic Site Access Control

This is when the facility is adequately delineated and secured at its perimeter, but with only unmanned entry point(s) which mean such facilities can apply some access control and can be closed or suspended to use by trucks by securing those entry points.

c. Level 2: Site Access and Entry Point Control

This is considered the minimum operating standard for a modern landfill. In this situation the site perimeter is fully secure and control of incoming waste loads is exercised at (typically) a single entry point. In addition to overall access control, loads are allowed into the site only when the entry is open and manned. At such facilities information about waste source, type and quantity can be acquired as part of the access control process.

d. Level 3: Site Access, Entry Point and Operations Controls

This is considered the normal operating level for a modern sanitary landfill. In this situation, in addition to waste acceptance controls at the site entry point (Figure 11.2), operations controls related to the tipping area (using a "spotter") as well as control over the placement and compaction of waste are employed.

e. Level 4: Site Access, Entry Point, Operations and Waste Material Controls

Level 4 requires the use of specified pre-determined Waste Acceptance Criteria (WAC) to permit particular waste loads. This process is administered at the point of entry allowing only permitted waste into the facility. Detailed documentation, including inspection and when necessary on the spot testing of waste as per the details of waste manifest provided, are usually associated with this level of facility operation. These sites ensures best compliance of any applicable Environment, Health and Safety Protocols applicable to such facilities.

11.2. WASTE CONTROL CHAIN OF RESPONSIBILITY

11.2.1. Generator

Waste control commences with the generator of the waste who has the responsibility of disclosing accurate information about the waste. This can be achieved with a Waste Profile Form (WPF), or by simply packaging waste in appropriately colour-coded bags as per the Universal colour coding criterion.

For hazardous waste, which will only be accepted at certain sites, it should be mandatory for waste generators to accurately consign its waste using a Waste Consignment Note (WCN), or similar. Such waste declarations provide firm information about the waste and are necessary for administration of waste control at the landfill facility and must be mandatory at sites accepting hazardous or scheduled waste. In some countries, a mandatory waste tracking system related to its movement by the consignee may be required to be followed.

11.2.2. Carrier/Haulage Contractor

Waste haulage contractors have the responsibility in the chain to ensure clear and correct documentation of information about the waste they are carrying to enable quick assessment at the facility. This can be transmitted with either a WCN or a Waste Manifest Form (WMF). It is an essential part of this process that waste generators endorse the haulage contractor and for corresponding waste to be delivered with the required documentation to the facility. The carrier should ensure it facilitates easy inspection or CCTV screening of loads by removing tarpaulins and/or correct positioning of delivery truck. The vehicle transporting such waste consignment should be authorized to carry the designated load of waste as per permissible quantity and duly authorized by local regulatory agencies.

11.2.3. Landfill Manager

The Landfill Manager effectively assumes ownership of waste admitted into the landfill and hence has final responsibility for ensuring the facility is operated in accordance with the predetermined waste control protocols. Therefore the landfill manager must ensure that all facility Waste Acceptance Criteria are met and, all information necessary for waste traceability is acquired at the entry point (weighbridge), or via the manifest system. The landfill manager is also vested with responsibility and authority of denying access to a category of waste, which does not comply with landfilling criterion, based upon the facility defined Waste Acceptance Criteria.

11.3. OPERATIONAL ASPECTS OF WASTE CONTROL

11.3.1. Security

All security measures and operating procedures should be in place prior to commencing site operations, as detailed in the Landfill Operations Guideline. All operating procedures and waste records should be appropriately and securely archived and properly secured as they constitute not only the recorded basis for site operations, but also fulfil a legal requirement that will usually exist for many years. Necessary applicable permissions and permits may be valid, which are normally issued by regulatory agencies for establishment and functional aspects of the landfill facility.

11.3.2. Entry Point

The site entry point, shown at Figure 11.2, should be manned during all hours of operation (and outside those hours as necessary) with personnel and equipment to:

- Weigh incoming waste
- Manually or automatically document waste information
- Screen incoming waste (visual inspection or automated CCTV camera screening)
- Options for decoding of any applicable waste tracking and movement bar codes

Figure 11.3 Waste reception at the landfill

The weighbridge should be capable of recording weights accurately from the computer system and should be calibrated regularly by the appropriate authority to ensure accuracy as per applicable local legislations. Waste load weights should be recorded, together with details of the corresponding waste load. Where a weighbridge is not available, loads should be recorded in terms of truck volume. Waste density as recorded by the Waste Manifest may be used to arrive at a tentative load carried by an incoming truck to the facility.

At modern sites an identification and automatic information collation system for trucks/carriers is often installed that is capable of delivering information direct to the site's waste database. At other sites, information is manually gathered, and either recorded by hand, or preferably entered into a computerised database.

Personnel at the weighbridge must be adequately skilled and trained, including having the ability to carry out visual inspection of waste loads to establish the accuracy of declared load information. They must be adequately trained to understand intricacies of waste compatibility index, under which the wastes are accepted and disposed with similar properties. This can be done by using an access gantry, or with the assistance of a CCTV camera mounted above the weighbridge. Personnel at the entry point must be regularly briefed on site operations such that they can direct the load to the appropriate disposal point. They may also be trained for meeting any anticipated situations such as vehicle accidents, which may lead to localized waste spillage and other related hazards such as fire, explosion and contamination of local environmental media.

11.3.3. Internal Control

These control processes relate to operations undertaken within the facility once the waste load has been accepted across the weighbridge.

a. Directions and Signage

Truck movement within the facility should be clearly laid out with signage and directions. Traffic directions should be clear, with routes to designated unloading areas clearly signed with arrows and identification boards to prevent incorrect unloading, traffic conflict and accident. For facilities that undertake night operations, internal truck routes should be well lit and the signs designed to be visible under night conditions. Adequate illumination may be provided and access road may also be categorized as all-weather access road, so as to enable swift and free movement during rainy season and any anticipated natural calamities. Local geographical conditions and site stability may also be considered, while providing access roads.

b. Communication

There should be provision for communication directly between the entry point personnel and the personnel at the waste unloading areas within the site to enable quick cross-checking of information related to waste loads, including waste load quantity and character, and to deal with any loads rejected as unsuitable at the tipping face. The communication may also be of such nature that it remains unaffected in worst weather conditions like rainy/stormy or typhoons. Though in such conditions, waste may not be accepted and facility may not be made operational, but internal communication should be robust enough to meet any un-interrupted communication requirement between site and control staff.

11.3.4. Work Face Control

Control at the working face by the operating personnel is targeted at not only directing traffic, but also at "spotting" incorrectly described, prohibited or potentially hazardous waste loads. This requires physical inspection and if necessary, re-direction for testing of specific loads.

In some situations a load may be rejected, and in a worst-case scenario may be required to be re-loaded after tipping for removal from the site.

A special area where any suspect loads can be carefully inspected should be provided in large scale landfill facilities.

11.3.5. Reporting

The waste types and quantities received at the Landfill should be recorded as a Waste Reception Report (WRR). At a large landfill such recording is usually carried out using an integrated weighing and data recording system, consisting of one or more weighbridges and computer which is shown at Figure 11.3. The recording system is often integrated with the payment and invoicing system. Key information that should be included in the WRR includes waste category, identification of the carrier, waste source, tonnage and any other special load features.

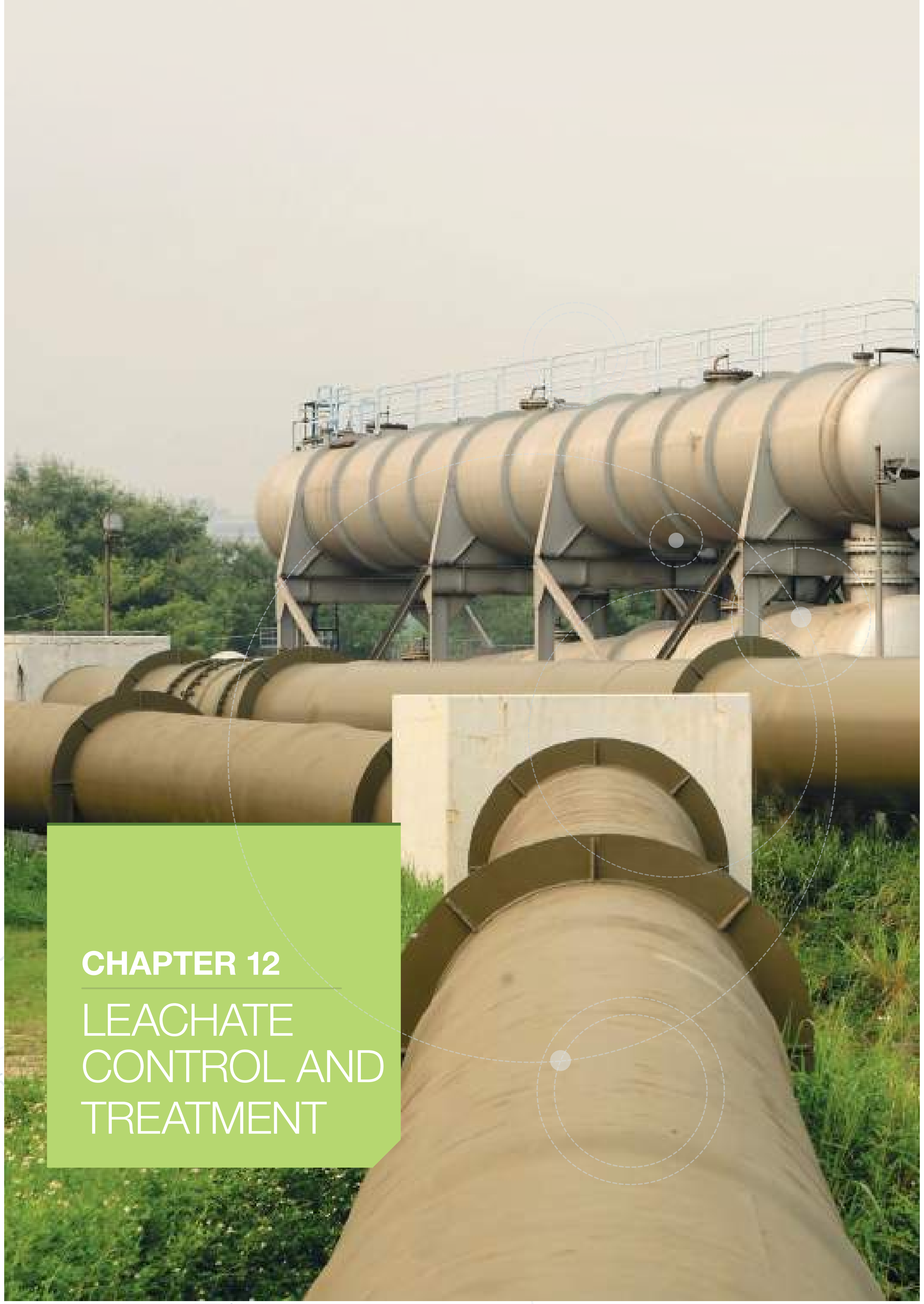
The WRR should be provided to the regulator as required under the site licence. The WRR data are used for statistical purposes, for charging the customers and as a tool for higher level waste strategy and control such as where a facility's permit conditions may include specific waste category limits by volume or weight.

If discrepancies develop between the entry point information and observations at the work face, the relevant parties should communicate immediately. This is particularly the case in respect of prohibited or hazardous waste, where licence conditions may require notification to be sent to the regulator, and in addition the load rejected.

11.4. CONCLUSIONS

Close control of waste acceptance is a key tool in ensuring a high standard of site operations, and in meeting common licence requirements which control the acceptance of hazardous and problem wastes for site design or operational reasons. A hierarchy of control measures can be applied, starting with overall site security and entry control for both personnel, and waste loads.

Achieving lose control over waste acceptance at the site entry point is the next level of control, coupled with careful recording and licensing processes for waste acceptance. Waste information recording, together with closely coordinated management of waste unloading and inspection within the site all combine to ensure that the waste that is tipped and compacted is what was declared by the generator/carrier and meets landfill licence requirements, ultimately aimed at ensuring satisfactory environmental performance of the site.



CHAPTER 12

LEACHATE CONTROL AND TREATMENT

12.1 INTRODUCTION

Leachate is the liquid generated from solid waste decomposition in a landfill or from handling of waste in waste treatment facilities. Leachate derives mainly from precipitation, surface run-on from adjacent areas, liquids disposed of in the waste mass and the decomposition of organic material in the waste itself.

Figure 12.1 Leachate collection and conveyance systems *Copyright Wehrle*

Figure 12.2 Landfill with lagoons systems (left) and after installation of a leachate treatment plant (right) *Copyright Wehrle*

As leachate forms and passes through the waste, organic and inorganic compounds become dissolved and suspended in the leachate. This process can be likened to the process of passing water through coffee grounds to make coffee.

This is a wanted effect in order to unload the landfill from pollutants and to reduce the environmental impact and the costs associated with it. The dissolved and suspended constituents of leachate have the potential to cause soil, groundwater and surface water contamination if not treated properly.

In addition to serving as a source of contamination, leachate typically has a strong odour (particularly young acetogenic leachate) and requires proper management. Appropriate leachate management measures include:

- Adopting best practice landfill design.
- Minimization/control of polluted liquids entering the waste mass and adding to the landfill load.
- Installation and operation of an engineered leachate collection and extraction system.
- Installation and operation of a site-specific leachate treatment system, and/or shipment of leachate to an off-site treatment facility.

The impetus for these controls is achieving minimal build-up of leachate and on the liner system. Minimising head on the liner system in term minimizes the potential for groundwater and surface water contamination.

12.2. DISCUSSION OF LEACHATE CONTROL MEASURES

12.2.1. Appropriate Landfill Siting

A key consideration for siting a new sanitary landfill is the presence of sources of water infiltration (other than precipitation). In general, a landfill should not be sited in or near a surface water body, or a surface water floodplain. Landfill sites should avoid wetlands (existing or old), seepage areas and locations with shallow ground water. These areas have the potential for increased infiltration of water and the subsequent production of greater quantities of leachate at a landfill site.

Figure 12.3 Physical–chemical treatment with chemicals (left) and ozone (right) *Copyright Wehrle*

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Other siting considerations include the native soil structure and type. In general, a landfill should be sited where low permeability clay-like soils exist to prevent infiltration of leachate to the surrounding groundwater. Sandy and loam-like (that is, highly permeable) soils should generally be avoided when siting a landfill, recognizing that more extensive engineering will be necessary in such situations.

12.2.2. Screening for and Restricting Liquid Waste Acceptance

An initial step to reduce the generation of leachate pollution is to prevent organics and liquid wastes from entering the landfill through incoming waste loads. Ordinances to ban liquid wastes from landfills help in this process. Operationally, all landfill personnel should visually screen for liquid waste brought in by haulers and other customers for disposal. A close watch on waste loads should also be maintained at the tipping face. Vehicles entering landfill property may be chosen randomly for a formal screening of their waste loads. Loads containing containerized liquid wastes should be rejected for disposal.

12.2.3. Landfill Operational Techniques

Some techniques used at the working face of the landfill reduce the amount of infiltration (that is, precipitation) into the landfill. A smaller working face favours the reduction of water infiltration and consequently leachate generation. Appropriately compacting and covering completed cells promotes reduced waste infiltration and increased run-off away from the active area, but reduce the positive effect of decontaminating the landfill via the leachate, especially for the inorganic water toxic compound NH4-N. Good compaction of waste and daily cover materials increases the amount of waste that can be stored on the landfill and therefore improves the economics. It also reduces waste settlement, thus, reducing the potential for depressions in the active area.

Depressions can fill with water (ponding) and allow precipitation to infiltrate directly into the waste mass. When depressions and ponding occur, particularly in intermediate and final cap areas, the water should be appropriately drained and the depression should be filled.

12.2.4. Run-On and Run-Off Controls for Precipitation

Precipitation must be carefully managed at any landfill facility and surface water systems need to be able to cater for high rainfall events. Design and engineering elements can be implemented to promote run-off of this precipitation and to minimize water ponding and infiltration through the landfill surface.

Exposed surfaces of the landfill (often with intermediate or final cover) should be sloped to drain excess surface water away from the waste mass. In addition, diversion ditches, trench drains, and localized soil berms may be constructed to guide excess water away from the landfill active area. Similarly, diversion ditches, trench drains, and soil berms also may be employed to divert precipitation that would otherwise run-on to the landfill site from higher elevations. Another step that may be appropriate (particularly at tropical sites with high rainfall) to control the amount of rain that infiltrates into the waste is to use temporary plastic tarpaulins or HDPE geomembrane covers.

12.2.5. Liner and Leachate Collection Systems

Leachate must be managed so as to prevent contamination of soil, groundwater and surface water. Leachate management is best accomplished through the installation of a landfill liner (for example, compacted clay, geomembranes, or both) and the installation and operation of an engineered leachate collection/conveyance (removal) system which is presented at Figure 12.1 (page 52).

Landfill liners retard the movement of leachate into adjacent soils due to their low permeability. Landfill liners are usually comprised of either in-situ or re-compacted natural clay soils or geosynthetics (flexible membrane liners [FMLs]) or some combination of the two.

Natural soil liners should be clay soils with a low coefficient of permeability and sufficient thickness to significantly retard leachate loss to groundwater. The most common material used for flexible membrane liners is High Density Polyethylene (HDPE), but other materials such as Linear Low-Density Polyethylene (LLDPE) and polyvinyl chloride (PVC) are sometimes used.

Figure 12.4 Evaporation technologies: passive (top) and thermal (bottom)

Copyright Wehrle

Other materials used in liner systems are Geosynthetic Clay Liners (GCLs) and geotextiles/geocomposites. The most common high-performance liner type usually comprises (top to bottom):

- Separation geotextile;
- Leachate drainage layer;
- Protection geotextile (if required);
- HDPE Geomembrane; and
- Compacted Clay Liner (CCL)/GCL.

The range of performance can vary greatly, but two key principles need to be recognized:

- Minimising the leachate head on the liner through active leachate extraction minimizes the risk of leakage.
- Any liner incorporating a geomembrane and CCL/GCL will be vastly superior in terms of containment to a clay liner alone.

To prevent lateral drainage of leachate above the liner system, a leachate collection and conveyance system should always be installed. Leachate collection systems comprise perforated piping installed above the liner and sometimes in other locations within the waste mass to enable the leachate to be drained and pumped to any one of a number of leachate treatment options. Both gravity flow and pumped systems are used but pumped systems are usually preferred as they enable liner penetrations to be avoided. A leachate buffer system has to be installed to cover peaks from heavy precipitations and to balance and homogenize leachate in flow and level of pollution.

12.3. DISCUSSION OF LEACHATE TREATMENT

12.3.1. Basic Thoughts

The choice of a suitable leachate treatment system for a single landfill is a question which needs to be evaluated and answered upfront site-specifically based on the following:

- Size, lifetime and possible future extension of the landfill;
- Type of waste to be disposed (humidity);
- Climate zone – expected precipitation and temperature regimes;
- State law and local law regulations;
- Direct discharge to a receiving body of water;
- Discharge to publicly owned sewage treatment works;
- Future installation of advanced waste treatment processes like MBT;
- Organisational setup for operation of the landfill incl. leachate treatment; and
- Budget for investment and operational costs for at least three decades.

Nowadays proven leachate treatment processes are available on the market out of worldwide experience since the 1990s. Each installation of a leachate treatment system requires a specific, detailed and customized view on the needs of each site.

12.3.2. Treatment Technologies

A first step to create a suitable leachate treatment system can be the installation of a leachate collection lagoon or tank as a buffer system, which can be realized on ground (see Figure 12.2, left). An alternative can be over-/underground tanks made out of concrete or various types of bolted tanks. The volume of a buffer tank system should be min. 5 x of expected average daily volume of leachate production – the more the better.

Find below an overview of available leachate treatment technologies.

Aerated Lagoons and Evaporation Ponds

By adding surface aerators into the lagoons/tanks oxygen will be mixed to leachate to oxidize organic compounds (COD). As expected, the elimination of organic pollution from leachate is very limited (< 20%) and inorganic pollution such as ammonia will be kept untouched. On the surface of evaporation ponds often a silt layer generates that inhibits natural evaporation. These treatment technologies require long retention times, can cause a lot of additional issues like aerosols or odour etc. and consume a lot of space, which could otherwise improve the economics if used for landfilling instead.

On-site Physical-Chemical Treatment

Various physical-chemical treatment technologies have been tested to treat leachate since the 1980s worldwide. Often good results had been achieved in laboratory tests. In most of these processes liquid chemicals are added to leachate to partly take out the organic pollution as a separate sludge, which has to be disposed externally. Others are trying to oxidize organic pollution to uncritical carbon dioxide (FENTON, AOP, Ozone, etc.), which requires high quantities of oxidizing agents and/or energy (see Figure 12.3). Also, here inorganic pollution of leachate like ammonia often remains untouched.

Until now it has been shown in full scale installations that physical-chemical treatment processes require large amounts of consumables due to the very high concentrations in leachate in combination with its high buffer capacity. In addition, health and safety precautions for handling large amounts of chemicals are needed.

Out of the reasons above stand-alone physical-chemical treatment of leachate has been shown to be economically challenging. Nevertheless, this process is sometimes combined with other processes as a post treatment process for very specific needs of single pollutants.

Thermal Treatment - Evaporation

Evaporation is always a “separation” process: raw leachate will be divided into vapour and remaining residues contain all the pollution from leachate, which needs to be disposed of in an uncritical place.

Evaporation of water requires a large amount of thermal energy. Low level evaporation processes like passive evaporation in evaporation ponds or spraying uses energy from the sun for drying and is not suitable for humid climates (see Figure 12.4). More sophisticated and closed evaporation units are using external energy which might be available from landfill flares, from the degassing of landfills.

All evaporation processes are faced with high operational costs, heavy odour and aerosols. Due to the generally high level of salts in leachate all equipment have to be prepared to these corrosive environment.

Membrane Technology (Reverse Osmosis, Nanofiltration)

Membrane technology improved a lot since the 1980s in water science, water supply and waste water treatment. Similar to the evaporation process, membrane processes, like reverse osmosis (RO) or nanofiltration (NF), are also always a “separation” process: raw leachate will be divided into water to be discharged and to concentrate with remaining residues containing all the pollution from leachate, which needs to be disposed of in an uncritical place (see Figure 12.5).

