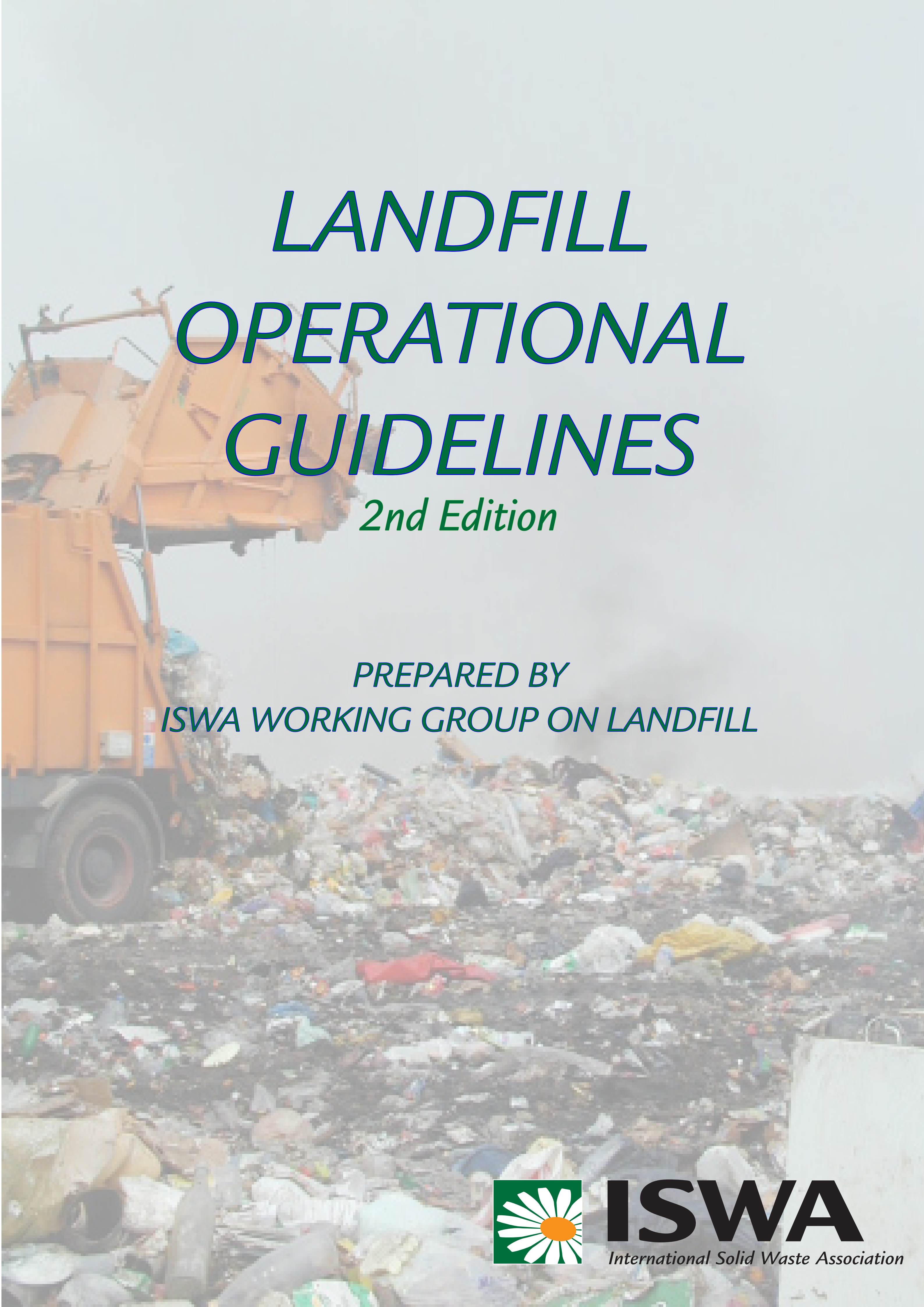

LANDFILL OPERATIONAL GUIDELINES

2nd Edition

PREPARED BY
ISWA WORKING GROUP ON LANDFILL

ISWA
International Solid Waste Association

PREFACE

The Landfill Operations Guidelines were first produced in 2002 as a loose leaf document to assist waste managers with the day to day operations of landfills. At that time it was not intended to be a technical document but one providing general guidance which would lead to improved operational practices.

The guidelines have now been updated by the ISWA Working Group for Landfill to reflect current operational practice and as appropriate some technical guidance. The guidelines now include a number of photographs which are used to illustrate the activities described.

The Working Group is particularly indebted to Tony Kortegast (Tonkin and Taylor International, New Zealand) who has edited the document ensuring consistency.

Contributions from the Working Group were from Derek Greedy (Chair Landfill Working Group, Warwickshire County Council, UK), Prof. Dr. Günay Kocasoy (President of Turkish National Committee on Solid Waste, Boğaziçi University, Turkey), Antonis Mavropoulos (Chair of Scientific and Technical Committee and EPEM, Greece), Jan Thrane (Vice Chair Landfill Working Group and Odense Waste Management Company Ltd., Denmark) Reuben Ossai (President of the Waste Management Society of Nigeria and The Initiates Ltd., Nigeria), Dr. Bharat Nagar (Jamshedpur Utilities & Services Company Limited, India), William de Bord (Caterpillar Inc., USA), Steve Hamilton (SCS Engineers, USA) and Diana de Bastos and Helena Bergman (ISWA Secretariat, Austria).

Derek Greedy
Working Group Chair

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TABLE OF CONTENTS

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. Access for landfill equipment also needs to be considered and often this needs to be on separate roads or equipment tracks.

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 ROADS

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. 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.

Figure 1.1. Site approach road

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.

Figure 1.2. Primary access road

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).

Figure 1.3. Barriers at a primary access road

1.5. SECONDARY ACCESS ROADS

Hard-core (gravel) roads, as shown at Figure 1.4, 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.

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.

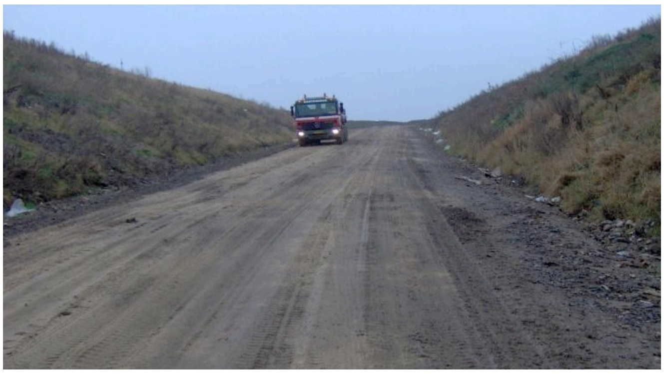

Figure 1.4. Hard-core secondary access road

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, 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.

If gravel aggregate is used, as with secondary access roads, a geofabric can be utilized to 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.

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.

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

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.

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.

Figure 2.1. Application of daily cover

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.

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 poor 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 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.

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 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.

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.

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	

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

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 2.4. Advantages and disadvantages of artificial/synthetic 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

Figure 2.2. Application of Geotextile Matting

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.

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

3.1. INTRODUCTION

Birds frequenting 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 and roof-water supplies. 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 will increase, as it is shown in Figure 3.1 this will the potential to attract more birds from a greater distance around the landfill site.

Figure 3.1. Birds at the landfill

3.2. BACKGROUND

Before bird numbers can be controlled at a landfill, it is important to have an understanding of 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 all of these, depending on the type of bird.

When a bird infestation issue is to be dealt with, it must be taken 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. Provided that 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 and Direct Shooting
- Heli-kites and Balloons
- Distress Calls
- Signal Pistols and Cartridges
- Falcons and Raptors
- Wires and Screens

3.4. OPERATIONAL PRACTICES

Effective management of the working face is the starting point when attempting to reduce bird numbers. 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 the next 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, a number of 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.

Lethal methods of bird control are sometimes not acceptable and may contravene local legislation. Also, public concern over lethal methods of control may produce adverse local comment. However, shooting and poisoning do 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.

Gas guns (bird scarers) are a non-lethal alternative to shooting or poisoning that are simple to operate and can be very effective for short periods at a time. 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 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.

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.

Figure 3.3. Spacing of wires

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 a considerable period of time to achieve.

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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.

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.

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.

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 4.1).

Figure 4.1. External Road Network

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

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. 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 offsite 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 fencing
- Bunds
- Litter 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 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.
- Keeping the working area as tight as practicable.

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. 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. 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.

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

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 general 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 tot e 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 <u>all</u> solid waste at all times, except the tipping face while it is being worked. Daily cover of at least 150mm of 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 operation 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.

There should be no uncontrolled or uncovered (stockpiled) waste, including litter, tyres, brush, appliances, construction/demolition waste or even inert industrial waste on the landfill property. 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.