Due to high retention rates for pollutants, using a defined barrier of a membrane with minimized pore sizes like reverse osmosis (RO), this technology was adapted to leachate treatment already in the 1980s with the first installations in a so called “plate disc” configuration. Overall improvements and developments of membrane technology in desalination over the past led to cheaper,

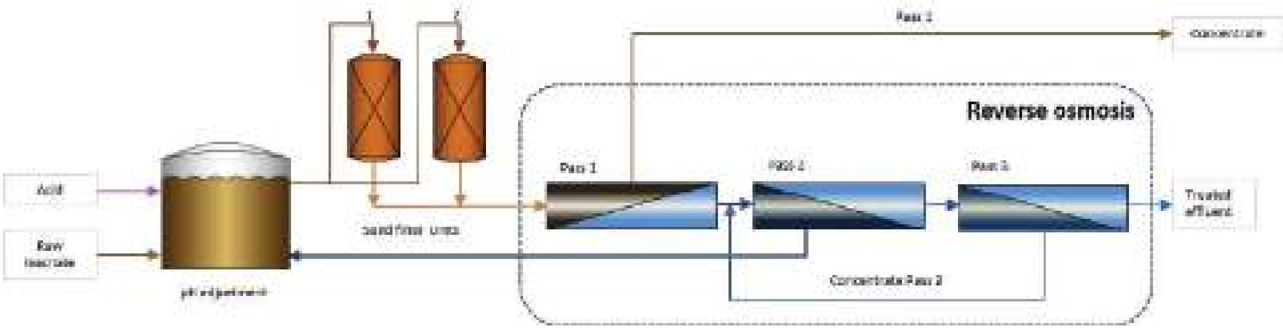

Figure 12.5 Reverse Osmosis (RO) technology: flow chart of a 2-pass unit

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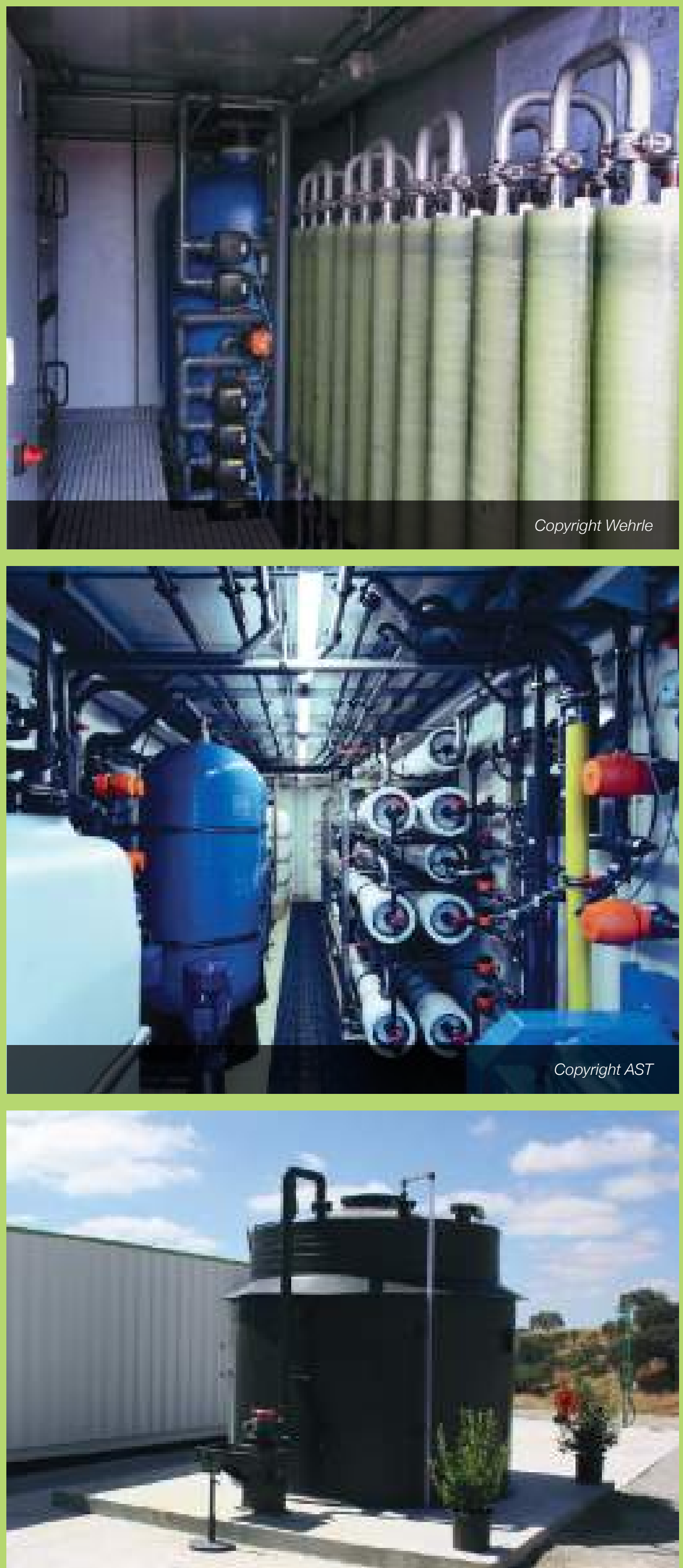

Figure 12.6 Stand-alone RO: plate disc (top) – spiral wounded (middle)– containerized (bottom)

comparatively more advantageous and modern spiral wounded membrane systems using standardized technical equipment. Depending on the requirements for effluent, several steps can be combined up to a 3-pass RO unit, where leachate "gets filtered three times" before final discharging.

Due to modular configuration suitable RO technology is available in standardized container sizes from various suppliers and can be adapted to each landfill site in the world easily and quick. Often it is common practise that remaining concentrate will be fed back to landfill due to missing or expensive disposal alternatives. An adequate engineering design for recirculation and reinfiltration of the concentrate should be done and must be site-specific.

RO technology can be an effective stand-alone installation for suitable leachate treatment and to meet highest effluent requirements (see Figure 12.6).

An interesting option in membrane technology application is Nanofiltration (NF) units – using a type of membrane which allow monovalent ions (e.g. salts) to pass through while achieving high retention rates for organic pollution but slightly lower than reverse osmosis membranes. However, in this case, and unlike RO technology, NF units are not commonly used in a stand-alone model and need to be combined with other treatment steps. NF units are used principally as a polishing step for biological or physicochemical treatment step.

GAC (Granular Activated Carbon)

The use of activated carbon is well known in environmental protection worldwide – even though not available in every country. With an adsorption process driven by diffusion, activated carbon can adsorb liquid or gaseous molecules on a very large solid surface offering a broad range of pore sizes.

For leachate treatment granular activated carbon (GAC) with irregular shaped particle sizes from 0.2 to 5 mm has shown best technical and economic performance – used in fixed bed pressure vessels constructed in steel or plastic, ensuring enough contact time to achieve high loadings of organic adsorption on the carbon (see Figure 12.7).

After achieving maximum adsorption rates the carbon needs to be changed. Depending on each country and its regulations and logistics either used carbon will be disposed externally or reactivated in special furnaces at 800°C – a service which gets offered by global suppliers of carbon.

Only in combination with a MBR upfront, the use of granular active carbon is effective and economical – supported by the solid free effluent of the MBR. The MBR "eliminates" all biodegradable pollution from leachate while the GAC polishes the effluent from MBR by adsorption of non-biodegradable organics down to the local discharge requirements.

Biological treatment SBR (Sequence Batch Reactor)

To fulfil discharge requirements for organic pollution (COD/BOD) and water toxic ammonia (NH4-N), a biological treatment process can be a sustainable solution. For nitrogen elimination, a biological process (with nitrification / denitrification) is also a suitable process. Biological treatment of leachate is always "eliminating" pollutants as much as possible. The biodegradable pollutants are effectively removed from the leachate. However, additional treatment is required for non-biodegradable COD

Figure 12.7 Granular activated Carbon (left) – stand-alone unit (center) – in combination with MBR (right)

(recalcitrant COD compounds) such as using activated carbon and/or nanofiltration, as well as handling of biological sludge that is produced in an excessive amount and needs to be disposed of in an uncritical place.

Classical biological processes like Conventional Activated Sludge processes (CAS) require large areas and substantial civil works (see Figure 12.8). Therefore, more compact biological processes where applied for the use in leachate treatment, for example the Sequence Batch Reactor process (SBR):

After adding leachate to the biological tank, several biological elimination steps (aerated, anoxic, settlement) take place in one single reactor – with moderate elimination rates in realistic plant sizes: organic elimination increases up to 60%, nitrogen elimination up to 80%. The discontinuous process of the SBR system has a limited flexibility for varying leachate loadings like a landfill is faced all over years due to precipitation. It is sensitive to temperature effects (winter, summer) and requires more or less constant concentrations of leachate in the inlet, which ends up in the need of very large buffer tanks upfront (typ. > 10 days daily leachate volume).

Due to the method of separation of treated leachate and biomass in a normal settlement step, SBR effluent contains small amounts of solids or biomass. This might cause further problems in post treatment, which might be needed to fulfil discharge regulations (e.g. for separation of salts).

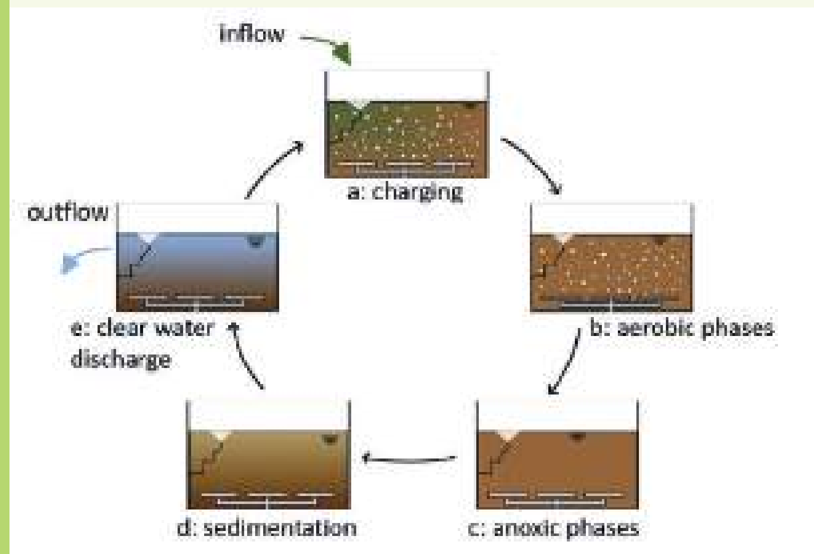

Figure 12.8 Biological "elimination" technologies: SBR process

Biological Treatment MBR (Membrane BioReactor):

Further improvement of biological treatment technology was achieved by combining the advantage of a biological treatment system with the advantages of membrane technology. A MBR consists of a bioreactor system and an ultrafiltration stage, being a highly loaded activated sludge process at the same time (see Figure 12.9). Instead of a settlement process like in CAS or SBR, biomass in a MBR will be separated from treated leachate with a membrane.

MBRs achieve highest pollutant reduction compared to other aerobic systems and require far less space and footprint using tubular side-stream or out-in submerged ultrafiltration membranes. Organic pollution will be eliminated up to a level above 80 %. Elimination rates for water toxic Ammonia of > 99.9 % are proven and shown in leachate installations worldwide on 5 continents. If needed the leachate treatment plants can be designed to eliminate also total nitrogen up to 99.9%. Effluent of a MBR is free of solids and ideally suited for further treatment steps.

MBRs are robust and handle variations of flow and concentration in leachate by dynamic and automated operation, modular design and configuration. Out of the reasons above MBR systems are nowadays – besides stand-alone reverse osmosis units – the most implemented leachate treatment process worldwide (see Figure 12.10).

However, non-biodegradable COD (recalcitrant COD compounds) require additional treatment, such as using activated carbon and/or nanofiltration, as well as handling of the MBR biological sludge that is produced in excessive amount and needs to be dewatered and disposed of in an uncritical place.

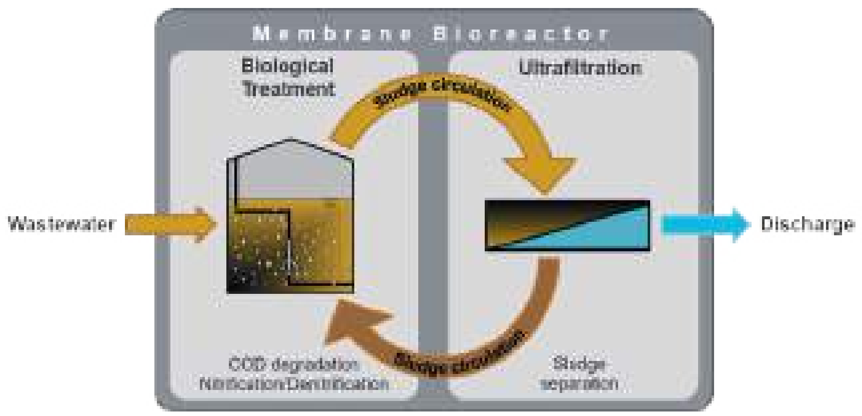

Figure 12.9 Biological "elimination" technologies: MBR systems

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Figure 12.10 MBR (left) - containerized MBR systems (right) *Copyright Wehrle*

12.4. CONCLUSION

Prevention of leachate migration and contamination of ground and surface water can be accomplished through implementing effective operational practices and engineering controls at the landfill facility. Operational practices to divert local precipitation and surface water run-on to the waste mass are an effective means to reduce the quantities of leachate generated.

Depending on the local requirements a single process might not achieve the requested results to cover all local environmental, economic and social needs. Whereas the dimensioning of a leachate treatment plant mainly depends on the actual load and quantity of the leachate, the determination of the appropriate process or process combination is above all a matter of observing the respective limit values. The processes available may hence be classified according to the discharge limits fixed.

CHAPTER 13 ODOUR CONTROL

CHAPTER 13 ODOUR CONTROL

13.1. INTRODUCTION

Odour can occur at a sanitary landfill from certain odorous loads of wastes and as a result of the biodegradation of wastes within the landfill. Odour may be associated with load transport, the tipping face, leachate and landfill gas (LFG). The emphasis when considering odour control in landfill design and operation should be on utilising efficient operating and management practices, backed up by robust environmental management systems.

The sources of landfill odours are chemical compounds, present at trace levels in air. Leachate odours may result from uncontrolled leachate seeps from the waste mass, or from leachate holding ponds or lagoons present on site. LFG is primarily comprised of methane and carbon dioxide - both odourless gases. However, the trace constituents present in LFG include compounds offensive to the human nose and these odours become noticeable when excess LFG escapes from the surface of the landfill, flows from passive vents, or leaks from piping of active LFG collection systems. Other sources of odour are waste hauling vehicles.

The odour typically associated with the waste tipping face is also distinctive, and differs from LFG odour. Depending on site location and available buffer distance, odour can be a greater or lesser problem at a landfill site. However, where a site is within approximately 500m of neighbours, odour control is usually an important consideration. Control of odours from all these sources is important for community relations as well as for worker comfort. Through effective operational and design elements, landfill odours can be controlled effectively.

13.2. ODOUR CONTROL MEASURES

The key odour control measures at a sanitary landfill are:

- Restrictions on the acceptance of odorous waste
- Restrictions on the acceptance of potential odour generating wastes
- Properly covering the waste
- Limiting the size of the working (tipping) face
- Positively extracting, collecting and treating landfill gas (by flaring or for beneficial use)
- Controlling leachate, especially ponded leachate
- Using odour control sprays where appropriate
- Use of buffer zones (maximizing separation distance)
- Careful planning of working face location.
- Establishing an onsite weather station
- Reduce the time waste hauling vehicles are waiting in line

13.3. DISCUSSION OF ODOUR CONTROL MEASURES

13.3.1. Restrictions on the Acceptance of Odorous Wastes

At sites where odour is a potential issue for neighbours (typically urban or sub-urban sites with limited buffer distance available), a key measure that can be adopted is placing restrictions or conditions on the acceptance of odorous waste. This can greatly reduce odour potential, but is not always possible if the landfill is the sole facility in the area.

Measures which may be considered include:

- Non-acceptance of highly odorous wastes without adequate stabilisation or pre-treatment (e.g. use of lime for septage wastes)
- Limiting waste acceptance to appropriate times of the day
- Use of special procedures, such as pre-arranged excavation of special burial pits, and having cover material and odour suppressant sprays ready at the time of waste delivery.

13.3.2. Restrictions on the Acceptance of Potential Odour Generating Wastes

Certain wastes do not have odours, but when landfilled with other wastes especially organic wastes, biochemically react and create odours. One of the most common problematic wastes is gypsum wallboard from construction and demolition waste streams. This material when exposed to organic wastes creates a very odourous hydrogen sulfide in landfill gas. To avoid this problem, one could either severely limit or not accept this material, or if possible, dispose of this material in a segregated area with only inert wastes to avoid landfill gas generation.

13.3.3. Properly Covering Wastes

Once layers of waste have been placed and properly compacted in the landfill, soil or sometimes other alternates including biocovers should be placed over all the waste the same day and generally, progressively throughout the day. This soil cover serves to limit the escape of odour and limits the infiltration of rainfall that may enhance the gas production process within the landfill. In addition, the daily cover soil serves to adsorb odours as well through biochemical (biofiltration) processes and soil cover layers have been shown to be effective in oxidizing LFG and its components. Odour control can be enhanced by the addition of biocovers to soil covers.

Intermediate and final cap soil layers also play a key role in odour control. Research has shown the effectiveness of soil layers and the bacterial/microbial communities they contain in oxidizing methane and other LFG constituents. Simply put, applying continuous thick soil cover at regular intervals can have a major benefits for odour control, especially when combined with an active LFG extraction and treatment system.

13.3.4. Limiting Working Face Size

In general, the working face of the landfill should be minimized in line with the size of the operation. As a general guide it should be no more than 600 m² (say 30 metres wide and 20 metres in length). This serves to minimise the surface area from which fugitive refuse odours can escape.

13.3.5. Properly Vent, or Collect, Extract and Treat Landfill Gas

Leaving aside consideration of the hazards associated with LFG, because the trace constituents of landfill gas are the odour-causing agents, proper control of LFG emissions usually contributes significantly to the effective control of odour. Passive LFG systems simply vent LFG to the atmosphere. If such a system is used (for example at small or closed sites) attention should be given to the direction of prevailing winds in the design and location of vents in order to minimize odour nuisance to property neighbouring the landfill. In general passive vents will not be effective as an odour control measure.

The most effective method of controlling odours from landfill gas is to design and install an active LFG collection system, with comprehensive coverage of the waste mass, and to subsequently flare or otherwise utilise the LFG. Typically, such active extraction systems include drilled vertical wells (spaced at about 1 well per 30m radius without significant overlapping), or horizontal trenches with connective piping.

A vacuum is applied to the well and pipework system using a blower (extraction fan). Each drilled vertical or passive gas well when spaced correctly should be capable of extracting of the order of 70m³/hr of landfill gas. Smaller "spike" gas wells can be installed quickly and in areas that are awkward for conventional drilling and can prove very useful for local control of odour.

It is desirable to install an active LFG collection system as soon as practical. The design of the landfill filling sequence should identify when the well or trench can be installed and connected to the vacuum. Care must be taken to not damage the landfill gas wells or piping as landfilling of waste is occurring around them.

Collected LFG is usually treated either by combustion in a flare, or in LFG engines for energy production. Modern enclosed (tube) flares can burn high volumes of LFG at up to 1000°C with a residence time of typically 0.3 seconds and such a treatment option will effectively eliminate both the hazard and the odour associated with LFG and the trace organic compounds it contains.

13.3.6. Control of Leachate

Leachate can also be a significant source of odour at a sanitary landfill due to decomposing organic material and LFG dissolved in the leachate. Odour problems from leachate primarily arise due to leachate seeps from the side slopes of the landfill itself, or from leachate holding/treatment lagoons (if present at the facility). When leachate seeps occur, they should be filled or covered, and sources repaired by improving the internal drainage of the landfill locally to prevent further breakout and to prevent runoff to nearby water bodies. The use of run-on and run-off controls and well-designed leachate management systems can lessen the frequency and severity of leachate seeps.

Maximising internal drainage within the landfill through "windowing" of cell area and through providing vertical drainage via LFG wells, as well as ensuring intermediate cap layers slope into the landfill rather than out of it, are all keys to minimising leachate breakout. In general, minimizing the leachate head over the bottom liner of the landfill and removing leachate routinely as it accumulates is an important control to avoid leachate head build-up and hence an increased risk of surface leachate breakouts and surface seeps. Odours from leachate holding ponds or treatment lagoons can be reduced through aeration, chemical treatment, or the use of physical covers including floating covers. In addition, leachate holding ponds (where used) should be located to maximise the available buffer zone (separation) to neighbours Leachate pumping stations, piping systems and manholes also are sources of odours. Gases within these systems should be collected through the same vacuum system used for the collection of LFG.

13.3.7. Odour Control Sprays

Chemical odour control agents are available for use at landfills and can be a very useful for localized odour control, particularly at the tipping face and for special burials of odorous waste. Odour sprays can provide an odour control "curtain" at the landfill perimeter, be applied direct to odorous loads, or used when old waste has to be excavated (for example to establish a retro-fitted LFG extraction system).

Odour control chemicals come in a range of formulas and can mask or chemically neutralize odour-causing compounds. Odour control agents when used in conjunction with a control system based on wind direction can prove useful in masking, scenting, or neutralizing the odour and altering its hedonic tone, thus reducing the risk of odour nuisance. Odour control sprays can, however, be costly and may not be effective over long durations or under certain weather conditions (such as during high winds or heavy rainfall).

13.3.8. Landscaping and Buffer Zones

This approach can be used in conjunction with other controls to as an adjunct addressing odour problems. Odour nuisance in some cases is based on or exacerbated by perception. The visual impact of a landfill can increase the odour awareness of sensitive receptors. It is likely that breaking the line of sight has the psychological effect of lessening perception and is therefore a positive control for landfill operators that can be employed along with other measures – often a minimal cost. Measures can include mounded soil berms, landscape planting or panel fencing.

In addition, separating the working area from receptors using a buffer zone (sometimes created within the site), can be very beneficial in relation to odour management. However, it should be noted that both landfill face (waste) and LFG odour can potentially be detected over significant distances under adverse climatic conditions.

13.3.9. Working Face Location and Special Burials

A simple and effective way for the operator of a landfill to reduce odour complaints is to locate as far as way as possible from inhabited areas and sensitive receptions, including potentially moving daily operations on the site to suit weather conditions – particularly wind direction. Even though sanitary landfill odours can be reduced by employing the toolbox of control techniques described, a certain level of odour will inevitably exist at the landfill working face. This can be significantly exacerbated by some types of odorous waste received. The availability of extra void space and hence alternative tipping face locations can help the operator to change the working face if wind direction changes. The use of (planned) special burials for known odorous loads as well as active control of such load odour using odour control sprays are also very effective techniques that can be added to careful selection of disposal location.

The level of odour at a site may vary seasonally, and wind direction will determine what neighbouring property could be affected by landfill odours. Careful planning of working face location to accommodate wind location and seasonal variations in odour production can serve to reduce the nuisance to properties surrounding the landfill. Accepting certain types of odorous waste only by arrangement (i.e. during certain hours), adopting immediate burial and covering practices for odorous and restricting the quantity and type of odorous waste, are all key control methods.

13.3.10 Establishing an Onsite Weather Station

Establishing an onsite weather station is necessary to gather important information that will be used to determine what changes to landfill operations need to be made to reduce the potential for odour issues. Wind direction, wind speed, barometric pressure changes, humidity, rainfall all have an effect on landfill operational decisions for odour issues.

13.3.11 Reduce Haul Vehicle Wait Time

Waste hauling vehicles can be odorous, especially certain ones that carry special wastes such as septage wastes or sludges. It is desirable to get them onsite and offsite as quickly as possible to reduce odour exposure.

13.1. CONCLUSIONS

Controlling odours at a sanitary landfill is best attained through a careful approach to the full range of operational, engineering and design controls. At most sites a key control can be introduced at the planning stage through maximizing buffer distance in and around a site. In most instances a minimum buffer distance to neighbours (including internal buffer) of 500m is recommended.

The next two key controls on odour are limiting the type, timing and method of acceptance of odorous wastes. Added to this are direct odour control methods including special burials, use of cover soil, and odour sprays. Beyond this, a hierarchy of controls exists, starting with effective cover practices and LFG control, through to specific measures for dealing with leachate seeps and ponds.

Dealing with factors outside of the landfill operator's control such low barometric pressure and wind direction to sensitive receptors, require the operator to implement a range of measures to manage odour effects. In most cases it is possible to prevent odour nuisance becoming an issue with the local community, but to achieve this, commitment is required from landfill management and operating personnel on a day to day basis for each control to work properly and efficiently. Careful planning from management personnel is the starting point for all odour control activities. As odours occur, it is best to identify the source and duration, and then apply corrective measures or work practices to control LFG and odour.

CHAPTER 14

LANDFILL GAS MANAGEMENT

CHAPTER 14 LANDFILL GAS MANAGEMENT

14.1. INTRODUCTION

Landfill gas (LFG) is generated in all landfills where organic waste is disposed of. LFG is a natural by-product of the anaerobic biological decomposition of the organic portion of solid waste. Landfill gas consists primarily of Methane (CH_4) and Carbon Dioxide (CO_2), but may contain many other constituents in small quantities, including nitrogen, oxygen, sulphides, disulphides, mercaptans, volatile organic compounds (VOCs), ammonia, hydrogen, carbon monoxide, water vapour, and many other organic gases.

14.2. Landfill Gas Generation

14.2.1. Phases of Landfill Gas Generation

Decomposition of waste in a landfill occurs in several distinct phases, related to conditions in the landfill. The primary phases are:

Phase I – Aerobic
Phase II – Anaerobic Non-Methanogenic (Acetogenic)
Phase III – Anaerobic Methanogenic (a non-steady phase)
Phase IV – Anaerobic Methanogenic
Phase V - Aerobic

Aerobic decomposition begins immediately the organic waste is disposed in the landfill and continues until all of the entrained oxygen is depleted from the voids in the refuse and from within the organic material itself. Aerobic bacteria produce a gaseous product which is characterized by relatively high temperatures, high CO_2 content, and no CH_4. Other by-products include water, residual organics, and heat (in such a quantity to increase the landfill temperature to typically 55-70°C). Aerobic decomposition may continue for 6 or more months depending on the proximity of the waste to air at the landfill surface. This time frame for aerobic decomposition may be shortened if CH_4-rich LFG from below flushes oxygen from voids in the disposed refuse.

After all entrained oxygen is depleted from the refuse, decomposition enters a transitional (acetogenic) phase during which acid-forming bacteria begin to hydrolyse and ferment the complex organic compounds in the refuse.

Decomposition then enters a long anaerobic period which can be divided into several distinct phases. During this period CH_4-forming bacteria, which thrive in an oxygen deficient environment, become dominant. Anaerobic LFG production is typified by somewhat lower temperatures (35° to 55° C), significantly higher CH_4 concentrations (40 to 60%) and lower CO_2 concentrations (35 to 45%). Anaerobic gas production will continue until all of the biodegradable material is depleted or until oxygen is reintroduced into the refuse, which returns the decomposition process to aerobic conditions. A return to aerobic decomposition does not stop LFG production, but will retard the process until anaerobic conditions resume.

14.2.2. Landfill Gas Generation Volume

LFG will be generated in all landfills containing organic (decomposable) materials, although the volume of production may vary widely over time and landfills. The total a mount of LFG generated over the entire decompositional life of the landfill is mostly a direct function of the total quantity of organic material contained in the landfill, with some components decomposing rapidly, some at a moderate rate, and some over a much longer period of time. Therefore, the quantity of refuse available for decomposition is the primary factor in determining the total volume of LFG that will be generated over the life of the facility.

14.2.3. Landfill Gas Generation Rate

The rate at which LFG is produced is primarily a function of the types of waste involved, e.g., rapidly decomposing food waste versus longer-lasting paper, cardboard or other organic waste. The overall rate of decomposition for all refuse components in a given section of a landfill also is influenced by a variety of other factors, such as moisture content, temperature, refuse particle size, site configuration, compaction and pH. Basically, the better the conditions within a landfill are for the anaerobic bacteria, the faster the decomposition will take place, resulting in a faster overall LFG generation rate build-up.

The optimum moisture content for LFG generation is approximately 60%. In areas of low to moderate rainfall the moisture content of the incoming and in situ waste is typically significantly less than this optimum moisture content. Therefore, recirculation of leachate can have significant benefits in optimizing landfill gas production. However, to avoid potential instability problems leachate recirculation should not increase pore water pressures within the waste mass.

14.2.4. Landfill Gas Composition

The typical constituents of LFG and the usual concentrations at which they are observed are:

Methane (CH_4)	40 to 60%
Carbon Dioxide (CO_2)	35 to 45%
Oxygen (O_2)	< 1 to 5%
Nitrogen (N_2)	<1 to 5%
Hydrogen (H_2)	< 1 to 3%
Water Vapour (H_2O)	1 to 5%
Trace Constituents	< 1to3%

Each of these constituents is discussed in more detail below.

Methane (CH_4) - is one of the two the main by-products of anaerobic decomposition. It is a colourless, odourless, tasteless gas which is lighter than air, relatively insoluble in water, and is explosive at concentrations of 5 to 15% by volume in air (the explosive range.)

Carbon Dioxide (CO_2) - is a by-product of both the aerobic and anaerobic phases of decomposition. It is also colourless and odourless, but is heavier than air, non-combustible, and highly soluble in water.

Oxygen (O_2) and Nitrogen (N_2) - oxygen and nitrogen are typically found in LFG samples. Typically, the combined volumes of oxygen and nitrogen remain in LFG are less than 10% and their ratios are similar as in air, but, with higher proportion of nitrogen. High oxygen and nitrogen concentrations are typically a result of air intrusion through the cover of the landfill, air leaks into a LFG recovery or control system, or air leaks in the sampling train during collection of LFG samples.

Hydrogen (H_2) - in landfills hydrogen typically is produced only during aerobic decomposition and the earliest stages of anaerobic decomposition. If hydrogen is present in anything more than trace concentrations in a mature landfill, it may indicate that areas of the site are not in the mature LFG generation phase for one reason or another.

Water Vapour (H_2O) - LFG typically is saturated with water vapour. The water vapour in LFG comes from water in the landfill that becomes entrained in the gas. Water vapour that condenses from LFG is the primary component of the condensate which forms in gas wells and extraction pipework. Consideration must always be given to proper handling and disposing of condensate as part of any LFG management effort.

Trace Constituents - LFG typically also contains small quantities (usually less than 1%) of volatile organic compounds (VOCs), and various other trace compounds. The presence of trace compounds in LFG usually is primarily due to the disposal of waste containing these compounds into the landfill. However, some may also be present because of natural decomposition processes within the landfill (e.g., hydrogen sulphide (H_2S) from the decomposition of gypsum board).

As many as 150 different compounds, mostly in the parts per million (ppm) or parts per billion (ppb) ranges have been identified in LFG, although not all landfills will have all of these compounds in their LFG. These gases may include harmful, toxic, or even carcinogenic compounds such as vinyl chloride, benzene, toluene, xylene, perchloroethlyene, carbonyl sulphide, siloxanes and various other chlorinated and fluorinated hydrocarbons. Other trace compounds found in LFG include mercaptans, which cause the distinctive odour associated with LFG.

The components of LFG are thoroughly co-mingled as they are produced during the decomposition process or as they move through the landfill, and will not separate into separate gases to flow in different directions.

14.3. LANDFILL MIGRATION AND EMISSIONS

Once the LFG has been generated, the forces of convection (movement from areas of higher to lower pressure) and diffusion (movement from areas of higher to lower concentration) may cause the LFG to move through and out of the landfill via the "path of least resistance". If the LFG moves out of the landfill into the surrounding soils it is called "migration". If it moves out of the landfill through the landfill cover into the atmosphere it is called "emissions". In either case, the LFG can have significant impacts on the environment and human health and safety. Some of these impacts are discussed below.

Explosion and Fire - One of the two major constituents of LFG is CH_4. CH_4 is a colourless, odourless gas that is explosive in concentrations ranging from 5% (the lower

'There are documented cases of spontaneous LFG explosions and fires causing death, injuries, and property damage.'

CHAPTER 14 LANDFILL GAS MANAGEMENT

explosive limit or LEL) to 15% (the upper explosive limit or UEL) by volume in air. At concentrations above 15% by volume, CH_4 is flammable. LFG may be explosive when all of the following conditions are met:

- The concentration of CH_4 is from 5 to 15% by volume in air.
- The gases are in an enclosed space.

There are documented cases of spontaneous LFG explosions and fires causing death, injuries, and property damage. The presence of carbon monoxide (CO) in landfill gas is a useful indicator of the presence of a fire.

Toxicity - LFG may contain toxic or carcinogenic compounds. Although these compounds generally do not pose a threat to human health or safety when confined to the landfill, their release into the atmosphere or the groundwater may create a potential health hazard. Therefore, LFG may present toxic hazards, both acute and chronic.

Acute toxicity may be of concern if trace constituents (mostly notable H_2S) are present in sufficient concentrations. Although H_2S is typically found in LFG at concentrations of only a few ppm, it has been documented in some landfills at concentrations above 3,000 ppm. H_2S has been shown to be deadly to humans at concentrations as low as 100 ppm. If LFG at a site has H_2S concentrations anywhere near these levels, an unprotected worker entering any enclosed structure into which the LFG has migrated could result in a fatality.

Chronic toxicity due to long-term exposure to LFG also may be a hazard. Many of the trace constituents of LFG are known or suspected human carcinogens. Some of the compounds that have been found in LFG at concentrations above their recommended long-term exposure toxicity thresholds and particularly at sites where industrial wastes are disposed of, this issue should be carefully examined.

Asphyxiation - both of the major components of LFG, CH_4 and CO_2, are asphyxiates. In closed structures or areas where LFG could potentially accumulate, LFG may present an asphyxiation hazard.

Air Pollution - many of the trace compounds found in LFG are known as constituents commonly found in smog or as reactants in smog formation. Therefore LFG may be a contributor to local air pollution.

Global Climate Change - CO_2 is a well-known greenhouse gas (GHG). Because landfill CO_2 is not derived from fossil fuel, but rather is part of the natural carbon cycle, it is typically not considered a contributor to global climate change. However, due to its higher infrared absorption capacity, CH_4 is actually a much stronger greenhouse gas than CO_2 by a factor of 21 or even more (on a mass basis) in terms of global warming potential. Because of the CH_4 contribution, uncaptured and uncombusted (fugitive) LFG is considered potentially a significant contributor to global climate change.

Odours - odours associated with LFG are a well-documented issue. The odours are due to many of the trace compounds found in LFG, particularly mercaptans and HsS.

Vegetative Stress – LFG migrating through soils can displace air in the interstitial soil spaces. If there are any plant roots in the area, the plants may suffocate and die.

Groundwater Contamination - many of the VOCs often found in LFG are water soluble. In addition, dissolved CO_2 from LFG may form carbonic acid, which weathers formation minerals causing increases in groundwater hardness and alkalinity.

14.4. LANDFILL GAS AND CONTROL

Due to the potential impacts described above, all landfills of significant size (nominally >1Mt waste capacity) should have LFG collection and control systems installed that are designed and operated to minimize both LFG migration and emissions. At smaller sites sufficient LFG control may be achieved by passive venting. However, even small sites may warrant further control measures and each site should be carefully assessed as LFG control requirements are very site-specific.

LFG control is a term that encompasses all methods for controlling movement of LFG, including active collection, barriers, passive control and monitoring. The purposes of a control system include:

- Controlling subsurface LFG migration
- Controlling surface emissions and nuisance odours
- Protecting groundwater
- Controlling fires / fire risk in the landfill waste mass
- Collecting LFG for its energy benefit
- Protecting structures
- Reducing vegetative stress.

A note on hazard:

LFG can present very real and immediate risk and there are documented cases of fatalities due to LFG at landfill sites. Never sniff vents or wells – this could be fatal. Similarly, never attempt to make pipe connections without assessing risk and appropriately isolating the area.

LFG control methods can be divided into two separate system types, which are:

- Passive venting and/or barrier system (sometimes with flaring capability)
- Active collection and flaring or beneficial use systems.

Figure 14.1. Landfill gas reception compound

Figure 14.2. Landfill gas enclosed flare

14.4.1. Passive Venting Systems

No active mechanical means are employed for a passive venting system . In the main, the pressure gradient created by gas generation within the landfill moves the gas toward a well or trench, which then intercepts the gas and conducts it to the surface.

There are two basic types of venting systems:

- Internal vents
- Perimeter trench vents.

Passive systems can be effectively used to control LFG migration, particularly at smaller or older sites. Passive venting alone should be avoided where practicable as the emissions will continue to contribute to global warming despite reducing the problems associated with LFG migration.

14.4.2. Active Control Systems

An active system uses a blower (extraction fan) to create a vacuum (Figure 14.1) within the landfill and withdraw the LFG via a network of wells/trenches and pipework. The typical components of an active LFG control system include:

- Vertical gas extraction wells
- Horizontal gas collection trenches
- Collection piping to move the gas to a central location for processing
- Condensate traps and handling equipment
- Blowers or compressors
- Water knockout tanks, dehydrators or other scrubbers
- "Candlestick" or enclosed flares (Figure 14.2)
- Other facilities to process the gas, and gas to energy equipment.

Active systems typically provide the most effective form of control for LFG emissions and are a key feature for sanitary landfill operation at sites of significant capacity.

14.5. LFG MONITORING

To provide assurance that excessive LFG migration and/or emissions are not occurring, or to test the efficacy of an existing LFG control system, all landfills should have LFG monitoring systems. The type of monitoring system employed tends to be site-specific, depending on the issues that LFG poses. Typically different monitoring systems are used for migration and emission monitoring.

14.5.1. LFG Migration Monitoring

There are several aspects of LFG migration monitoring systems:

- Surface emissions monitoring
- Off-site migration monitoring systems
- Structures migration monitoring systems.

a. Surface Emissions Monitoring

Surface emissions monitoring using a FID or similar device is a key check on the effectiveness of the landfill cap and extraction system that together form the main control and management component for LFG at a site. A build up in surface emissions of LFG can provide early warning of the need for changes or improvements in cap or LFG system implementation and possible offsite odour or LFG migration issues.

b. Off-site Migration Monitoring

These systems typically are employed to monitor for CH_4 concentrations at a landfill site property boundary. They typically consist of a series of monitoring wells (Figure 14.3) or probes spaced at intervals around the site.

The spacing and positioning of the LFG migration monitoring wells is very important. In some places, arbitrary distance criteria (e.g., 300 meters) between probes have been mandated. However, because the probes only monitor discrete points, they may not truly indicate all migrating LFG. It is important to consider what is to be protected and the nature of site conditions in selecting the location for LFG migration monitoring probes.

c. Structures Migration Monitoring

Depending upon the location and construction of a structure, the risk for accumulation of LFG within it needs to be considered and may vary considerably. Structures on a landfill site, or near a landfill, particularly those involving enclosed spaces, should be evaluated for exposure to LFG migration. The factors that should be considered in the evaluation include:

- Form of construction
- Subsurface conditions
- Surface conditions
- Subsurface connections
- Existing LFG monitoring and/or control systems or devices
- Distance from LFG source

For any structure where migrating LFG poses a risk, whether an active control system is in place or not, a permanent or portable CH_4 monitoring system should be employed. There are a number of permanent and portable combustible gas indicators on the market.

14.6. LANDFILL GAS UTILIZATION

Though LFG can present a hazard to human health and safety and the environment, it can also be a very significant asset in relation to the energy potential of the CH_4 that it contains, and hence its potential for use as a fuel.

The primary utilization modes for LFG which have been implemented successfully on a broad-scale are:

- On-site generation of electric power using LFG as a fuel within an internal combustion engine, gas turbine or steam turbine generator.

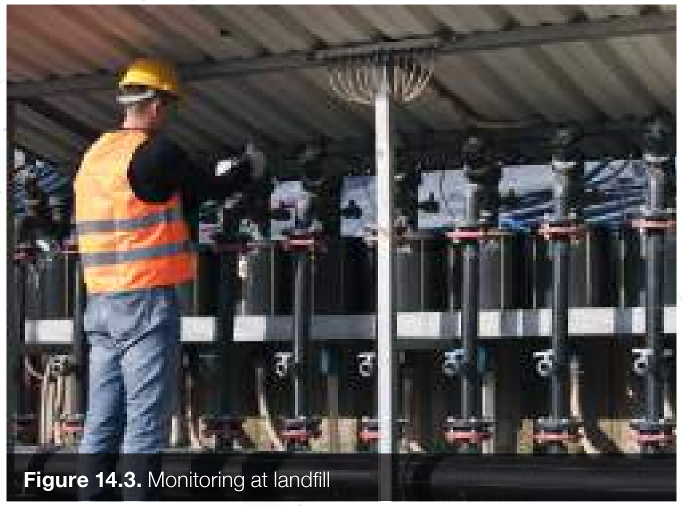


Figure 14.3. Monitoring at landfill

Figure 14.4. Gas engines

Figure 14.5. Greenhouse heated by LFG

- Fuel gas for direct sale to industrial fuel gas consumers.
- Pipeline quality gas for sale to utility companies.

Each of these technologies is discussed in more detail below.

14.6.1. Electric Power Generation

The most common energy application for LFG is on-site generation of electricity using raw or partially processed LFG as a fuel. Typically, the LFG is used in a reciprocating internal combustion gas engine (Figure 14.4) or gas turbine driving an electrical power generator. Micro turbines have been used at a number of facilities and there are a few facilities that use the LFG as boiler fuel for a steam turbine generating facility as well.

Typical LFG clean-up for electric power facilities consists of filtration and mechanical dewatering, but treatment systems to remove H_2S and/or siloxanes is becoming more common in some locations as experience shows that a cleaner gas fuel can result in substantially reduced corrosion and reduced maintenance costs over the life of the equipment.

14.6.2. Direct-Use

In this application, the collected LFG typically is minimally processed and then sent to a nearby end-user (Figure 14.5), through a dedicated pipeline. The processing required to produce fuel gas from LFG is relatively minimal. It may range from selling the gas in its raw form, to the removal of moisture on up to the additional removal of siloxanes, H_2S, and/or non-methane organic compounds (NMOCs).

This latter procedure is approximately equivalent to the pre-treatment step that precedes the production of pipeline gas.

14.6.3. Pipeline Quality Gas

The production of pipeline quality gas from LFG requires more extensive processing in order to remove all virtually moisture, trace organic compounds, CO_2, and air from the raw LFG. This results in virtually pure CH_4, with a good calorific value.

Of particular concern to many gas utility companies is the presence of halogenated compounds in raw LFG. Some halogenated compounds are not destroyed by combustion and may present a danger to consumers if they are released through a home gas stove or heater.

The production of pipeline quality gas from LFG is typically performed in two steps. The first step, known as pre-treatment, is the removal of moisture and trace components by refrigeration, dehydration, filtration, adsorption, or other processes. The second step is to separate the CO_2 from the CH_4 by one of the many processes commonly used for that purpose in the petroleum industry.

14.6.4. Other Potential Uses of LFG

Some other potential uses of LFG are presented below:

a. Vehicle Fuel, Compressed Natural Gas (CNG)

Purified LFG may be compressed under pressure to approximately 3,000 pounds per square inch (psi) and is referred to as CNG.

b. Vehicle Fuel, Liquid Natural Gas (LNG)

LFG may be purified, cooled (to approximately minus 260ºF), and compressed to a liquid form. When natural gas or LFG is compressed into a liquid form, it is known as LNG.

c. Chemical Feedstock

To date, no practical application has been implemented using LFG as a chemical feedstock. The most likely use would be the utilization of the CO_2.