Figure 6.1. Typical rat often found at landfills

There should be no ponding water on the landfill property except as designed for runoff storage or sedimentation. Sedimentation ponds can, however, aid vector reproduction if not designed and controlled properly so as 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 in particular. 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 on a daily basis 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 are able to 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, sightings, 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. shooting 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 birds, 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 face. 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 even then, only if there have been no problems noted over an extended period. As a minimum, monthly monitoring is recommended.

CHAPTER 7

MANAGING THE WORKING FACE

7.1. INTRODUCTION

The working face is the focus of activity 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 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 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).

Figure 7.1. Placement of the first layer of waste

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 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.
- 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 area 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 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 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.

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 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 m and each truck should stop at least 2-3 m 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.

Figure 7.2. Trucks unloading their waste

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 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. Waste Compaction/Placement

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.

Figure 7.3. Compaction of the wastes at the landfill

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. 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 10H to 1V 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 3H to 1V 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 the Working 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.

7.3.9. 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.

Figure 7.4. Bulky waste

- 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.

Figure 7.5. Low density wastes

7.4. 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.

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

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 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?		

7.5. CONCLUSIONS

The working face is the most critical part of any landfill operation. It is the centre of vehicle, equipment and personnel activity; 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, increase acceptance by neighbours and regulators, and result in the efficient utilisation of landfill air space.

CHAPTER 8

WASTE COMPACTION

8.1. BENEFITS OF WASTE COMPACTION

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:

- Compacted waste provides a stable surface for vehicles to move on and on which to establish access roads and tipping areas.
- Birds and rodents find it more difficult to dig into the waste to access food.
- Compaction helps to prevent litter escape from the site surface.
- Well compacted waste inhibits odour release.
- Well compacted waste reduces fire risk.
- Compaction displaces air and increases the rate of onset of anaerobic conditions.
- A compacted surface aids stormwater run off and provides a good base for applying cover soil.
- Well compacted waste consumes less airspace.

A thoroughly compacted waste pile is the first sure sign of a well managed operation.

Compaction is typically achieved using a bulldozer or a specialist waste compactor, as shown at Figure 8.1. Waste compactors can achieve relatively high waste densities (in excess of $1 t/m^3$) and can result in very efficient airspace utilization. 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 provide a better, more efficient machine option. The term “compactor” in the following discussion covers either a specialist landfill compactor, or a bulldozer, or a combination of the two, as applicable.

A high waste density should always be targeted and this should be checked by regular surveys using airspace geometry (allowing for settlement) and waste tonnage data. Densities of $> 0.85\ t/m^3$ should be readily achievable with modern equipment. Densities less than $0.6 – 0.7\ t/m^3$ significantly reduce landfill efficiency and will increase the risk of landfill fires.

Figure 8.1. Wastes compacted by bulldozer/compactors

8.2. COMPACTION METHODS

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 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.

The compactor, as it pushes the waste to its final point of disposal, will mix, track over, and crush or shred it. Once crushed/shredded and in place, the compactor should pass over the waste a number of times, but as a minimum four passes is typically used to achieve effective compaction. While the optimum amount of compaction is controlled by a number of variables, including the nature of the waste and the machinery used, there is usually little benefit from exceeding four passes over the waste.

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. Asian waste) will likely require less than 4 machine passes to optimize compaction.

The waste should be placed in layers targeted at no more than 300mm-400mm in compacted thickness and where practical, compaction should be up-slope (typically 3H:IV-as shown at Figure 8.2) to maximize the compactive effort of the machine.

Figure 8.2. Compaction slope (3:1) of the landfill area

The waste layers should be formed into slopes to aid surface water run off following cover placement. Compacted slopes should, where possible, be diverted towards internal drainage paths as leachate and landfill gas will preferentially follow these layers. As a consequence it is better to have waste slopes at the 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. CONCLUSIONS

Well-compacted waste is an essential component of good management at a landfill site and an efficient, practical method should be developed at each site to ensure a high degree of waste compaction is routinely achieved. Compaction methods create preferential pathways for the flow of leachate and landfill gas and therefore should be directed inwards towards drainage pathways within the waste mass to encourage the flow of leachate and landfill gas, and to minimize the risk of leachate breakout.

CHAPTER 9

LANDFILL FIRES

9.1. INTRODUCTION

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.

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 in the waste such as paper, plastics and wood represent the main fuel. Oxygen is usually present in the wastes when deposited, or it can be drawn in through the surface. Finally there needs to be a source of ignition: sufficient heat to ignite the combustible material and sustain the combustion (e.g. hot ash), smouldering material, sparks, spontaneous combustion chemical reaction, or even arson.

Figure 9.1. Fire at the landfill

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 m^3 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.

Fire at the landfill area is shown at Figure 9.2.

Figure 9.2. Fire at the landfill area

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 fire fighting, 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
- Characterization of the fire – choice of alert level
- Appointment of an incident commander
- Application of communication plan
- Selection of the most appropriate fire fighting 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 9.3)

Figure 9.3. Protective Equipment to be used in the vicinity of a fire

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 fire-fighting 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 h 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 fire fighting 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.

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 thermister strings is recommended. A multi-channel read out box is used to measure temperatures at surface, as shown at Figure 9.4.

Figure 9.4. A multi-channel read out box

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 9.1, the relation of landfill conditions and temperature is presented:

Table 9.1. The relation between landfill conditions and temperature

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

9.5.2. Gas Composition Monitoring

Monitoring of gas composition provides very useful insight fire conditions at depth and the success of fire fighting 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 9.2 an empirical scale is presented that assists to the assessment of fire conditions in demolition landfills.

Table 9.2. The relation between CO concentrations and fire at the landfill

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

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. 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 to 21% oxygen. As fire fighting 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 fire fighting 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. Fire Prevention and Control Plan

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.

9.6. CHECKLIST

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 9.3 remedial action must be considered.

Table 9.3. Checklist for monitoring landfill area

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		
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		
There is stockpile of earth close to the working face		
There is on site 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		

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.

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. 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. This can potentially lead to significant contamination of runoff from the site and ultimately of surface receiving waters 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 are 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 water by waste either directly or due to leachate 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 fire fighting (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.

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 and that there is the potential for impact on the Landfill operations area (for example due to secondary drain overflow into 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 (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. The main rule of thumb is that any rainfall or surface water contacting waste must be treated as leachate, so clearly 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

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.

Prohibited wastes can include specified waste categories such as tyres, sludge 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 waste 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 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 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.

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, and other legal instruments.

These criteria are usually implemented jointly by both the facility operator and regulators. Facility permits often detail operational procedures, guidelines, and other procedures to be adopted by a facility. The fundamental objective of such control methods is to ensure adequate:

- Pollution control
- Operational and public safety
- Information management
- Optimisation of Facility capacity.

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 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).

Figure 11.1. Site roads reaching to landfill

11.1.4. Levels of Control

The degree of facility control achieved can be are 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 are vulnerable to receipt of all types of waste and to 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 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, are usually associated with this level of facility operation.

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.

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.

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.

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.

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.

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).

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. 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.

Figure 11.2. Entrance to a sanitary landfill

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. 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.

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.

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.

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.

Figure 11.3. Waste reception at the landfill

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

12.1. INTRODUCTION

Leachate is the liquid generated from solid waste decomposition in a landfill. Leachate derives 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. 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. The dissolved and suspended constituents of leachate have the potential to cause groundwater and surface water contamination.

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[1] of liquids entering the waste mass.
- Installation and operation of an engineered leachate collection and extraction system.
- Installation and operation of a leachate treatment system (Figure 12.1), and/or shipment of leachate to an off-site treatment facility.

Figure 12.1. Typical leachate plant

[1] In some cases leachate is deliberately recirculated for reasons of increasing waste degradation or seeding the landfill cell to promote the onset of methanogenic conditions.

The impetus for these controls is achieving minimal build-up of leachate within the waste mass 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.

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 is to prevent 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

Techniques used at the working face of the landfill can help to reduce the amount of infiltration (that is, precipitation) into the landfill. Appropriately compacting and covering completed cells promotes reduced waste infiltration and increased run-off away from the active area. Good compaction of waste and daily cover materials 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. Temporary diversion berms can also be created near the working face to capture and direct surface water flow away from the active portions of the landfill. 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 surface water away from the waste mass. In addition, diversion ditches, trench drains, and localized soil berms may be constructed to guide 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 reduce 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

Even with good operational practices and surface water controls, most landfills will generate leachate. This leachate must be managed so as to prevent contamination of 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 12.2.

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.

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
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.