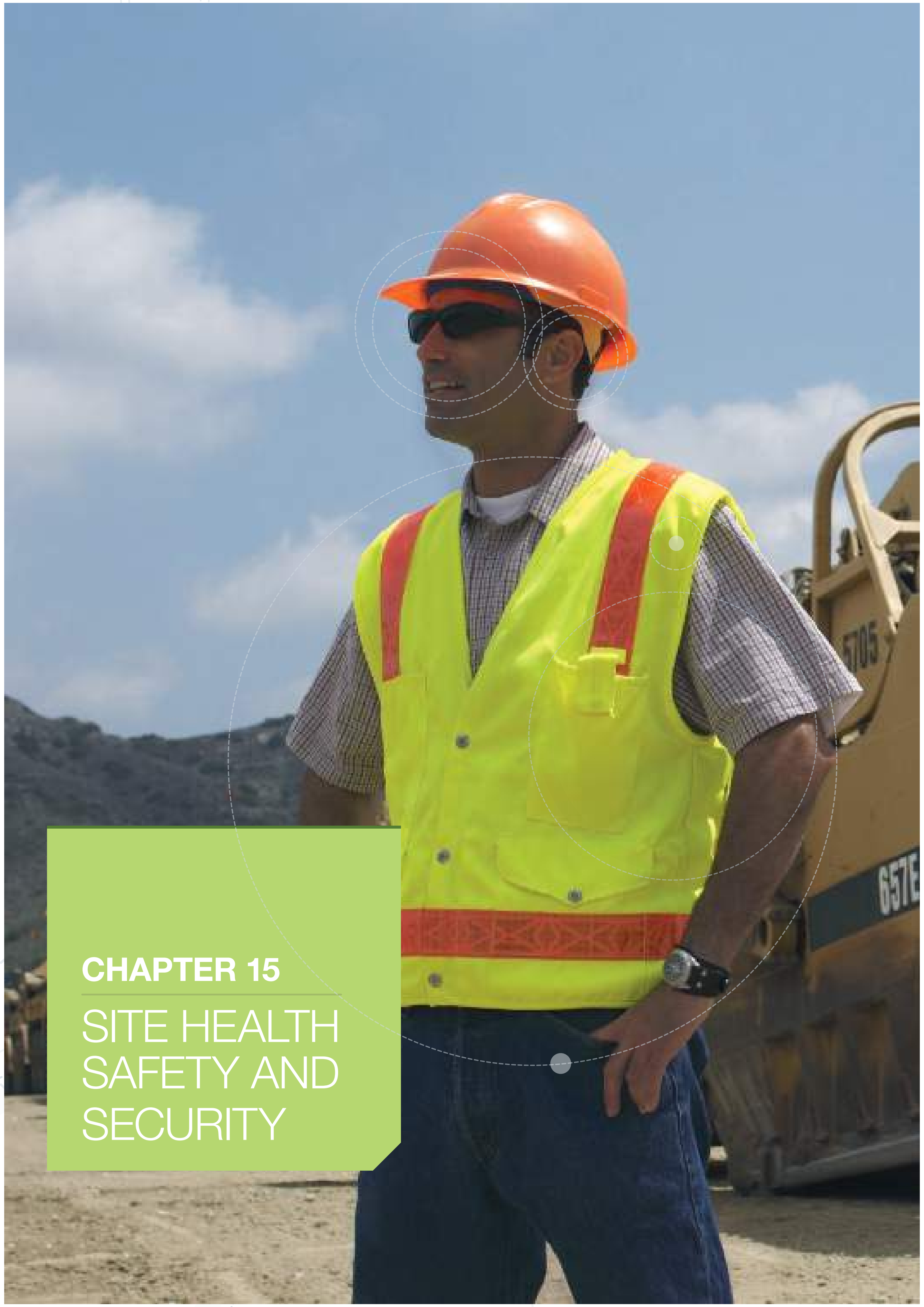
14.7. CONCLUSIONS

LFG is a natural by-product of the decomposition of biodegradable solid waste. LFG represents a hazard at landfill sites due primarily to its explosive and asphyxiation risk. Chronic exposure to LFG can also result in other contaminants (e.g. H2S, vinyl chloride) being of concern even though they may be present in relatively low concentrations.

Management of LFG requires careful consideration of site-specific issues and risks, but for a range of reasons an engineered LFG extraction and destruction system is an essential part of the engineering of most landfills accepting significant amounts of degradable waste. However, the design of such systems is beyond the scope of this Guide.

Careful monitoring of confined space areas and for LFG migration away from landfill sites is part of any comprehensive Landfill Management Plan.

LFG can be destroyed by combustion in an "candlestick" or enclosed flare to maximize destruction efficiency, but it can also be used to produce energy – something that is increasingly becoming the norm at larger landfill sites.



CHAPTER 15
SITE HEALTH SAFETY AND SECURITY

CHAPTER 15 SITE HEALTH SAFETY AND SECURITY

15.1. INTRODUCTION

Sanitary landfill, as its name describes, is safety deposit of discarded materials that are handled so that they don't harm the people or the environment. Landfill is a hazardous place and all guidelines given on previous chapters, are in pursuing of the minimization of risk, either if it is for bird control or proper road network.

Like all industrial activities, there are inherent hazards associated with the operation of a landfill. Historically accidents at landfills have in the main resulted from the temporary nature of much of the site infrastructure – e.g., site roads, sharp bends and steep gradients – and because vehicles and machinery are often operated in confined areas and in close proximity to each other. Reversing vehicles are a significant problem, particularly where staff is required to cross the working area on foot or direct vehicles at the landfill face.

Minimisation of risk is done by a careful planning and evaluation of the risks faced on each site. We can group the following main areas of hazard as the following:

Landfill Specific Risks	Common Risks
Environmental Risks are those where broader effects are suffered, like: Leachate and flooding, Atmospheric emissions from Landfill Fire and Bio-gas, Epidemiological hazard.	Common Health Safety assessment: Many of the activities in the Landfill are similar to common activities Civil works and machinery maintenance are everyday tasks for landfill employees and contractors. Replication of standard rules from transport, construction and manufacturing industry's procedures can be instructed in the landfill regulations to minimise risk in well documented activities.
Personal Risks are caused by individual and can affect a limited number of peo-ple and can came from: Traffic, Biolog-ical hazards, Scavenging, Lack of knowledge, Gas leaks and caves in the Landfill.so they are associated to indi-vidual's damage.	

15.2. SECURITY

First step to take is to control who, where and when people is in the landfill. Although it is discouraged, the site planner should decide whether or not salvaging/scavenging will be allowed and regulate access to the site.

Scavenging is the separation and removal for re-use of items such as scrap metal. The practice is dangerous and interferes with the efficient operation of a landfill. Scavenging is perhaps the greatest single cause of accidents and fatalities at landfill sites. For these reasons, scavengers should be prohibited on all sites.

Commonly, a landfill will be separated from surrounding properties by fences and/or other barriers, i.e., ditches, bodies of water; extensive open space etc. and these to some extent provide a degree of security at a landfill site. However, 'site security' generally means achieving much more control than is represented by a simple fence or barrier. Site security includes controlling access onto the site and supervising the activities of all persons on-site.

Thus site security includes:

- Restricting entry to the site by using a fence or barrier all around the site and having one gate through which all vehicles and persons enter and leave
- The employment of appropriately trained staff (Figure 15.1) to control access to the site by vehicular and pedestrian traffic
- The maintenance of physical access control features and components such as gates, fences, bridges, moats and streams
- The surveillance and control of all on-site visitors, site users, and employees

Figure 15.1 What not to do

15.3. SAFETY

Site safety, is maintained and/or achieved through careful planning, the provision and utilisation of appropriate equipment, and through personnel training.

Accidents can be minimized by the implementation of safety and training programmes and by effective site management.

These programmes should include the following:

- Identification of potential sources of risk
- Assessment of the degree of risk from these sources
- Determination of procedures for addressing the risks
- Development of procedures to minimise accident/risks when they occur
- On-going monitoring to ensure proper implementation of safe working procedures

Site plant and all structures should be equipped with fire extinguishers. A well-stocked first aid kit should be available on-site and first aid training should be considered essential for one or more of the operating personnel who spends the majority of the working day on the site.

At least one person properly trained in first aid should be on site at all times.

CHAPTER 15 SITE HEALTH SAFETY AND SECURITY

At least one person properly trained in first aid should be on site at all times.

All of these procedures, as well as emergency response procedures, should be documented in the Landfill Management Plan and should be the focus of regular training of site staff.

It's recommended that Landfill Management Plan include graphical resumes of the protocols when possible so that reading facilitates retention of the protocols and facts.

15.4. EMPLOYEE TRAINING

Employees should be adequately trained in the safety aspects pertaining to the operational area and the implementation of the primary safety rules, examples of which are as follows:

- Do not permit those under the influence of alcohol or controlled substances to work on, or use the site.
- Do not allow horseplay or idle time in the tipping area.
- Do not make the first compacting pass over deposited wastes with the tractor or compactor in reverse (full containers may spray their contents on the operator with little warning).
- Do not permit trucks to discharge waste within 3 meters of others.
- Complete separation of mechanical discharging trucks from those which must be hand unloaded increases safety and decreases the area of tipping face required. Hand unloading will require less space between trucks but requires a great deal more time to unload.
- Only allow drivers to enter the disposal area. Ensure the spotter is not distracted by external activity.
- Smoking at the tipping face or exposed surface shall be prohibited and considered a violation of safety rules.
- Salvaging, if permitted on site, should not result in tipping face activity or the deposit of salvaged material on the deposited waste, especially near the active working face.
- All site personnel should be required to sign in and out each time they arrive or depart from the site.

15.4.1. Staffing Levels

All staff and users of the site should be effectively supervised. No site open to receive waste should be manned by one member of staff working on their own. Similarly no unloading of vehicles should occur in the absence of site staff or out of their immediate view.

15.4.2. HYGIENE FACILITIES

Good personal hygiene is essential to workers on landfill sites and hence hot and cold washing facilities must be provided. Locker room should be designed as a flow, dirty < > clean, where areas for pre-washing are separated from areas to clean and street clothing. Clean Lockers should be different from those of dirty ones, and be located in different rooms, so that we avoid contamination to be taken home. Showers should be in the middle of both areas.

Dirty clothing should be cleaned by the employer on the site or in appropriate facility.

All workers at landfill sites, including those employed temporarily by the operator or by contractors working on the site should have adequate protection against tetanus and infectious diseases. This protection must be kept up to date, with boosters given at 10 yearly intervals. The onus should be on the employer to ensure that these injections have been received by employees and to require appropriate assurances from contractors working on the site.

15.5. PERSONAL PROTECTIVE EQUIPMENT

As shown in Figure 15.2, all site users must be equipped appropriately. High visibility clothing should be provided and worn. Safety boots and/or wellingtons should be issued to all site workers. They should have steel toecaps and have a steel insert in the sole to resist injury from projections of glass, metal or other items in the deposited wastes.

Gloves should be issued as required. The type of glove should be puncture resistant and should be suitable for the relevant task, e.g., litter collection, vehicle fuelling, cold weather conditions. Safety helmets and eye protection should be available as necessary. Ear defenders should be available for those driving site machinery or working in high noise areas.

Figure 15.2 A properly dressed labourer at the landfill

Operatives at landfill sites work in all weather conditions and will need to be provided with suitable windproof wet weather clothing. In most instances, bright coloured jackets, shirts, coveralls or vests, sturdy shoes and gloves are considered to be essential. A strong management's lead in terms of personal safety is essential and establishes the basis for all landfill operations which cannot then be misinterpreted by others.

Some additional safety items as shown in Figure 15.2, which should be considered, are:

- Hard hats
- Steel mid-soled and steel-toe capped footwear
- Ear protection
- Dust masks
- Goggles or face masks
- Communication devices - air horns, whistles, intercoms, or radios

15.6. COMMON RISKS

Here we will briefly introduce some common risk that should be assessed in the operations handbook of the landfill:

- Slips, trips, or falls
- Material & Manual Handling
- Collapse
- Asbestos
- Airborne Fibres & Materials – Respiratory Diseases
- People being hit or run over by vehicles
- Falls from vehicles
- Vehicle overturns
- Language barriers

Common hazards to skin:

- corrosive
- irritating
- harmful
- sensitising
- Toxic or very toxic
- very hot or cold water temperatures
- not using hand washing products or barrier creams
- excessive hand washing or not drying them fully
- wet work – where hands are wet or in water for prolonged periods of time
- Exposure to the sun or ultra violet rays without effective application of adequate sunscreen
- Repetitive, excessive noise causes long-term hearing problems and can be a dangerous distraction, causing countless accidents

15.6.1. Fuel Storage

All fuel should be stored only in tanks located in bunded areas. The bunds should be constructed to be of a capacity of 110% of the contained tank (or 110% of the combined volumes in the case where more than one tank is present) and no taps, gauges etc should project beyond the internal side of the bund. All bunds should be waterproof. No drainage taps should be permitted in the bund and any retained water should be pumped out for disposal. Inevitably, when drainage taps are provided, they are often left open, completely negating the purpose of the bund itself. As a properly constructed bund will quickly fill with rainwater, it may be desirable that the bunded area is roofed.

All tank outlets should be adequately secured by locking mechanisms with a view to the prevention of vandalism.

Mobile re-fuelling equipment such as fuel bowsers should generally not be left out on the landfill at night. Instead, they should be locked away in a surfaced and bunded area in either a site building or storage compound. Tank bunds and bowser storage areas are easily damaged in the landfill environment. Hence they should be subject to regular inspection by the site staff and repaired as necessary.

15.6.2. Construction, Repair and Maintenance in Confined Spaces

Construction, as well as repairs and maintenance to existing landfill facilities may mean working in enclosed (confined) spaces. Some examples of confined spaces are storm water pipes and manholes, sanitary sewer, manholes, and leachate control manholes. That is, spaces where natural ventilation is limited, and where gaseous contaminants can potentially make entry hazardous. Other instances are spaces where insufficient air may be present, and access or escape is potentially difficult.

Some of the confined space hazards to which a landfill employee may be exposed are as follows:

- Fire and/or explosion in the confined space due to the presence of methane in explosive concentrations with air (5-15% methane in air). The concentration of methane in landfill gas is typically around 50%.
- Asphyxiation due to inadequate oxygen supply is a very dangerous situation. This can result from anaerobic conditions, LFG build-up, and the presence of Hydrogen Sulphide (H_2S). At low concentrations H_2S

has an offensive rotten egg odour, but at higher concentrations it quickly numbs the olfactory senses such that the employee's nose – his first line of defence – can no longer detect its presence. This is a very dangerous situation and creates the potential for fatality. H_2S is one of the trace gasses that may accompany methane (CH_4) and carbon dioxide (CO_2) in landfill gas, but it can be a direct hazard in situations where concentrations are high.

When it is necessary for someone to enter and work in a confined space on or near a landfill, specific procedures should be clearly established and carefully followed, including:

- No confined access should be made by a lone individual, no matter how pressing the need may appear to be.
- An entry procedure should be documented and approved prior to any confined space entry.
- Before entering any confined space a check must be made for explosive concentrations of methane, as well as oxygen and H_2S levels. Usually strong odour near a confined space is an immediate indication of a dangerous situation.
- Natural ventilation or mechanical ventilation may be essential but of itself may not be sufficient to make the entry safe.
- If ventilation does not assure safe entry, specialists should be involved and specialist equipment used such as breathing apparatus.

In summary, the Landfill Manager for a site which has confined spaces, must have a safe entry procedure documented, his employees trained for entry, and the appropriate equipment to hand in serviceable condition. Records of confined space entries must be maintained on site – even if the space is entered by a contractor or public utility representative.

15.6.3. Landfill Inspection

Since monitoring wells and other monitoring installations are rapidly becoming the method for measuring the success of the containment engineering at a landfill, their care is another important security focus. Wells and monitoring equipment must be protected from physical damage, the placement of foreign substances into wells, and the potential for infiltration of pollutants in their immediate vicinity.

All site staff should be made aware of the possible hazards from landfill gas. Smoking on site should be forbidden except in designated areas in the site cabins.

Subsurface burning, compaction, settlement can induce the formation of caves in the waste deposit that when passed by could abduct vehicles and workers on the surface.

15.7. PATHOGEN SAFETY

Landfill is a bioreactor, with unique characteristics that promote it as a pathogen reservoir and capable of major epidemic dispersion not only it can infect people on the site, but the presence of birds, insects and animals that find refuge and food and have made this their habitat favours the possibilities of transmissible diseases to humans, in the vicinity. Scavenger birds such as starlings, crows, blackbirds, and gulls are most commonly associated with active landfills. They can be a nuisance, transfer pathogens, litter and scraps to neighbouring areas and also be a hazard to aircraft.

"The major sources of MSW contributing enteric pathogens were food waste, pet faeces, absorbent products, and biosolids. The largest contribution of salmonellae (97.27%), human enteroviruses (94.88%) and protozoan parasites (97%) are expected to come from pet faeces. Biosolids from wastewater treatment sludge contribute the greatest number of human noroviruses (99.94%)."

Most important is that special conditions in the landfill allow for it to maintain constant conditions that favour the persistence of many zoonotic pathogens. Areas where endemic pathogens are found must pay special care to maintain barriers that limit the spread of it.

In such a way, as explained before daily cover is the first and most efficient way of dealing with this hazard. And avoiding contact with landfill zoology is advisable.

Well known are enteric pathogenic micro-organisms such as bacteria, viruses and parasites capable of causing disease in man and animals. Pathogenic micro-organisms in landfills may originate from food waste, pet excrement (i.e. dog and cat faeces), and human excrement in absorbent products (e.g., disposable baby napkins for children and adults, feminine hygiene products) and biosolids generated at wastewater treatment plants. Examples of non-enteric pathogens are hepatitis B virus, herpes virus, rhinovirus, cytomegalovirus, influenza, and Staphylococcus aureus.

Of special consideration is where a landfill elects to take biomedical waste, written procedures must describe the appropriate training, equipment and medical support given to the landfill staff. Managers are required to review their sites and prepare a written report, which assesses worker exposure to blood-borne and other pathogens which can occur through:

- Medical waste and related sharps
- Sewage screenings and sludges
- Secondary pathogen waste sources (e.g. food processing wastes)

This issue is particularly relevant at sites where various degrees of scavenging may be occurring, without suitable attention to waste control and hence to managing this risk pathway.

15.8. ACCIDENT PREVENTION RESPONSIBILITIES

The Landfill Manager is responsible for the initiation and maintenance of accident prevention programmes and for frequent and regular safety inspections of job sites, materials and equipment. Training in site safety measures should become a regular activity. Preventing accidents and improving site safety site preparation aid in preventing injury and death on construction sites. Site safety preparation includes removing debris, levelling the ground, filling holes, cutting tree roots, and marking gas, water, and electric pipelines.

Ways to prevent injuries and improve safety include:

- Management safety
- Integrate safety as a part of the job
- Create accountability at all levels
- Take safety into account during the project planning process
- Make sure the contractors are pre-qualified for safety
- Make sure the workers are properly trained in appropriate areas
- Have a fall protection system
- Prevent and address substance abuse to employees
- Make safety a part of everyday conversation
- Review accidents and near misses, as well as regular inspections
- Innovative safety training, e.g. adoption of virtual reality in training
- Replace some of the works by robots (many workers may worry that this will decrease their employment rate)

The employees or employers are responsible for providing fall protection systems and to ensure the use of systems. Fall protection can be provided by guardrail systems, safety net systems, personal fall arrest systems, positioning device systems, and warning line systems.

Making sure that ladders are long enough to safely reach the work area to prevent injury. Stairway, treads, and walkways must be free of dangerous objects, debris and materials.

A registered professional engineer should design a protective system for trenches 20 feet deep or greater for safety reasons. To prevent injury with cranes, they should be inspected for any damage. The operator should know the maximum weight of the load that the crane is to lift. All operators should be trained and certified to ensure that they operate forklifts safely.

15.8.1. Operational Excellence Model to Improve Safety for Construction Organizations

There are 13 safety drivers to improve safety:

1. Recognition & Reward
2. Employee Engagement
3. Subcontractor Management
4. Training & Competence
5. Risk Awareness, Management & Tolerance
6. Learning Organization
7. Human Performance
8. Transformational Leadership
9. Shared Values, Beliefs, and Assumptions
10. Strategic Safety Communication
11. Just & Fair Practices and Procedures
12. Worksite Organization
13. Owner's Role [IV]

Each safety driver mentioned above has some sub-elements attributed to it and has to be developed in the Landfill Management Plan.

At many landfills, appointment of a Health and Safety Inspector / Manager may be appropriate to address the following:

- First aid and medical services
- Fire protection and fire prevention plans
- General housekeeping, especially within structures
- Illumination of work areas
- Sanitation and drinking water provisions
- Personal protective equipment (as well as training for its use) to ensure:

- Visibility
- Protection from direct injury such as lacerations
- Protection from LFG and dust
- Protection from noise

- Motor vehicle and equipment maintenance/ condition (including Rollover Protection Systems, seat belts, back-up alarms etc.)
- Asbestos management plans and/or procedures
- Hazardous waste acceptance plans and/or procedures (note that to exclude hazardous waste also requires a plan)

Figure 15.3 Typical safety signs. Better with images, and multilingual if necessary

- The benching and/or bracing of trench construction on site
- Safe work procedures

The Landfill Manager or Health and Safety Manager should prepare a written summary (risk assessment) with recommendations and conclusions for each item listed – even if the comment is as brief as "Through a stringent random screening programme we plan to exclude all listed hazardous waste." Accidents on site are never planned but the Manager will almost always be required to describe the plans, programmes and training that were implemented to prevent such an occurrence.

The better the contingency planning and the more consistent its implementation, the easier it will be to respond to accident incidents and subsequent investigations.

A key site management objective is to never have an accident for which a response is required.

15.9. SIGNS THAT COMMUNICATE EFFECTIVELY

Both security and safety can be enhanced through the placement of appropriate signs (Figure 15.3). Typically entry signs will show the hours of operation, the name of the owner/operator, and provide site and emergency phone numbers. Often the entry sign will also state the disposal fees and any limitations on waste types accepted that the site owners may impose on users.

Other signs within the site can be used to direct traffic to the gatehouse, office, or to the tipping face. Where distinctions are made between mechanical and hand unloading points, signs may be used to provide that information.

Other site features that may be identified using appropriate signage include property limits, the location of observation wells, leachate facilities, salvage and materials storage areas, and gas vents and wells. Where necessary bi-lingual signs may increase performance and add to the safety of on-site personnel, and add to the overall level of security of the site.

However, a site operation that respects neither personnel safety, nor site security cannot be improved simply with a few signs. On the other hand, the use of well-designed signs, carefully placed on-site, can and should result in better communication of the requirements for site security and personnel safety.