Figure 12.2. Leachate collection and conveyance system

12.2.6. Leachate Treatment

Leachate treatment options include the following:

- Direct discharge to a receiving body of water (only if permitted by regulations and the leachate is relatively weak);
- Discharge to publicly owned sewage treatment works sometimes with limited on-site pre-treatment;
- On-site physical, chemical, thermal, or biological treatment;
- Land application or land treatment;
- Recirculation back into the landfill;
- Passive evaporation to the atmosphere (often through aeration in holding ponds or storage lagoons); and
- Active evaporation units powered by electricity or landfill gas.

Selection of the most appropriate option at a particular site will depend on a range of factors including:

- Site location relative to sewage works
- Volume and strength of leachate generated
- Climatic conditions
- Nature of the waste
- Availability of land for on-site treatment
- Capital and operating cost considerations.

12.3. CONCLUSIONS

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.

A good standard of engineering design of landfill liner and leachate collection/conveyance systems serves to reduce leachate movement outside the waste mass and to enable leachate to be extracted thus minimizing the head on the liner. The leachate can then be stored or pumped for proper handling and subsequent treatment with the most appropriate leachate treatment option(s) being a very site-specific decision.

CHAPTER 13

ODOUR CONTROL

13.1. INTRODUCTION

Odour can occur at a sanitary landfill occur as a result of the biodegradation of wastes and 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.

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
- 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 masking sprays where appropriate
- Use of buffer zones (maximizing separation distance)
- Careful planning of working face location.

13.3. DISCUSSION OF ODOUR CONTROL MEASURES

13.3.1. Restriction 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 seepage 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. Properly Covering Wastes

Once layers of waste have been placed and properly compacted in the landfill, soil (or sometimes other alternate) cover 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. Other materials such as wood chips are sometimes used, but are generally less effective than cover soil in terms of odour control.

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.

13.3.3. 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 m^2 (say 30 metres wide and 20 metres in length). This serves to minimise the surface area from which fugitive refuse odours can escape.

13.3.4. 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.

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 1000ºC 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.

13.3.5. 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.

13.3.6. Odour Masking

Chemical odour masking 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 masking chemicals come in a range of formulas and can mask or chemically neutralize odour-causing compounds. Odour masking agents when used in conjunction with a control system based on wind direction can prove useful in masking or scenting the odour and altering its hedonic tone, thus reducing the risk of odour nuisance. Masking agents 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).

13.3.7. 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.

13.3.8. 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.

13.4. CONCLUSIONS

Controlling odours at a sanitary landfill is best achieved 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

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 (55° to 70°C approximately), 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 (38° to 55° C), significantly higher CH_4 concentrations (40 to 60%) and lower CO_2 concentrations (40 to 48%). 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 total volume of production may vary widely over time. The total amount 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, 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 10%
Hydrogen (H_2)...< 1 to 3%
Water Vapour (H_2O)...1 to 5%
Trace Constituents...< 1 to 3%

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 also is 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 due primarily 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) range 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 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 four 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 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 (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 H_sS.

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.

14.4.1. Passive Venting Systems

No active mechanical means are employed for a passive venting system[2]. 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.

[2] In some cases wind or thermal vent cowls are used.

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
- Other facilities to process the gas, and gas to energy equipment.

Figure 14.1. Landfill gas reception compound

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 14.2) 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.

Figure 14.2. Monitoring at landfill

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.
- 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 14.3) 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.

Figure 14.3. Gas engines

14.6.2. Direct-Use

In this application, the collected LFG typically is minimally processed and then sent to a nearby end-user (Figure 14.4), 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.

Figure 14.4. Greenhouse heated by LFG

14.6.3. Pipeline Quality Gas

The production of pipeline quality gas from LFG requires more extensive processing in order to remove all virtually all 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. H_2S, 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 is usually destroyed by combustion in an enclosed (tube) 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

GUIDELINE FOR SITE SAFETY AND SECURITY

15.1. INTRODUCTION

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

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.

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

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.

15.2. 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.

15.3. PERSONAL PROTECTIVE EQUIPMENT

All site users must be equipped appropriately. 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 midsoled and steel toecapped footwear
- Ear protection
- Dust masks
- Goggles or face masks
- Communication devices - air horns, whistles, intercoms, or radios.

Figure 15.2. A properly dressed labourer at the landfill

15.4. 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.

15.5. 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 stormwater 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. BLOOD-BORNE AND OTHER PATHOGEN SAFETY

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 developing country sites where various degrees of scavenging may be occurring, without suitable attention to waste control and hence to managing this risk pathway.

15.7. 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.

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).
- 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.

15.8. 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.

Figure 15.3. Typical safety sign

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.

15.9. 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.

SUBJECT INDEX

C

G

M

R

S

X