15.10. PREPARATION FOR THE UNUSUAL

Every facility manager must prepare for unusual events or occurrences on site. Managers who do not do so are forced to make decisions quickly and to defend those decisions after the event. For instance, it pays to keep in touch with local emergency services and therefore fire, police, and rescue squad or ambulance phone numbers must be appropriately and clearly posted on every building and in every vehicle on site. Emergency service personnel should be provided with an opportunity to review and inspect the site at least annually. The review will permit those personnel to become familiar with procedures and on-site personnel prior to their reaction to an actual emergency. Fire Training sessions might be an appropriate time to schedule such a visit.

In addition to the emergency service arrangements, certain landfill emergency plans are required by other agencies of government and an emergency response plan is an essential component of every Landfill Management Plan.

15.11. CONCLUSIONS

With well documented safety and security procedures, landfills can be very safe places of work. Training in, and the understanding of site safety procedures is essential if the key aim of minimising harm is to be achieved. Maintaining security and safety at any landfill is an ongoing, active process, and procedures should be regularly reviewed for relevance and applicability. What must not be forgotten is that there are no short cuts to safety and that safety in all aspects of site operation is at the core of an effective landfill operation.

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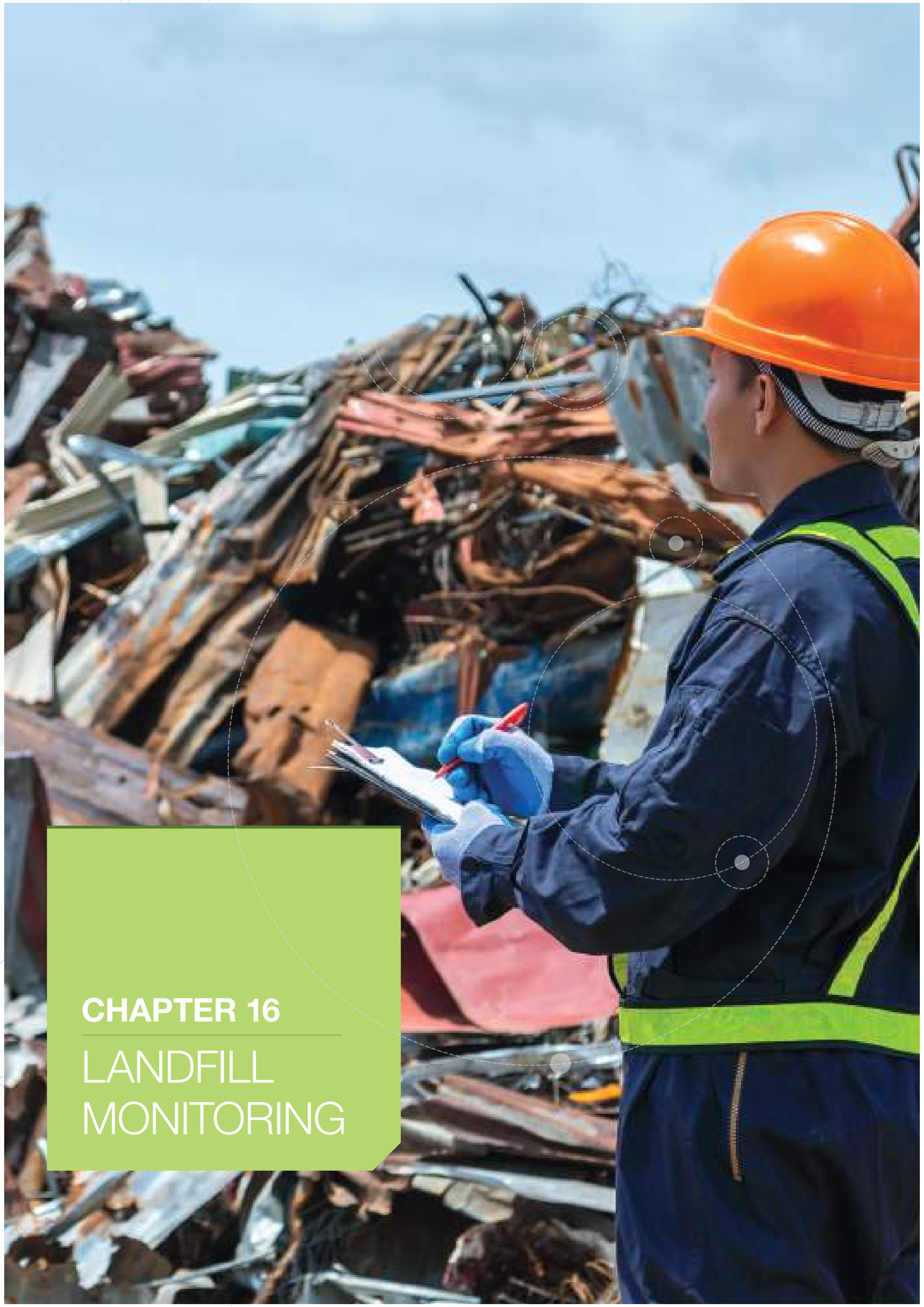

CHAPTER 16
LANDFILL MONITORING

CHAPTER 16 LANDFIL MONITORING

16.1 INTRODUCTION

Landfill monitoring is critical for proper landfill operation, environmental protection and minimizing cost and liability. The potential problems associated with landfilling of solid waste are contamination of ground water, surface water pollution, landfill gas (LFG) migration, odour generation, noise, dust and other nuisances. The monitoring program should extend from the pre-operational monitoring through operational and post-closure monitoring of the landfill.

Figure 16.1 Flux Chamber Sampling and Determination of Concentration with Gas Chromotograph (Samir, S., 2014)

Figure 16.2 Flame Ionization Detector (Samir et al., 2014)

16.2 LANDFILL GAS MIGRATION AND EMISSION MONITORING

Landfill gas collection system is provided primarily to collect the landfill gases and reduce emission to the atmosphere. Gas migration might still occur from the landfill envelope due to inefficiency of gas collection system. In the contrary, stored gases might build up excessive pressure. Active or passive venting systems are required to reduce excessive pressure build up within the landfill.

Surface emission is a function of temperature, moisture, wind speed, barometric pressure, type of cover, and landfill operations. Oxidation in soil covers, especially the clay covers, are highly affected by the moisture content of soil, as the porosity or the voids within the soil cover changes with the presence of moisture (Samir, S., 2014). The higher the moisture content, the more the voids are filled with water and less gas migration is possible. On the other hand, if more voids are available, higher gas diffusion will occur through the cover soils. The precipitation and the temperature are the two major controlling factors that impact the soil moisture content in the field; hence, the gas migration through the cover (Samir, S., 2014).

EMISSION MONITORING METHODS

Landfill emissions can be measured directly using a static flux chamber, dynamic flux chamber, micrometeorological methods, tracer method, vertical plumes and flame ionization techniques (Scheutz et al., 2009). Flux chamber method is most widely used for landfill methane emissions measurement. However, flame ionization techniques is very convenient, easy, quick and in many cases most effective method of emission monitoring. Therefore both flux chamber and flame ionization methods presented here:

Flux Chamber - Flux chamber (Figure 16.1) is commonly used to take field emission measurements of area sources. Emission flux measurements provide an estimate of the amount of gas emitted from a specific surface area enclosed by the flux chamber at any given time. This data can be used to develop emission rates for a given source and to develop emission factors for remedial actions. The flux chamber measurement could be both static and dynamic depending on the measurement technique.

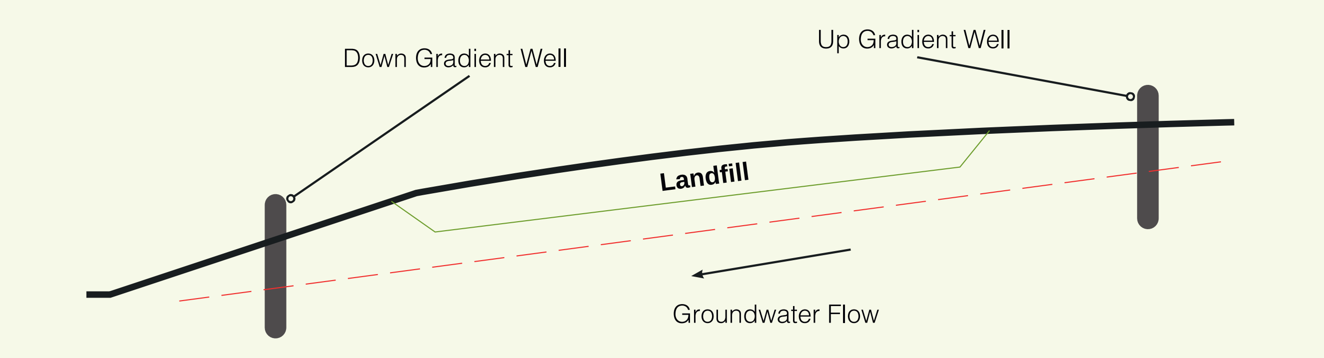

Figure 16.3 Schematic of Ground Water Monitoring Well

Flame Ionization Detector (FID) - FID instrument is equipped with a microprocessor, integrated pump sample and hand held portable gas detector. The pump directly collects samples from the ground and analyzes the methane concentration using the same technique as a laboratory gas chromatograph (GC). This method provides a semi-quantitative measurement of methane emission which is processed with linear kriging method to plot methane emission zones. This method provides continuous surface emission profile, easy to implement, low cost, and can detect high methane concentration area on the landfill surface. Figure 16.2 shows Flame Ionization Detector.

GROUNDWATER MONITORING

Groundwater monitoring is one of the principal concerns in landfill operation and maintenance. Bottom liner and leachate collection systems in the landfill are designed to prevent the contamination of groundwater. Although the proper engineering landfill design reduces ground water pollution concerns, leachate may escape through the landfill liner and cause ground water contamination.

Inadequate landfill design or open dumpsites may contaminate nearby water body by leachate seeps through the bottom and side slopes of the landfill. Therefore, perimeter ground water monitoring wells provide indication of groundwater contamination from leachate seeps.

16.3.1 Types of Groundwater Monitoring Well

There are two types of ground water monitoring well (Figure 16.3).

- Up gradient wells
- Down gradient wells

The effect of leachate contamination from landfill can be assessed by comparing the down gradient well constituents with up gradient well constituents. Any changes in concentrations of any particular constituents indicate possible contamination from the leachate leak.

16.3.2 Ground Water Monitoring System

Ground water wells detect path/flow of contamination in the event of any potential contamination. Number of ground water monitoring well depends on the thickness of the aquifer. The well spacing between monitoring wells depends on hydrological condition of the site.

Multiple wells may be grouped together (Figure 16.4) for ground water monitoring in landfills. Closer well spacing of wells enables the landfill operators to detect point discharge contaminant plumes.

16.3.3 Process of Ground Water monitoring

Detection Monitoring - Landfill owner/ operator monitors different constituents in accordance with state/ federal regulations. The samples from groundwater are tested (Figure 16.5) periodically throughout the active phase and post closure period according to state regulatory requirements.

Assessment Monitoring - An assessment monitoring programme begins within 90 days of detecting a significant increase in any of the regulated constituents. Samples are collected (Figure 16.6) from all wells to detect the presence of different constituents accordance with state/ federal regulations. This is mandatory to establish a ground water protection standard (GWPS) if any of the regulated constituents are detected.

Corrective Action - Corrective action begins based on assessment of corrective measures. The selected corrective measure must meet GWPS, control the potential source of contamination, complaint with human health and environment.

Figure 16.4 Multiple Grouped Ground Water Monitoring Well

Figure 16.5 Detecting Constituent in Ground Water Monitoring Well

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Figure 16.6 Sample Collection and Detection of Constituent

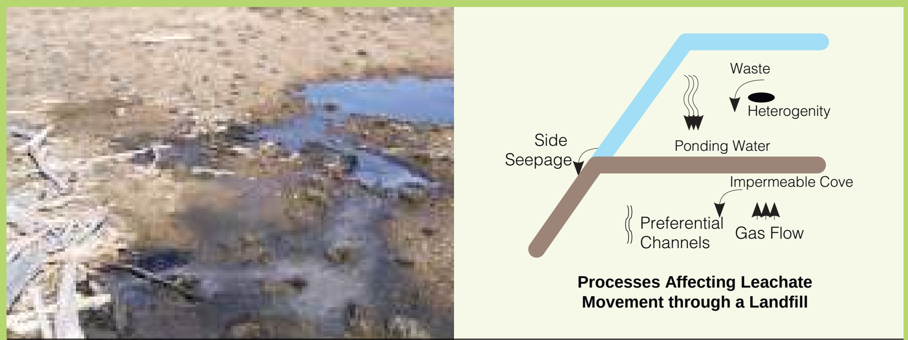


Figure 16.7 Leachate seepage through side slopes (Alam, 2016)

Figure 16.8 Collection, storage and determination of moisture content

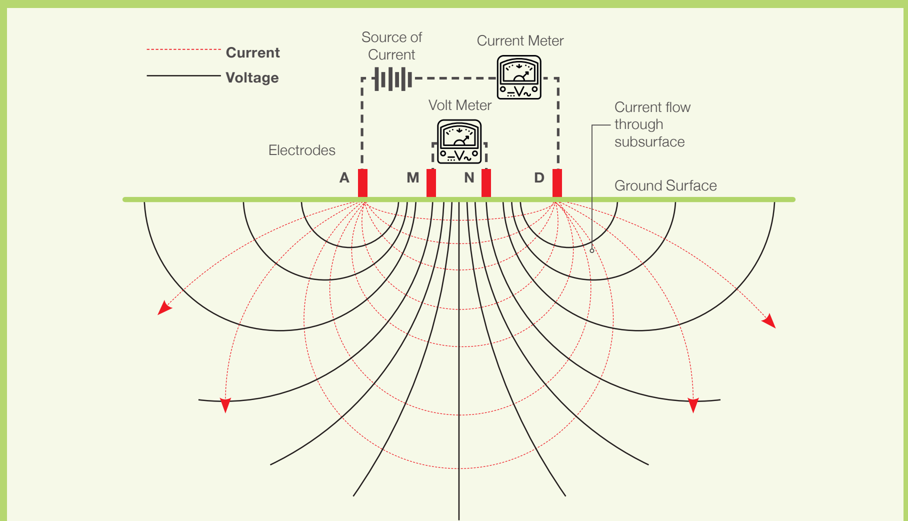


Figure 16.9 Equipotential and Current Lines for a Pair of Current Electrodes A and B

This correction measures must be continued for three consecutive years or in accordance with corresponding state/ federal regulatory requirements until all the required criteria are met.

16.3.4 Early Indicators of Ground Water Contamination

Early indicators to assess the groundwater contamination of leachate contamination are (1) Elevated chloride levels, and (2) Lowered pH

16.4 WASTE MOISTURE CONTENT MONITORING

Moisture content of solid waste is a significant parameter for any landfill operation. During the landfill operation it is important to monitor the moisture content both in working face and below surface. Leachate seepage through side slopes (Figure 16.7) are often indicator of excess moisture within waste or non-uniform distribution of moisture within waste. Leachate seepage may cause potential failures of landfill slopes.

Moisture content is the quantity of water contained within a material. It can be expressed as volumetric or gravimetric basis. Moisture content is more commonly expressed as the percentage of wet weight of solid waste. Available moisture monitoring methods for landfills are: bucket augur sampling, time domain reflectometry (TDR),neutron probes, partitioning gas tracer, electrical resistance sensor, fiber optic sensors, electrical resistivity imaging. However, most of these methods are destructive and provides only point information. These destructive methods also interrupt landfill operation. Electrical resistivity Imaging (ERI) is non-invasive and non-destructive. ERI may be the most advantageous to monitor moisture movement in the landfill. ERI provides continuous moisture profile and suitable for large scale field investigation.

16.4.1 Monitoring Waste Moisture Content at Working Face

Solid waste samples are collected from working face to determine the moisture content. Samples are collected from three (3) to four (4) different sections of the working face to get representative samples.

Ten bags of 30-40 lb samples are collected to determine the composition and moisture content of solid waste samples (Taufiq, T., 2010). Samples may be stored in an environmental growth chamber (Figure 16.8) at 4oC to preserve its original condition and moisture.

Approximately two pounds of sample from each bag is dried for 24 hours at 105°C, as shown in Figure 16.8.

Figure 16.10 (a) Electrical Resistivity Equipment (R8/IP Resistivity Meter) **(b)** Field Setup **(c)** Execution of RI test

The percentage of weight loss from the wet to dry sample is expressed as the amount of moisture. The moisture content of solid waste is determined using the following equations (on a wet weight basis (Ww) and dry weight basis (Wd), respectively):

$$W_w = \frac{Mw}{Mt} \times 100\ \% \quad \text{and} \quad W_d = \frac{Mw}{Ms} \times 100\ \%$$

Where Mw is the mass of water, Mt is the total wet mass and Ms is the dry mass of water after drying.

16.4.2 Subsurface Moisture Monitoring of Landfill Waste using ERI

ERI is a non-destructive method which is used to evaluate geo-physical properties (i.e. degree of saturation, moisture content, and/or fluid composition) of subsurface material.

The method works on the principle of Ohm's law, where the resulting potential differences are measured by transferring artificially-generated currents to the surrounding medium. The principle mechanism of ERI method is shown in Figure 16.9.

16.4.3 Field Investigation Program

The field setup consists of electrodes being inserted into the ground and connected to each other through a cable. A multichannel Super Sting R8 system (Figure 16.10a) measures the subsurface profile with the connection of the switch box and electrode-cable system.

Dipole-dipole array configuration is commonly used which provides the best resolution. Figure 16.10 demonstrate the field setup and execution of the ERI test.

16.4.4 Results and Interpretation of ERI Test

Resistivity profile provides moisture distribution profile within the solid waste. The depth of the profile depends on the spacing between the electrodes. It may provide high resolution moisture profile up to 200ft. A low resistivity zone in the moisture profile signifies high moisture area, and vice versa. Moisture movement of the fluid can be traced by resistivity imaging profile immediately after leachate or water recirculation in the landfill. ERI method provides qualitative information on the state of solid waste. ERI method is also advantageous in determining the frequency of leachate recirculation. Figure 16.11 shows three resistivity profile conducted at the same location at before leachate injection, after one and 24 hours of recirculation into the waste.

The baseline resistivity profile in Figure 16.11(a) shows the pre-existing condition of moisture distribution before leachate injection. The dotted line in the figures indicates the position of the horizontal recirculation pipe. The grey zone in the image is the high resistivity zone and the blue contour indicates high moisture. Figure 16.11(b) shows one hour after recirculation, the high resistivity zone turns green. This indicates the moisture movement within the waste. Figure 16.11(c) shows the resistivity profile after 24 hours of leachate recirculation, which also shows significant change in the resistivity contour and moisture distribution. Resistivity profile also indicates accumulation of moisture in the solid waste near the slope as depicted by the blue circle. This demonstrates that no leachate recirculation can to be made until the moisture build up at the slope dissipates. Therefore, ERI method is an effective method for monitoring moisture distribution within the solid waste and frequency of leachate recirculation.

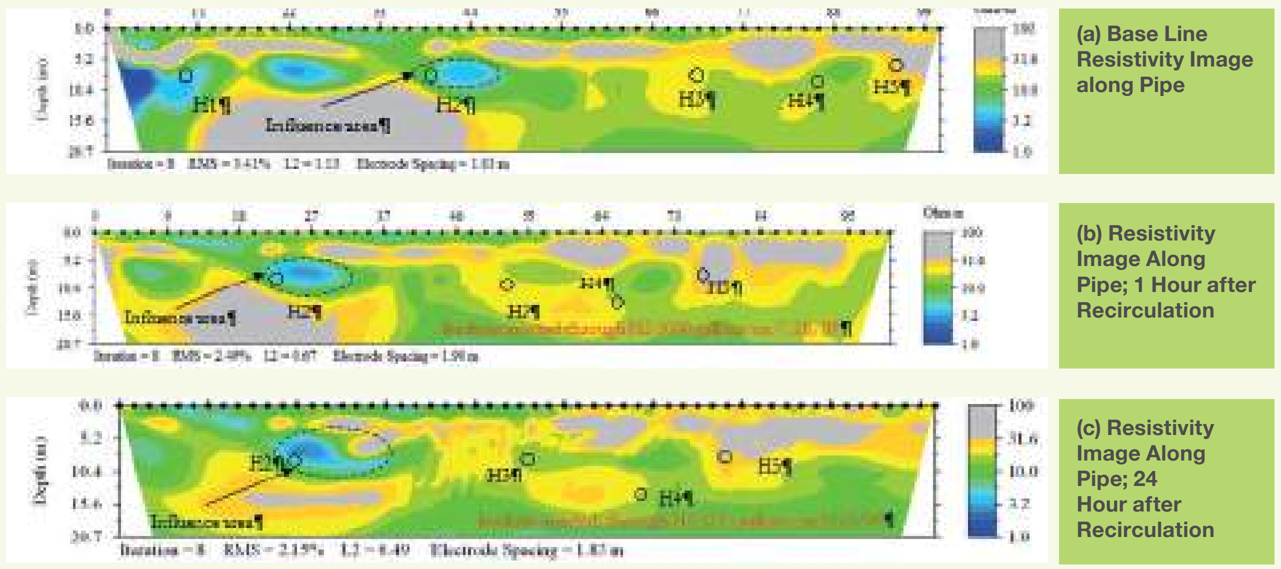


Figure 16.11 Resistivity Profiles Inside a Bioreactor Landfill after Leachate Recirculation (Ref: Manzur, 2012)

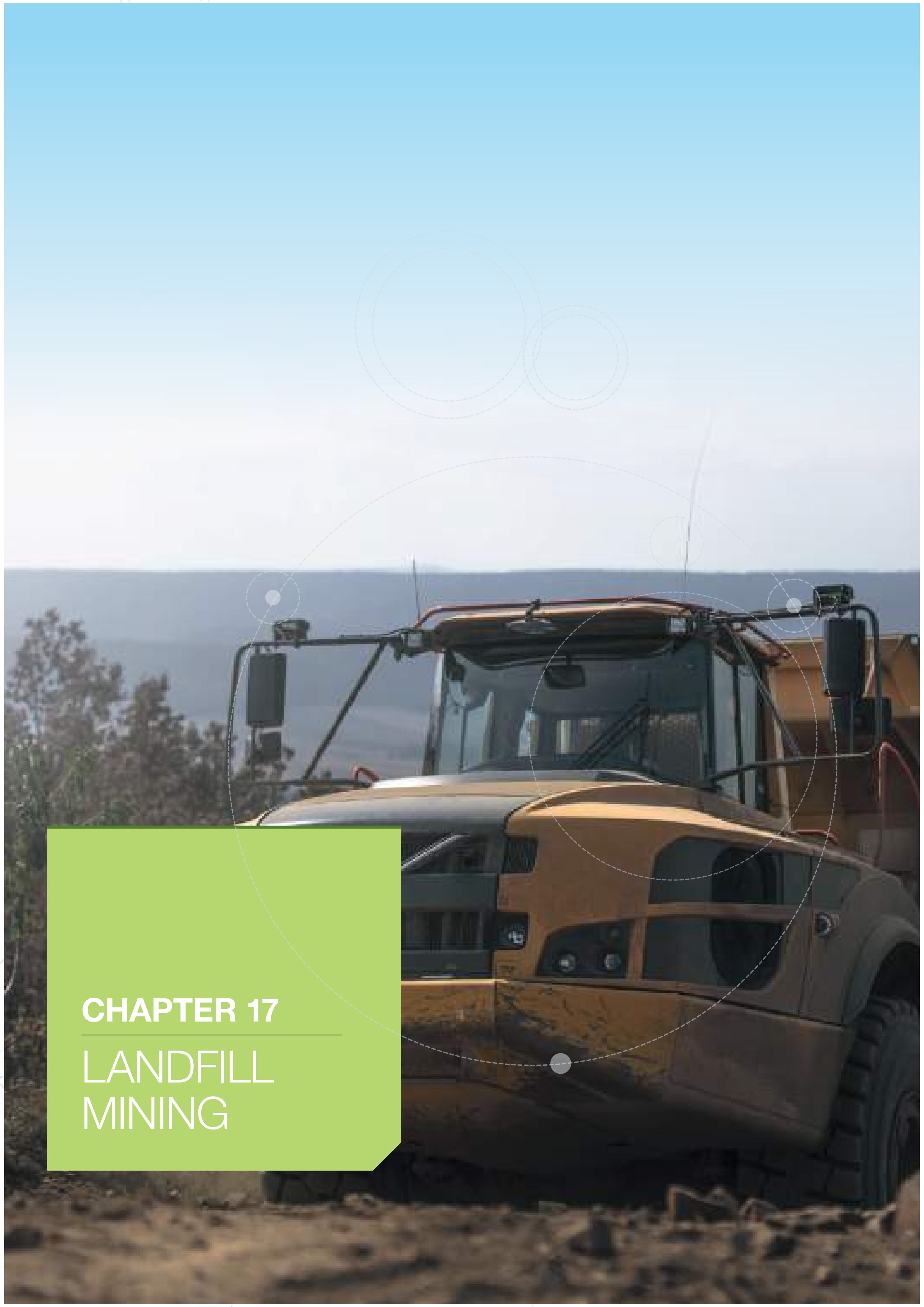
16.5 LEACHATE MONITORING

Regardless of the operational perspective of landfill, leachate monitoring is required. Leachate treatment for both on-site or off-site, sampling and testing of leachate is vital. Leachate sample may be collected from the bottom of the landfill where it accumulates (Figure 16.12) or from the leachate evaporation pond. Leachate tests includes: Total Dissolved Solids (TDS), Chemical Oxygen Demand (COD), concentration of heavy metals, electrical conductivity, temperature and pH.

These test results of leachate affect the type of treatment system and its efficiency. Record keeping of leachate monitoring is also important. In case of leachate evaporation pond, the level of leachate should be recorded to observe the seasonal variation of leachate and determine the pond capacity.

16.6 CONCLUSIONS

Landfilling of waste may pose long term threat to the environment. Therefore, it is important to monitor landfills to ensure not to pose any significant threat to environment, pollute groundwater, pollute the air quality, cause nuisances or odours, and endanger human health in any circumstances. A well designed and well implemented monitoring programme will allow early indication of any adverse environmental impacts. Early detection will facilitate rapid corrective measures and eliminate any potential future threats to the environment.



CHAPTER 17

LANDFILL MINING

17.1 INTRODUCTION

The concept of mining landfills is not new. Some 60-80 examples have been cited in solid waste literature since the first reported project in Israel in the 1950s. Landfill mining is a practice not unique to any particular country or even region.

So far, landfill mining has primarily been seen as a way to solve traditional management issues related to landfills such as lack of landfill space and local pollution concerns. Although most initiatives have involved some recovery of deposited resources, mainly cover soil and in some cases waste fuel, recycling efforts have often been largely secondary. Typically, simple soil excavation and screening equipment have therefore been applied, often demonstrating moderate performance in obtaining marketable recyclables.

17. 2 REGULATIONS, STANDARDS AND POLICIES

Because of the emerging nature of LFM operations, there are few regulatory controls in place, mainly set at a local level and the perspective they take varies. Regulatory controls do not specifically focus on LFM but merely the processing of the recovered materials and rely on existing environmental pollution and nuisance legislation to minimize the risk of pollution of the surrounding area. The most significant set of regulatory controls are likely to be local health and safety regulation.

17.3 PLANNING ASPECTS

Excavation and disposal operations require detailed planning and management. The complexity of the planning and design stage clearly depends on the scale and nature of the operation.

17.3.1 Conduct a Site Characterization Study

The first step in a landfill reclamation project calls for a thorough site assessment to establish the portion of the landfill that will undergo reclamation and estimate a material processing rate. The site characterization should assess facility aspects, such as geological features, stability of the surrounding area, and proximity of groundwater, and should determine the fractions of usable soil, recyclable material, combustible waste, and hazardous waste at the site.

Site-specific conditions will determine whether or not LFM is feasible for a given location, and include:

- Composition of the waste initially put in place in the landfill
- Historic operating procedures
- Extent of degradation of the waste
- Types of markets (price) and uses for the recovered materials

17.3.2 Assess Potential Economic Benefits

A benefit–cost assessment should be conducted to justify pursuing a landfill mining project. One way to approach a benefit–cost assessment is to compare the estimated cost of mining the landfill against the value of the "new" airspace that created by mining and used for future landfilling, or the value of the reclaimed property.

Information collected in the site characterization provides project planners with a basis for assessing the potential economic benefits of a reclamation project. The environmental and economic benefits of landfill mining include the following:

- Use of recovered soil fraction as landfill cover material
- Recovery of secondary materials
- Reduction of landfill footprint and, therefore, reduction in costs of closure and post-closure
- Reclamation of landfill volume

Most potential economic benefits associated with landfill reclamation are indirect; however, a project can generate revenues if markets exist for recovered materials. Although the economic benefits from reclamation projects are facility-specific, they may include any or all of the following:

- Increased disposal capacity
- Avoided or reduced costs of:
  - Landfill closure
  - Post closure care and monitoring
  - Purchase of additional capacity or sophisticated systems
  - Liability for remediation of surrounding areas
- Revenues from:
  - Recyclable and reusable materials (e.g., ferrous metals, aluminum, plastic, and glass)
  - Combustible waste sold as fuel
  - Reclaimed soil used as cover material, sold as construction fill, or sold for other uses
- Land value of sites reclaimed for other purposes
- Current landfill capacity and projected demand
- Projected costs for landfill closure or expansion of the site
- Current and projected costs of future liabilities
- Projected markets for recycled and recovered materials
- Projected value of land reclaimed for other uses

17.3.3 Invest Regulatory Requirements

Before undertaking a reclamation project, however, local authorities should be consulted regarding any special regulatory requirements or environmental permits.

17.3.4 Establish a Preliminary Worker Health and Safety Plan

After project planners establish a general framework for the landfill reclamation effort, they must account for the health and safety risks the project will pose for facility workers. Once potential risks are identified from the site characterization study and historical information about facility operations, methods to mitigate or eliminate them should be developed. This information then becomes part of a comprehensive health and safety program. Before the reclamation operation begins, all workers who will be involved in the project need to be well versed in the safety plan and receive training in emergency response procedures.

Drawing up a safety and health plan can be particularly challenging given the difficulty of accurately characterizing the nature of material buried in a landfill. Project workers are likely to encounter some hazardous materials; therefore, the health and safety program should account for a variety of materials handling and response scenarios.

Although the health and safety program should be based on site-specific conditions and waste types, as well as project goals and objectives, and should also cover the protective equipment workers will be required to wear, especially if hazardous wastes of landfill gas may be unearthed.

17.4 SITE PREPARATION

Excavation and disposal operations at dumpsites may have adverse public health and environmental impacts during excavation, materials handling, off-site transfer or on-site disposal due to:

- Air pollution, through the emission of hazardous particulates, fibers and gases
- Surface and groundwater pollution through the discharge of contaminated solids, sludges and liquids
- Transfer of contaminant off-site due to inadequate vehicle decontamination or sheeting of vehicles
- Noise and vibration
- Odors
- Traffic movements and congestion

17.4.1 Public Health and Environmental Protection Measures

The severity of these effects depends on a number of factors including: the nature of the contamination; the scale and duration of the remedial operation: weather conditions; the proximity and sensitivity of potential targets such as neighboring residential populations, surface or groundwater resources and ecologically significant habitats; and the extent to which mitigating measures are taken to eliminate or reduce the impacts.

Mitigating measures should be consistent with both the magnitude of the risks involved, and the scale and extent of the operation. Where excavated material has a significant potential to affect public health or the environment, consideration should be given to the use of active containment of the operational area (e.g. mobile tents with controlled air movement). The use of temporary cover on a daily basis is likely to be required for friable contaminated materials undergoing on-site disposal.

17.4.2 Site Services

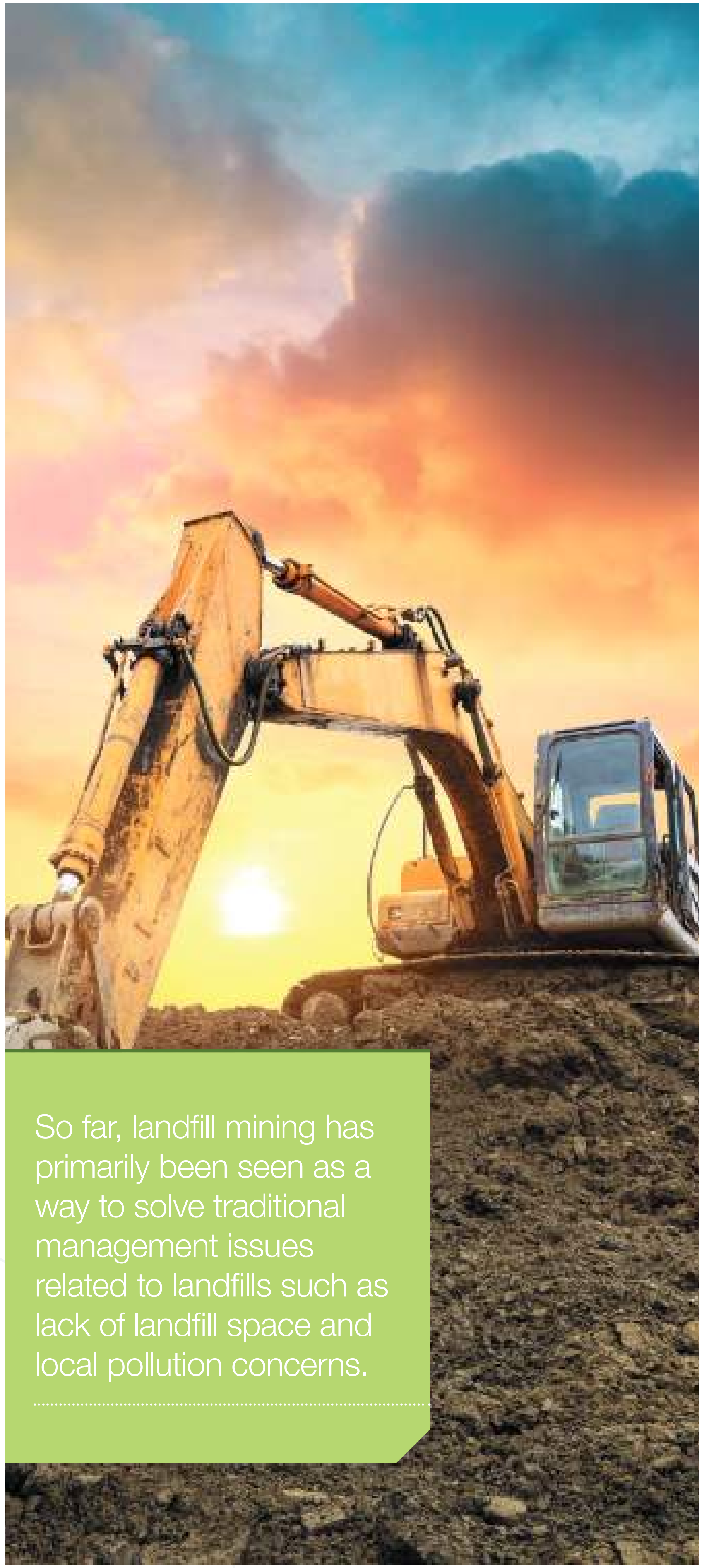
For excavation operations lasting for periods longer than a couple of weeks or for particularly hazardous operations, power, water and drainage services will be needed to:

- Support office and sanitary accommodation for the workforce
- Support any on-site laboratory facilities
- Provide water for an environmental protection measures such as water sprays, wheel wash
- Provide foul water drainage for site accommodation, operational and storage areas

Special provision may have to be made for 'fixed' materials handling facilities such as weighbridge, rail sidings, wheel washers etc. Telephone links should be considered for health and safety reasons.

17.4.3 Storage

Areas for the temporary storage of excavated solid materials, recycled material and contaminated surface and groundwater may have to be accommodated on the site. Areas designed for the storage of material



So far, landfill mining has primarily been seen as a way to solve traditional management issues related to landfills such as lack of landfill space and local pollution concerns.

Figure 17.1 Vibrating Screen

should be located on untreated parts of the site. Some form of containment may be necessary to prevent contaminants leaching out of stockpiles and exacerbating ground conditions beneath. Temporary cover, such as tarpaulins, plastic sheeting etc. may be needed to reduce infiltration of rainwater into stockpiles or prevent the release of dust.

17.4.4 Site Security

The security requirements of the site will vary depending on local conditions and existing provision. Appropriate measures should be taken at the site boundary to prevent unauthorized access, particularly by children, and in respect of individual operational areas where necessary. Access restraint, in the form of temporary fencing, visual markers etc., should be used around excavations greater than 1.2 m in depth which are left unattended for any period of time.

17.5 EXPLORATION AND SAMPLING METHODS

In the context of landfill mining prospection and exploration activities are performed to locate landfills, estimate their dimensions and characterise the material quantities and qualities. In this way, data for a feasibility study are obtained. Several prospecting and exploration methods are available.

As part of the exploration stage, test excavations or drillings into the landfill body play a central role in assessing the composition of the landfilled waste. Therefore, proper sampling and characterization of wastes at possible landfill mining sites is needed to evaluate the feasibility of a landfill mining project.

In some applications, sampling and analysis requirements may be significant in terms of the numbers of samples and tests to be processed often within a very short period of time e.g. on-site testing during excavation works to delineate the edges of contamination, or detailed monitoring prior to the off-site disposal of excavated material.

17.6 EXCAVATION AND RECLAMATION PROCESS

Landfill reclamation is conducted in a number of ways, with the specific approach based on project goals and objectives and site-specific characteristics.

The equipment used for reclamation projects is adapted primarily from technologies already in use in the mining industry, as well as in construction and other solid waste management operations. Basic landfill mining equipment may include the following:

- Waste excavation: hydraulic excavators (backhoes)
- Waste screening (large objects): grizzly screen
- Waste screening (smaller objects): trommel screen
- Screen feed: front-end loader
- Waste hauling: dump trucks

The production of a landfill mining operation is mainly dependent on the size and number of pieces of equipment deployed, the types of soils used during landfill operations (e.g., sandy versus clayey materials), the types of waste disposed, weather conditions, liquid levels in the landfill, and gas emissions. More equipment means more production, but more equipment also means additional capital costs.

Certain types of waste are more difficult to excavate and process than others, which can slow productivity. High liquid levels and highly saturated wastes require additional steps to excavate and process, which, again, slows production. Inclement weather is a less controllable factor; however, the timing of major excavation efforts can be scheduled to take advantage of seasons with less inclement weather. Lastly, health and safety issues associated with gas emissions such as combustible gases, odorous gases, and such must be considered and can negatively impact surrounding properties if not controlled properly, ultimately impacting the excavation and processing activities.

Equipment involved in the waste excavation activities typically limits the actual capacity of an operation. This equipment is involved in excavating compacted waste, loading trucks, and moving as the excavation progresses.

The other machines in a landfill mining operation, such as shredders, screens, magnets, and conveyors are generally static (i.e., they are not moved for periods of time), and are processing materials that have had some loosening and separation, and are for one function only, so their capacity usually does not limit the operation.

17.6.1 Separation Techniques

Once material has been extracted from landfills a series of processes need to follow in order to separate the extracted waste into reusable resources or waste-derived fuels. The unit processes within the process chain needs to be optimized throughout the entire chain in order to decrease the possible losses and achieve as high recovery rate as possible without decreasing remarkably the grade of the produced fractions.

Types of separation processes:

1. Handpicking
2. Screening (trommel-, disc- and star screening)
3. Magnetic separation
4. Air classification
5. Optical separation
6. Eddy's current method
7. Flotation

17.6.2 Materials and Waste Composition

Characterization of deposited material is the most studied main topic within landfill mining research. There are also some recurring patterns regarding the composition of waste deposits in the literature. Typically, municipal landfills consist of about 50–60 weight percent of a soil-type material (cover material and heavily degraded waste), 20–30 weight percent combustibles (e.g. plastic, paper and wood), 10 weight percent inorganic materials (e.g. concrete, stones and glass) and a few weight percent of metals (mainly ferrous metal). This is often the case even when considering landfills situated in totally different parts of the world. Several studies, therefore, also stress the potential for resource recovery, both in terms of recycling of earth construction materials and metals, and energy recovery of combustibles. The presence of hazardous waste in the deposits has generally been found to be low, often comprising far less than one weight percent.

17.7 Economics of Landfill Mining

It is well known that landfill mining reduces or eliminate closure costs and, in most cases, reduce the long-term environmental problems. Traditionally, the economics of landfill mining often is dependent on the depth of the waste material and the ratio soil-to-waste due to the fact that as deeper the waste is buried the more expensive a site is to reclaim per hectare. Furthermore, the lower the soil-to-waste ratio is, the more material will need to be either reburied or transported for disposal off site. It is usually believed that the recyclables recovered might provide economic revenue which is a fact depending on several aspects, such as the quality of the separated fractions, local situation and the market price, In specific circumstances, recovery focused on ferrous metals, aluminum, plastic and glass as well

CHAPTER 17 LANDFIL MINING

as fine organic and inorganic material can have economic significance if they represent significant enough volume for recovery. This might be true for industrial landfills as for the car fragmentation industry and scrape dealing industry. Industrial landfill with toxic contents as those related to old glass factories and battery factories might be very expensive to reclaim. Even though it can be estimated the existence of hundreds of thousands of sites good candidates for landfill mining and land reclamation, such strategy is seldom applied, mainly due to lack of information and the way of making the economic evaluations of' the projects. Factors affecting the economic feasibility of reclamation differ for each site and each reclamation goal.

The accounting of economic benefits of a landfill mining project must be comprehensive and include reduction or elimination of the need of capping, long-term monitoring and after case, maintenance and potential remediation costs, effective use and logistics of machinery, increased value of the reclaimed land and avoidance of finding a new site and infrastructure costs in the case the reclaimed land is used for constructing a new landfill.

The costs and benefits of landfill mining vary considerably depending on the objectives (closure, remediation, new landfill etc.) of the project, site-specific landfill characteristics (material disposed, waste decomposition, burial practices, age and depth of the landfill) and local economics (value of land, cost of closure materials and monitoring). Cost heads related to project planning including capital and operational costs of the landfill mining project are as summarized below:

Capital Costs:

- Site preparation
- Rental or purchase of reclamation equipment
- Rental or purchase of personnel safety equipment
- Construction or expansion of materials handling facilities
- Rental or purchase of hauling equipment

Operational Costs:

- Labor (e.g., equipment operation and materials handling)
- Equipment fuel and maintenance
- Administrative, planning and regulatory compliance expenses (e.g., record keeping)
- Worker training in safety procedures
- Hauling costs

Analyzing the economics of dumpsite mining calls for investigating the current capacity and projected demand of the landfill, projected costs for landfill closure or expansion of the site, current and projected costs of future liabilities, projected markets for recycled and recovered materials and projected value of land reclaimed for other uses.

Major factors influencing the cost of such projects will include the volume and topography of the dumpsite; equipment parameters; soil conditions; climate; labor rates; the regulatory approval process; excavation and screening costs; sampling and characterization; development costs; the contractor's fees; hazardous wastes disposal; and revenue from the sale of commodities such as compost and recyclables.

In practice, the environmental costs and benefits should be added to the project costs and benefits before using decision criteria like Net-Present Value, Benefit-Cost Ratio, or the Internal Rate of Return of the project.

The main challenge is to estimate the environmental costs and benefits properly. Unlike project costs and benefits which are more tangible, estimating environmental costs and benefits is not so easy. As such no data are currently available to monetize the local environmental benefits that will arise out of the project from the control of smoke and air pollution due to open burning of garbage and control of odor and fly nuisance as well as ground water pollution due to leachate.

17.8 CONCLUSIONS

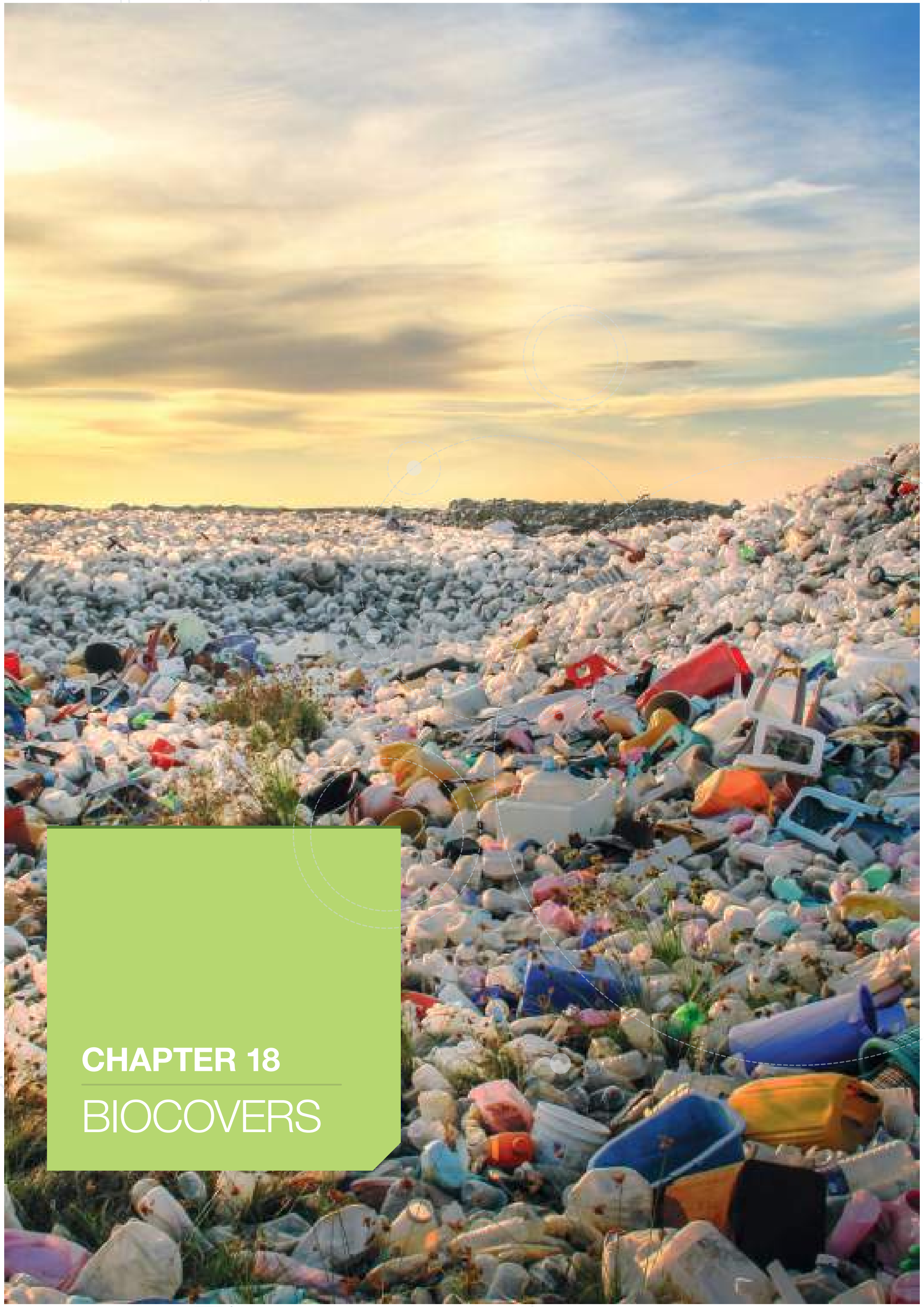
Landfill mining and reclamation is a developing technology and method of waste management. Given its developmental status, only tentative conclusions can be drawn regarding LFM potential, and prospects for fulfilling that potential.

The technology of LFM can be effective in recovering landfill capacity for reuse for landfilling or for use as reclaimed land for other applications. It can also be employed to recover landfilled resources such as a soil fraction for reuse on-site as cover material and for use as a soil amendment. Based on the few analyses reported thus far, the heavy metal content and other characteristics of the recovered soil fraction indicate that the fraction can be suitable for landfill cover material. However, it should be emphasized that the characteristics of the recovered materials are substantially a function of the composition of the buried waste - including concentrations of heavy metals and of other toxic compounds. Some organic materials may be recovered that may have a use as RDF.

Low-quality ferrous scrap is readily recovered, but its utility has only been demonstrated to a limited degree. The percentage of recovered materials and their characteristics and properties are functions of the composition of the landfilled material and the configuration and operating conditions of the landfill mining process. The concept of landfill mining and reclamation and related technology merits serious consideration. It may be relevant to consider the incorporation of the concept into landfill design so that the landfilled waste can be readily accessible for mining.

Although the potential of this approach appears significant, it is argued that facilitating implementation involves a number of challenges in terms of technology innovation, clarifying the conditions for realization and developing standardized frameworks for evaluating economic and environmental performance from a systems perspective. In order to address these challenges, a combination of applied and theoretical research is required.

Due to the shortage of reported full-scale projects in the reviewed literature, comprehensive cost-benefit analyses of landfill mining are rare. It can be concluded that although valuable research on landfill mining has been conducted for more than two decades, the field is still somewhat immature when it comes to standards and common principles for realization and evaluation.



CHAPTER 18 BIOCOVERS

CHAPTER 18 BIOCOVERS

18.1 INTRODUCTION

Methane emissions from active or closed landfills can be reduced by means of methane oxidation enhanced in properly designed landfill covers, known as **"biocovers"**. Biocovers usually consist of a coarse gas distribution layer to balance gas fluxes placed beneath an appropriate substrate layer. The application of such covers implies use of measurement methods and evaluation approaches, both during the planning stage and throughout the operation of biocovers in order to demonstrate their efficiency.

Principally, various techniques, commonly used to monitor landfill surface emissions, can be applied to control biocovers. However, particularly when using engineered materials such as compost substrates, biocovers often feature several altered, specific properties when compared to conventional covers, e.g., respect to gas permeability, physical parameters including water retention capacity and texture, and methane oxidation activity. Therefore, existing measuring methods should be carefully evaluated or even modified prior to application on biocovers.

18.2 METHANE OXIDATION PROCESSES IN LANDFILLS

Landfills containing organic wastes produce biogas containing methane (CH_4). Landfills are significant sources of methane, which contributes to climate changes. At some landfills utilization of landfill gas (LFG) is not or cannot be carried out, and the gas is either flared with risk of producing toxic combustion products or just emitted to atmosphere. Landfills may be covered with biological active materials, so-called biocovers. Experiments have documented that a very high methane oxidation rate can be obtained in biocovers, high enough to significant reduce the methane emission from the landfill. Documentation of the efficiency of biocovers has so far only been carried out in full scale in a few cases.

Gases emitted by landfills are produced anaerobically under specific soil conditions, where methane and carbon dioxide are the two main gases produced (among other trace gases) in a ratio of 55 - 60% v/v to 40 - 45% v/v, respectively. However, the oxidation of this methane by methanotrophic bacteria in the topsoil layer is affected by numerous factors in the surrounding environment (e.g. temperature, precipitation, and barometric pressure) as well as the properties of the material chosen for the top cover.

These categories are the main factors that influence the oxidation process of methane by the methanotrophic bacteria within landfills and the methane production by methanogens. This can either be a result of an influence of each factor individually, or by an influence of combined factors working collectively, that affects the oxidization and production process of methane. Notwithstanding, engineers, waste planners, and researchers are interested only in those factors that can be managed, changed, and modified within landfill wastes and the environment of the containments.

In terms of exploring landfill factors in general, existing research has focused on the effects of soil conditions, moisture content methane oxidation, biomass accumulation, physical determination of methane oxidation, landfill cover materials, landfill containments, inhibiting substances soil temperature, gas diffusivity, soil capacity and methane diffusivity, and the methanotrophic community structure in landfills. Additionally, oxygen availability has been identified as the most important factor affecting the growth of methanotrophic bacteria in the top cover layer (dependent on porosity).

However, other factors are also important, such as landfill waste content and methane production rate, structure and location of landfills, pH of cover soil, and soil mineral composition, all of which are difficult to manage and control from an engineering standpoint.

Consequently, research has been focusing on identifying factors that are most effective in reducing methane emissions and those most readily manageable in stimulating an increase in methanotrophic activities.

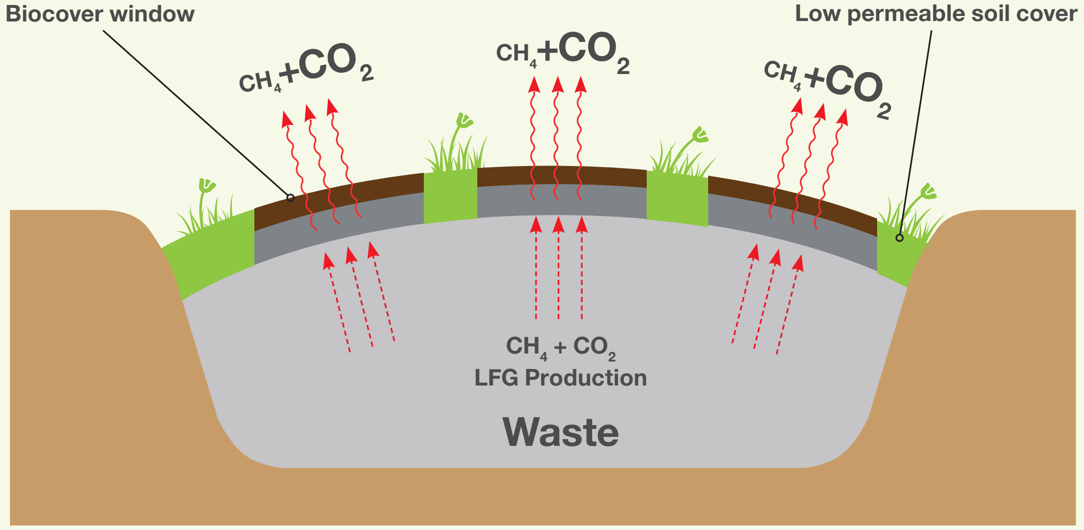


Figure 18.1 BioWindow Design

18.3 MATERIALS FOR BIOCOVERS

Different approaches can be used when deciding, which material should be used in a field-scale or full-scale passive biocover or in a passive biofilter. In the following the approaches used in the literature is attempted divided into four different approaches.

1) Choose in theory the optimum material with the optimum physical properties; high porosity, high specific surface for bacteria to adhere to and less attention is given to whether the material is available on site and feasible to use

2) Rank locally available materials by criteria given in the literature

3) Rank locally available materials by testing CH_4 oxidation rates

4) Use a material, which proved high capacity for CH_4 oxidation, with a minimum of testing prior to implementation

Different approaches have been applied in the literature, but to date many studies have included testing of the potential CH_4 oxidation capacity in column incubations prior to selection of the optimum material for full-scale application. As the diversity and range of materials tested in both column incubations and in the field increase, the fourth option listed above becomes more and more reasonable. However, the production of compost is heterogeneous and standards for compost quality varies between countries and even within countries so a minimum of testing will always be necessary.

18.3.1 Dimensioning Biocovers

Locally available materials should be used when implementing full-scale biocovers, but this can cause low (< 50 g CH_4 m-2 d-1) CH_4 oxidation rates as there is no guarantee that materials which are optimum for CH_4 oxidation will be present at the site. This is however not a problem if the biocover systems can be designed in a way that provides a load of CH_4 that can be oxidized in the available material.

Therefore, to be successful in using locally available materials it shou ld be possible to design the biocovers with a low load (< 50 g CH_4 m-2 d-1) and the intensity of hot spots should be minimized. If the layout of the landfill does not allow such conservative design, other more optimum biocover materials could be considered and the design costs should be balanced towards the costs of transporting optimum materials to the landfill site.

18.3.2 Measuring and Documentation of the Efficiency

CH_4 emissions can be measured by several methods, e.g. above ground micrometeorological methods and tracer methods, and with static and dynamic chambers. The static chamber is the most common technique for measuring landfill emissions and has been field validated. Flux chamber measurements are single point measurements, whereas the micrometeorological and tracer techniques can be used to measure total emission from landfills.

Whole site methane emission quantifications based on combined tracer release and downwind measurements in combination with several local experimental activities (gas composition within biocover layers, flux chamber-based emission measurements and logging of compost temperatures) proved that the biocover system in a Danish landfill had an average mitigation efficiency of approximately 80-90%. The study showed that the system also had a high efficiency during winter periods with temperatures below freezing. An economic analysis indicated that the mitigation costs of the biocover system were competitive to other existing greenhouse gas mitigation options.

18.4 CONCEPTS AND DESIGNS

Flaring or using methane as an energy source is one of the well-known conventional processes for methane oxidation for decades. Conversely, and in light of recent discoveries, researchers have started to employ aerobic reactions as a way of methane elimination, through the use of methanotrophic process, which is regarded both as an economical and an

CHAPTER 18 BIOCOVERS

Figure 18.2 Bio cover in Denmark

environmentally viable elimination process. Taking all these into account and the knowledge that approximately 85% of produced methane gas from conventional uncontrolled landfills escaping into the atmosphere, have prompted researchers to explore other means of enhancing methane oxidation.

Increasing number of investigators have concentrated more of their efforts on the redesign of the top cover soil of landfills, showing a potential of eliminating higher percentage of produced methane. The most commonly redesigned system of landfill's top cover soils is the arrangement of different layers on top of each other, in which an oxidation layer, typically compost material, is placed over a gas distribution layer, made up of a material, such as gravel, that has the features of high permeability.

Figure 18.2 Collection system below compost layer

14.4 CONCLUSIONS

Biocover systems are economically feasible options for controlling low levels of CH_4 emissions from landfills. Biocover solutions appear to be appropriate at landfills where LFG collection is in operation because of their high CH_4 uptake capacity.

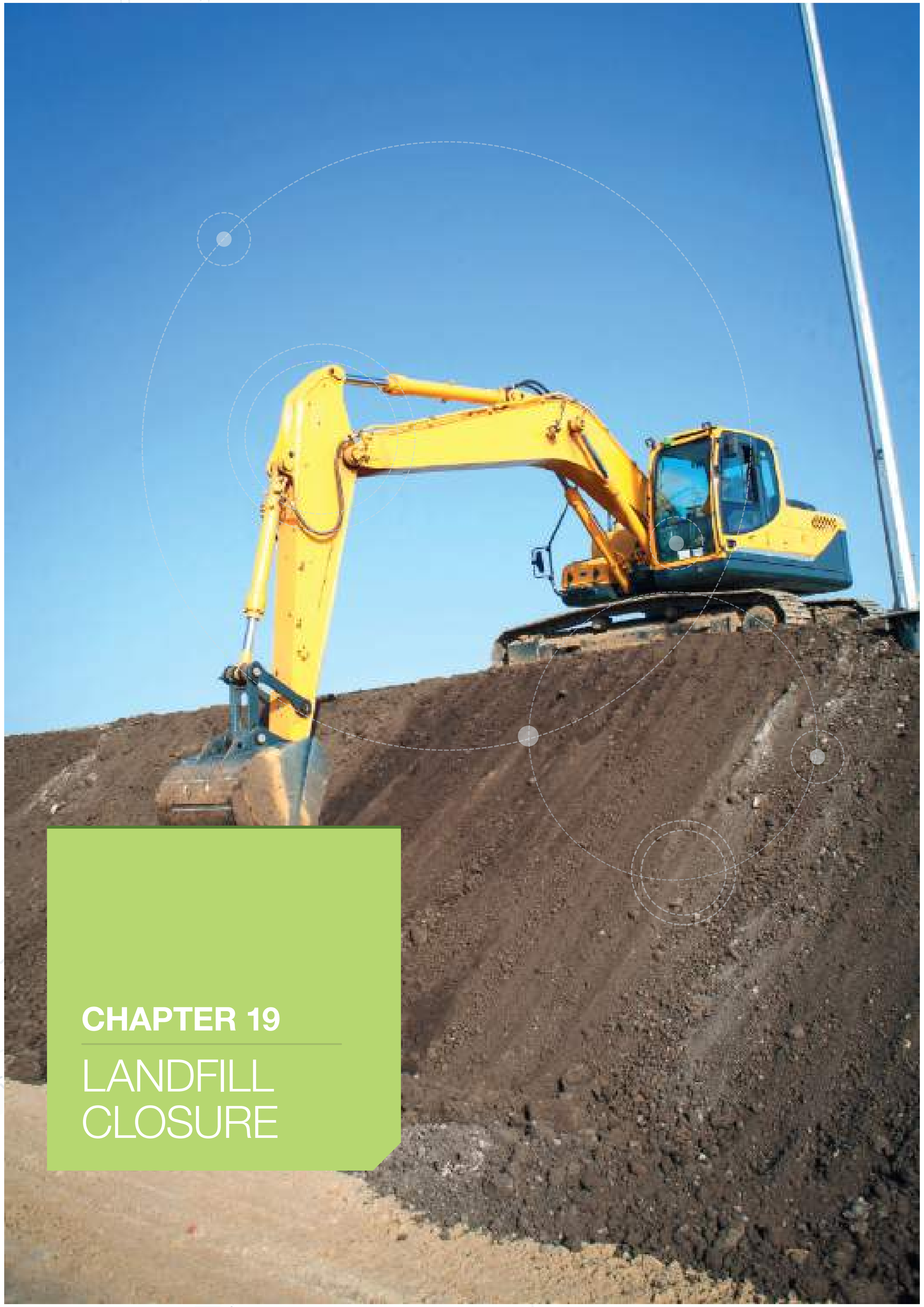
Biocovers offer the advantage of covering an entire landfill while simultaneously providing good water-holding capacity and porosity for vegetation and evapotranspiration. Biowindows can be used at landfill hotspots. Biotarps can be appropriate alternative daily covers for use in mitigating CH_4 emissions during landfill operations at times when no CH_4 collection occurs. Each type of biotic system has advantages and disadvantages, and the choice of which method to apply depends on economic constraints, treatment efficiency and landfill operations.

This arrangement, known as a biocover system, is intended to encourage the homogenization of gas and air fluxes together, and therefore, could have a higher potential for methane oxidation. Biocovers are more effective when used on a large scale, in order to cover more of the area of the landfills for higher rate of oxidation, making it necessary to use large amounts of structural support materials. Thus, even though biocover systems are relatively an efficient way of eliminating methane, they could also prove to be a potentially expensive undertaking.

Another methane oxidation enhancing method is the biofiltration system. This gas capture system is constructed by digging a small area of space in the top cover soil, then, the space is filled with biomaterials for purposes of capturing the gases produced from bacteria degrading the waste. Three different bio-filtration design systems have been used, such as:

- Biowindows, which are cells of spaces, cut into the cover soil and filled with support mediums
- Biofilters, which differ from biowindows in that, they are contained in the cover layer of the landfill
- Biotarp cover, which is a temporary system made of a thick film, infused with methanotrophic bacteria, and placed daily over an on-going operation of filling an active landfill site. The inducement of bacteria is done, so that the bio-tarp could immediately consume the escaped methane gas reaching the top soil, thereby, reducing fugitive gases while operating on the site.

These systems are designed so that they can create a favorable environment for the methane capture and elimination. Moreover, by utilizing these types of systems, the parameters for oxidation, such as methane and oxygen loadings, moisture content, temperature, filter material composition, and layer arrangements become more obtainable and measurable. In comparison to the active gas management systems, such as the active collection and flaring of the gas, the use of biofilters has been determined to be economically more viable, particularly for smaller landfills.



CHAPTER 19

LANDFILL CLOSURE

19.1 INTRODUCTION

Landfill management does not stop at termination of waste acceptance and placement. Before a landfill can be abandoned or returned to society a top cover needs to be constructed and financial provisions for aftercare need to be safeguarded. In addition, closure of a landfill usually involves establishing of vegetation on the site, securing permanent installations decommissioning of redundant structures and (contracts on) future use.

Figure 19.1 Damage of soil cover and barrier layer *Copyright EQC*

Closure is not the moment that the gate is closed and waste processing is stopped. Closure as defined in regulations is the moment that the competent authority has concluded that the operator has fulfilled all the permit requirements concerning environmental protection measures and provisions for aftercare. It takes several years before all the protection measures at the top of the landfill are installed. Landfills can be closed entirely or in distinct phases. The engineering of the top cover, the nature of the aftercare and the financial provisions depend on the type of end-use that is selected for the landfill. Often landfill sites also have old sections that do not meet current standards. Local regulations do not always require remediation to current standards. These old landfill sections are not dealt with here.

19.2. Regulatory Framework

Closure and aftercare of landfills are often specified by national regulation. Guidelines provide the technical requirements of the top cover, which is the main technical feature of landfill closure. Invariably regulations aim to control rainwater from entering into the waste body. It is important to note the difference between control and prevent. In a climate with an annual precipitation of 600 mm control can also be realised with a suitable soil cover with adequate vegetation that reduces the infiltration to for example 50 mm per year. Post closure protection of soil, groundwater and surface water is to be achieved by a top liner. The required level of permeability depends on the environmental risk at each specific site. If the potential impact due to the nature of the waste or level of stabilisation of the waste is low, then infiltration of a certain amount of precipitation will not harm the environment. A majority of the national regulations in Europe has however made barrier layers mandatory on both hazardous and non-hazardous waste landfills. These regulations require an 'artificial sealing liner' and an 'impermeable mineral liner'.

19.3. FINAL TOP COVER

19.3.1 Temporary Cover

After termination of waste acceptance and placement the landfill is capped with a temporary cover. This is usually a locally available soil in a layer of 0.3 to 1.0 m thickness. The final cover, in many cases a clay liner and/or a geo membrane, cannot be installed immediately. Final top covers are described in paragraph 19.4.2. Several years (maybe 7 – 10 years) after the landfill (cell) has reached its final volume significant settlement may still occur. When the settlement is irregular and not evenly distributed over the surface, damage to the top cover construction may occur; see Figure 19.1. Geomembranes can be ripped. Cracks in clay liner can occur. Mineral liners are supposed to be 'self-healing', however, if the crack is too big, mineral liners are not able to heal. In practice it has been observed that cracks fill up with drainage sand overlying the liner or that plant roots invade the cavities that arise. When this happens, the result is a permanent leak in the clay liner. After termination of waste placement (and under the condition of effective gas control) it is therefore good practice to first be patient and follow the development of settlements.

19.4.2 Settlement

Settlement refers to the overall volume reduction in the landfill body. Settlement should not be underestimated. For municipal solid waste landfills containing a lot of biodegradable material total settlement can be 25% or more of the initial fill height. Settlement can be due to compression of the soil on which the landfill is situated and to degradation and compression of the waste itself. Weak clay and peat are soil materials that can be compressed considerably by the weight of overlying material. Specific measures prior to the construction of the bottom liner can be carried out to reduce this type of settlement. The volume reduction of the landfill body is caused by the combined effect of compaction during placement and the mass of overlying waste. It strongly depends on the nature of the waste.

Secondary settlement in the landfill body is caused by a combination of mechanical creep, physico-chemical corrosion and biodegradation. The effect of degradation is highest for waste that contains a high percentage of biodegradable material.

Regulations often require annual height measurements. In practice very few landfill operators actually perform settlement measurements prior to installing a permanent barrier layer. Settlement of the top of the waste can be measured by installing permanent measurement points in the soil cover. This can be a simple concrete tile on top of the soil or a 1 by 1 m steel plate and pipe that is installed at the boundary of soil and waste. The measurement itself can for instance be carried out with the well-known surveyor's levelling instrument or the theodolite.

Methods based on drone or satellite are being developed. To date they still suffer from inaccuracies caused by vegetation length. The settlement of the soil beneath the bottom liner can be measured in a variety of ways. A simple approach consists of installing a 2 by 2 m reinforced concrete slab on the drainage layer of the bottom liner. Steel pipes with a known length are attached to the concrete slab and periodically extended with the increasing height of the waste. The measurement of the height of the pipes and comparison with a known level outside the landfill indicates the settlement of the subsoil. A disadvantage is that the pipes are obstacles during waste placement and have a limited lifetime due to corrosion of the steel.

Plastic pipes cannot be used due to their flexibility especially under increased temperatures that occur in landfills with active biodegradation. Another approach is to insert a pressure sensor into the leachate drains. The pressure difference with a sensor at the bottom of the drainage system collection well indicates the difference in height. Cable length measurement or GPS data enable comparison of the measurement data with the designed height of the drainage system. The data collected gradually shows less and less settlement. There are no guidelines for acceptable settlement, but it can be considered safe to install a barrier layer when the settlement has reached values below a few cm per year. Figure 19.2 shows annual landfill cover settlements (5-30 cm /year) monitored over 7 years.

If settlement occurs gradually in the same rate over the entire surface, it will not damage the barrier layer. The real threat for the liner system is differential settlement. Data collection and evaluation aiming at verifying differential settlement over small distances is quiet, laborious. Therefore, in practice it is easier to follow the general settlement in the landfill. If the general settlement itself has decreased to a very low level, then differential settlement is small as well.

19.4.2 Final Top Cover

Final top covers serve to contain the waste and provide a physical separation for the protection of human health and the environment. Many regulations require minimisation or control of infiltration of water into the waste layers. This can be achieved with top cover components such as low permeability clay liners and/or geomembranes. In addition, the final cover also has to control the release of landfill gas, minimise erosion and support vegetation. The design of final top covers strongly depends on local regulations and local (climatic) conditions. It can vary from a relatively simple soil cover to design consisting of multiple barrier and drainage layers.

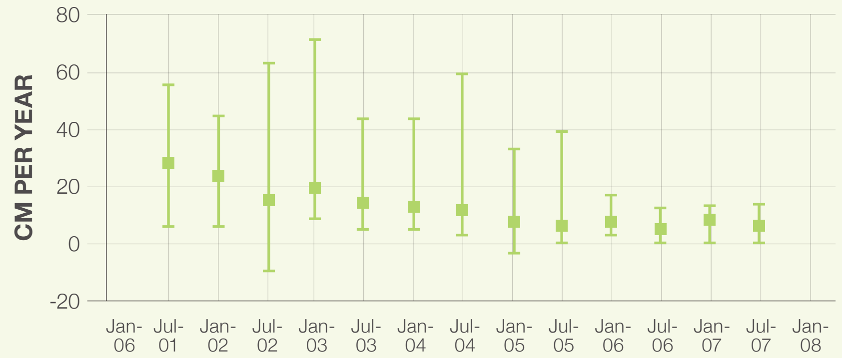


Figure 19.2 Settlement (average and range of 17 measurements points) on a 22 ha landfill since operation ended in 2000 *Copyright Afvalzorg*

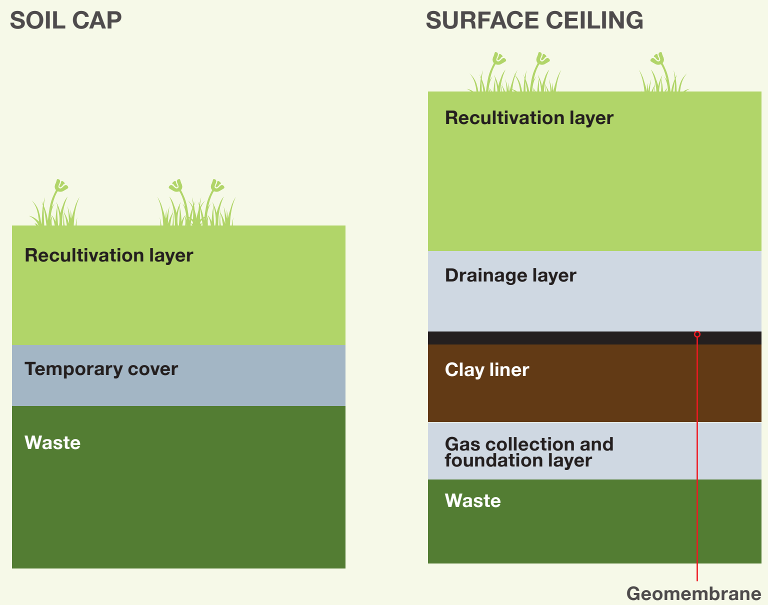


Figure 19.3 Examples of a simple soil cover and a state-of-the-art barrier layer *Copyright Afvalzorg*

The final top cover design may include the following layers:

Recultivation layer: the function of the recultivation layer is to protect the barrier (from desiccation, freeze/thaw, mechanical damage or root intrusion), support vegetation (by offering nutrients water storage for evapotranspiration) and prevent erosion. The thickness of the recultivation layer typically varies from 0.8 to 1.5 m. The most suitable materials are natural loamy and/or fine sandy soils. Clay soils are prone to compaction during construction. In addition, they may have insufficient water buffering capacity and insufficient hydraulic conductivity. It is recommended to construct during dry periods and use light equipment to maintain maximum porosity.

In some cases, the top most layer can be a soil with a higher organic matter content (e.g. by compost addition) to improve vegetation conditions. In arid areas where vegetation cannot be sustained other materials (e.g. geosynthetics or cobbles) can be used to protect the drainage and barrier layers. In some cases, the thickness might be reduced.

Drainage layer: the drainage layer reduces infiltration and discharges the rain that cannot permeate the barrier. In order to enable transport of water materials with a relatively

Figure 19.4 Construction of a recultivation layer with a bulldozer *Copyright Afvalzorg*

Figure 19.5 Geosynthetic drainage mat (left) and drainage layer over a soil cap *Copyright Afvalzorg*

Figure 19.6 Construction of a geomembrane over a geosynthetic clay liner *Copyright Afvalzorg*

Figure 19.7 Construction of a combined gas collection and foundation layer *Copyright Afvalzorg*

high hydraulic conductivity (e.g. sand, gravel, geosynthetics) need to be used. Furthermore, the entire final cover system requires a slope of 3-5%. The side slopes of the landfill usually are steeper (20% to 33%). Slopes provide a stability risk. Especially under conditions of heavy rainfall and gas pressure building up underneath. Friction between different layers reduces and can result in slope failure. Depending on conditions sometimes special materials need to be selected to prevent erosion and instability. Slopes steeper than 33% require special design and construction. The thickness of the drainage layer can vary from a few cm (geosynthetics) to 15-30 cm (sand, gravel).

Barrier layer: where reduction of infiltration is mandatory, the barrier layer is the most critical component of the final cover. At the same time as preventing infiltration of water into the waste, the barrier also prevents emission of landfill gas to the atmosphere. The barrier layer typically consists of a low permeability plastic polymer geomembrane and/or geosynthetic clay liners or compacted natural clay liners. Since clay liners are granular, by definition they cannot completely stop diffusion. Therefore, they are often overlain with a geomembrane. A geomembrane typically has a thickness between 1 and 3 mm. Compacted clay liners typically have a hydraulic conductivity between 10-9 to 10-11 m/s. Depending on the hydraulic conductivity they are applied in a thickness of 10 to 50 cm. Geosynthetic clay liners typically have a hydraulic conductivity between 10-11 to 5x 10-11 m/s. They are typically applied in a thickness of around 1 cm. The European Landfill Directive in Annex 1 furthermore requires that the barrier provides "sufficient attenuation capacity to prevent a potential risk to soil and groundwater". This is not further explained, but it should be clear that a clay barrier of 50 cm thickness provides more adsorption potential for contaminants than a clay barrier of 1 cm thickness.

Gas collection layer: in order to prevent gas pressure building up under the barrier layer and causing instability and slope failure, a layer of porous material is required to through which the landfill gas can easily migrate. Similar to the drainage layer materials with a relatively high hydraulic conductivity (e.g. sand, gravel, geosynthetics) need to be used. The thickness of the gas collection layer can vary from a few cm (geosynthetics) to 15-30 cm (sand, gravel). Incorporation of horizontal pipes can help to facilitate transport of gas into the gas collection and treatment system. More and more secondary materials are used to construct the gas collection layer and the foundation layer. Secondary materials may contain some contaminants. As the layer is below the barrier, there is no increased risk of extra groundwater impact as compared to the waste body. From an environmental impact perspective, it is advantageous to use secondary instead of virgin materials.

Foundation layer: for construction of a final cover a suitable foundation is required. Settlement within the cap should be avoided to protect the barrier layer. To a limited extent a well-constructed foundation layer can also protect the barrier against further settlement in the waste body. As the name suggest compacted clay liners require compaction. This can only be effectively done when a suitable foundation layer is present. In case a sufficiently porous material is used, the gas collection and foundation layers can be combined. It should be checked if the properties of the foundation and gas collection layer are compatible with the material of the barrier layer. E.g. salts and sharp coarse objects can damage the barrier layer.

19.4.3 Alternative Final Top Covers

In the last two decades new concepts for final top covers have been developed. These alternatives have been proposed either to use other materials, to optimise evapotranspiration from the recultivation layer, to allow water to infiltrate into the waste body to continue the stabilisation processes or to mitigate landfill gas emissions especially at sites with low landfill gas generation rates.

Leak detection: the traditional barrier layer consisting of the combination of a geomembrane and a mineral liner leans heavily on the conviction that the two materials increase the long-term existence of a low hydraulic conductivity. Leaks in the geomembrane will due to the presence of the mineral liner not results in infiltration of large amounts of water. During the lifetime of such a barrier layer this can however not be tested and confirmed. In order to overcome this uncertainty leak detection systems have been developed.

Leak detection relies on geophysical measurements. At specific intervals electrodes are installed both under and above the geomembrane. Periodically a weak electrical signal is sent to individual electrodes on one side of the geomembrane. The geomembrane acts as a resistance for the transmission of the electrical signal. In case there is a leak in the geomembrane, the resistance is lowered and transmitted through the moist soil or drainage sand. Electrodes on the other side of the geomembrane can detect a signal. The strength of the signal measured on individual electrodes provides information on the location of the leak. Leak detection systems are able to detect leaks of several mm2 and locate them with an accuracy of less than 0.5 m. In some countries leak detection can be used to replace the mineral liner in the barrier layer. The advantage of leak detection is that it provides quantitative feedback on the performance of the barrier layer. A disadvantage is that it requires a periodic action and consequently costs to assess that performance.

Capillary barrier concept: a capillary barrier reduces infiltration of water into the waste body. The principle is based on the difference in grain size between two materials. A layer of relatively coarse material underlies a layer of more fine material. Due to capillary forces the water has a tendency to stay in the fine-grained layer. The construction should be on a slope of 5 to 10 degrees. The slope ensures that the water accumulating in the capillary layer can be discharged to a drainage pipe. The layers should be constructed very carefully with sharp boundaries.

Filter-stability is very important. This means that the two materials should have a very distinct particle size distribution. No particles of the capillary layer should intrude or migrate into the capillary block. That would impede the functioning. This implies that the materials are not cheap and construction is complicated. The drainage pipes (depending on site-specific conditions and material properties) should typically be spaced at 5 to 50 m intervals in order not to exceed the drainage capacity of the capillary layer. If that occurs the water enters into the capillary block and then into the waste body. Capillary barriers are most effective when the annual precipitation is less than 600 mm/year. But also with higher annual precipitation a significant reduction of infiltration can be achieved. The overall effectiveness can be further increased by providing more water buffering capacity in the recultivation layer (see evapotranspiration landfill cover).

Evapotranspiration landfill cover concept: evapotranspiration reduces infiltration by use of natural processes, requires simple technology and can be implemented at many sites. Each site does however require a site-specific design because of differences in climate, soil properties and plant cover. It relies on soil and plant transpiration to evaporate most of the precipitation.

The plants are an important feature as they can remove water faster than evaporation alone. They should be native to the site and adapted to the soil. Evapotranspiration can significantly reduce the amount of water infiltrating into the waste body. If more water infiltrates through the cover than the soil layer can hold at field capacity, some water will infiltrate into the waste body. In order to enhance evapotranspiration, it is therefore necessary to maximise water buffering capacity in the recultivation layer. This is

Figure 19.8. Installing cables and electrodes of a leak detection system. *Copyright Afvalzorg*

the reservoir from which soil and plant evaporate. A recultivation layer of appropriate thickness (1.5-2 m) and from suitable material (loamy sand or sandy loam) can be selected. The so-called mid-size pores can easily hold water against gravity. At the same time plants can easily absorb water from them. In a relatively dry climate infiltration reduction is easier to achieve with evapotranspiration than in wet climates.

Leachate recirculation cover concept: in general, final covers are designed to prevent or reduce infiltration of rain into the waste in order to minimise generation of leachate and consequently collection and treatment. This has the disadvantages that large parts of the waste have not been stabilized. In order to enhance stabilization, the collected (and possibly treated) leachate can be recirculated into the waste in order to accelerate the degradation of organic matter. Leachate can be recirculated by means of spraying (not accepted in some countries), by means of transport into trenches or infiltration fields or by means of subsurface injection in wells. Recirculation increases the amount of water infiltrating into the waste body by a factor 3 to 5. In addition to a higher gas generation and accelerated settlement, there will also be a higher leachate production. Recirculation can therefore only be carried out on landfill cells with a fully functional bottom liner and a leachate collection system with sufficient removal capacity.

Methane oxidising cover concept: microbial oxidation of methane can serve in two ways: to complement existing gas recovery, when collections efficiencies are considered not high enough and to replace landfill gas recovery. In some cases, landfill gas recovery might technically or economically not be feasible. Microbial methane oxidation might serve as treatment of residual methane emissions after gas recovery has been terminated or on old landfills without gas collection systems. Microbial methane oxidation systems can also be useful on landfill sites containing waste of low gas generation potential (e. g. dredged material), landfills storing pre-treated wastes or landfills in the initial phase of operation. Another example is waste with low porosity or reduced ratio of vertical and horizontal permeability as a result of which the sphere of influence of gas-wells is limited.

Oxygen is required to oxidize methane, highlighting the importance of oxygen supply for the complete oxidation of methane fluxes. Conversion rates vary greatly in relation to the environmental conditions and the properties of the filter or cover material. Hence, the choice of a material with adequate physical and chemical properties as well as the design and dimensioning of methane oxidation systems in adaptation to the expected methane fluxes and the climatic conditions are of eminent importance to warrant high methane oxidation efficiencies.

Guidelines assume that well designed methane oxidation covers can oxidise fluxes of up to 25 kg per m2 and year.

In principle, three approaches can be distinguished: methane oxidation filters (reactor type operation), gas windows (open compartments integrated into the landfill cover, also called 'methane oxidation windows') and optimized covers (also called 'methane oxidation covers').

19.5 Vegetation

Revegetation of completed landfills is essential in order to adapt the site to the surrounding environment, to improve public acceptance, to minimise erosion on slopes and to minimise leachate production by increasing evapotranspiration. The main aspects to observe for revegetation are gas migration control, soil cover, plant species selection and planting strategies for woody species.

19.5.1 Vegetation Damage

Vegetation on temporary covers or final covers without gas- and watertight lining can become exposed to landfill gas. Vegetation damage due to landfill gas occurs frequently, especially during and shortly after the operational period.

Vegetation damage can be observed as mono-growth, dwarf growth, superficial root development, dying leaves, dying branches or plant death. The damage to plants is caused by migration of landfill gas into the root zone and displacement of soil air. This usually results in depletion of oxygen and consequently anoxic conditions in the soil air.

The plant may be affected by asphyxiation ('suffocation' due to the lack of oxygen), by the presence of toxic gasses or by changes in pH and composition of the soil pore water. The effect of these aspects may be increased by external stress to the plant such as drought and strong wind.

Toxicity of trace gasses in the landfill gas has not been convincingly demonstrated. Asphyxiation is considered a much more dominant aspect. Methane is not considered toxic to plants. The microbial oxidation of methane leads to oxygen depletion in the soil. This adds to the effect of soil air displacement by landfill gas migration. Most plants normally grow at 5-10% oxygen in the soil air. Several woody species are more demanding and require 12-14% oxygen. In a landfill cover with a significant landfill gas flux, oxygen sufficient for plant growth may be found only within shallow depths and the roots will not penetrate deep in to the soil. In such a situation there will be limited access to water and nutrients.

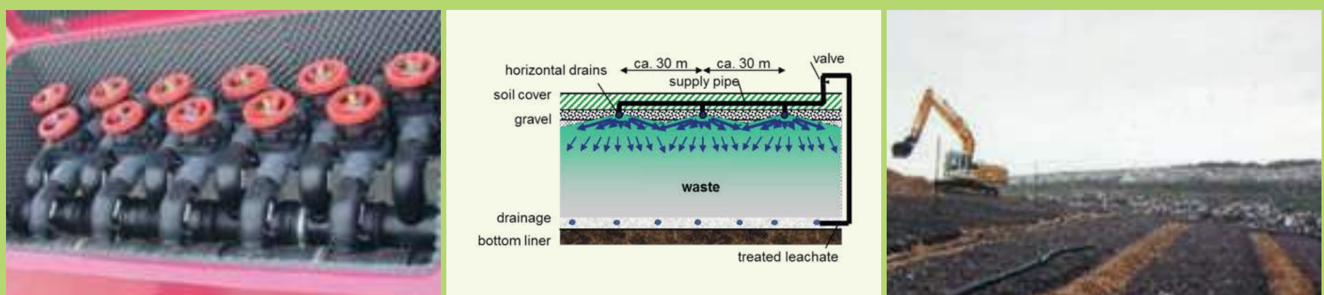


Figure 19.9 Schematic, valve box and construction of leachate recirculation. *Copyright Attero*

19.5.2 Prevention of Vegetation Damage

In order to sustain a healthy vegetation, gas control in terms of extraction of gas is necessary to prevent substantial amounts of landfill gas from migrating into the root zone. Another important aspect for prevention of vegetation damage is the depth, structure and composition of the cover soil. Deep rooting plants cannot be applied on methane oxidising cover soils. The roots could also create preferential pathways and result in local landfill gas emissions. Grass covers require a minimum of 0.5 m soil and trees require a minimum of 1.5 m soil for proper root development. Methane oxidising covers can therefore only be combined with grass vegetation.

In addition, the recultivation soil should provide suitable structure, sufficient water storage capacity and sufficient nutrients. Plants cannot grow without nutrients. Sufficient water storage is necessary for plants in order to survive dry periods.

Structure is necessary for soil aeration. Too much clay can hamper soil aeration and result in cracks and consequently preferential pathways for landfill gas emission during dry periods. Too much sand on the other hand could result in insufficient nutrients and water storage capacity.

19.5.3 Selection of Vegetation

Grasses and herbs provide suitable vegetation for temporary covers. A temporary cover needs to be removed in order to install the permanent clay liners and/or geomembranes. A vegetation of grasses and/or herbs does not require removal. The cover soil can be stockpiled and re-applied on the permanent liner including the remains of grasses and herbs.

The desired vegetation strongly depends on the nature of the end-use selected for the landfill. A park with intensive use will require a different vegetation than a landfill that is not intended to be used, but just fitted into the natural environment. Species selection should always include consideration of the local conditions such as climate, soil types, depth of the soil layer and wind-exposed areas. Alternatively, the soil that is present could be replaced or improved in order to be able to support the vegetation of choice.

19.6 STRUCTURES

19.6.1 Permanent Installations

On the completed landfill several installations have to remain intact and operational for those activities that need to be continued during aftercare. These installations may include leachate collection pits, leachate treatment plants, piezometers, monitoring drains, gas wells, gas manifolds, condensate traps, flares and biofilters. When a gas and watertight liner is installed, transits through the liner for these installations have to be accounted for. In general, existing installations are not designed to allow for the liner to be installed on and around it. The installations usually have to be redesigned and re-fitted. It is considered good practice to try to minimise the transits through the barrier layer. In redesigning it is also recommended to consider the end-use of the landfill. This requires close cooperation between the engineers and the landscape architect. Thus, installations can be located where they are least conspicuous. Piezometers and gas wells can be equipped with lids at 'grass root level'. Gas manifolds with control valves can be located in shrubberies. A flare can be located behind a group of trees. At the same time the installations should be accessible for the people that operate, maintain and monitor them. On those sites that are freely accessible to the general public the installations or the access to the installations also needs to be 'vandal proof' in order to guarantee continued functionality.

19.6.2 Decommissioning

Various structures on a landfill lose their functionality when waste disposal ends. Some of these structures may still be useful during closure. A weighbridge may be used for establishing the correct amount of construction and capping materials. The site office, canteen and sanitary facilities can be used by the contractor responsible for capping and landscaping. It should not be excluded that a building or the foundation of a building can have a function for the new destination of the landfill. Structures that become obsolete should be torn down and taken away or integrated into the landscape. Fencing can be taken down in case the new destination offers unlimited access to the general public. This is however not always the case. In some countries, landfills often are not opened to the public. In this case the fencing needs to be maintained.

12.4. CONCLUSION

Prevention of leachate migration and contamination of ground and surface water can be accomplished through implementing effective operational practices and engineering controls at the landfill facility. Operational practices to divert local precipitation and surface water run-on to the waste mass are an effective means to reduce the quantities of leachate generated.

Depending on the local requirements a single process might not achieve the requested results to cover all local environmental, economic and social needs. Whereas the dimensioning of a leachate treatment plant mainly depends on the actual load and quantity of the leachate, the determination of the appropriate process or process combination is above all a matter of observing the respective limit values. The processes available may hence be classified according to the discharge limits fixed.

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