GUIDELINES

FOR THE

DISPOSAL OF WASTE BY LANDFILL

First Edition,
1997
GUIDELINES

FOR THE

DISPOSAL OF WASTE BY LANDFILL

The principal method of waste disposal in Botswana is by land burial. The uncontrolled burial of waste however can lead to serious groundwater pollution problems. For a country almost totally reliant on its already scarce groundwater resources, it is important that the standards of waste disposal by landfill are sufficiently improved to minimise the risk of pollution to water resources, and furthermore to public health and the degradation of natural resources. Water is a public commodity, and it is not ours to pollute as we wish. Due to the regional characteristics of water, any actions by users or polluters of a water source, will affect other "innocent" persons downstream of that source.

Legislation is being drafted which will require all landfill sites (as well as all waste facilities, transporters and even generators) to be licensed. In this respect, it is essential that the licensing authority has a guideline on which to base their licensing decisions, and the specific licensing conditions which they are to impose on each individual facility.

The underlying philosophy and guiding principles used in drawing up the guidelines are that they should be:

- regionally compatible - to avoid the situation where Botswana could become a dumping ground for the southern African region, merely because it has lower environmental standards than the neighbouring countries
- specific to Botswana - to incorporate the specific social, cultural, economic and political criteria within Botswana
- affordable without compromising on risk - to provide optimum protection of water resources

Because of its sparse population, and the predominance of small villages in the country, and being a largely and country, a degree of flexibility is needed in specifying requirements. A system of graded standards has therefore been introduced, where the requirements could be adjusted up or down according to the risk imposed. Graded standards, an innovation developed and used extensively by the authors of the South African minimum requirements for landfills, are applied to different categories of landfill site (categorised according to its risk of pollution) as defined by the type and the quantity of wastes to be landfilled.

In this way the standards for landfilling of waste can be improved without incurring excessive development and operation costs, and without subjecting the community to an unacceptable risk.

I believe that these guidelines are practical and specific to Botswana, yet regionally compatible, and should be widely used by waste management practitioners. The guidelines should be seen as a dynamic set of requirements which will change with time, to reflect the latest in relevant landfill technology as the results of world-wide landfill research dictates. Thus the document should have a shelf life of approximately 5 to 10 years before revising it to reflect the latest in landfill technology and world-wide trends at that time.

I would like to acknowledge the many people in government, councils, NGO's and private enterprise, who have provided valuable and
constructive comments, criticism and suggestions. These have all assisted in developing these guidelines, both through various workshops and discussions held in the country, and through written responses.

In particular I would like to single out the Department of Water Affairs and Forestry (DWAF) of the Republic of South Africa who provided a model with their Minimum Requirements for Waste Disposal by Landfill, and the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) who have provided both technical assistance and funding for the project.

Furthermore I would like to especially acknowledge our international contributors, Mr Nick Crick of Integrated Skills Limited (United Kingdom), Mr Jarrod Ball of Jarrod Ball and Associates (South Africa) and Metago Environmental Engineers (South Africa), Dr DorhSfer, Busch and Oeltzschner of Germany, and locally Ecosurv Environmental Consultants, Messrs Selotlegeng, Nels, Hojem and Matsoga of the NCSA/GTZ Waste Management Project and Mr Mokokwe of DGS for their contributions.

Without the valuable effort and time put in by many of the Environmental Health Officers, Health Assistants and Technical Officers throughout the country, officers from other authorities, consultants, NGO’s and the University of Botswana, these guidelines could not have been developed and seen as a home grown product.

R P ( Balopi

Minister of Local Government Lands and Housing
LANDFILL GUIDELINES FOR BOTSWANA

These guidelines indicate the required standards for waste disposal in Botswana and provide the basis on which the Department of Sanitation and Waste Management (DSWM) will issue Licences for landfills under the proposed Waste Management Act. The DSWM's objective in developing the guidelines is to take pro-active steps to prevent pollution and to improve the standard of waste disposal in Botswana by:

- Providing guidelines for **environmentally acceptable waste disposal** for a spectrum of landfill sizes and types
- Providing a framework of **cost-effective minimum waste disposal standards** within which to work and upon which to build.

The aim is to provide **affordable environmental protection**. This is achieved by applying graded standards to different classes of landfills. Landfills are therefore classified according to waste type, size of operation and pollution potential. Where high moisture or hazardous waste is involved or where significant leachate is generated, the most stringent standards are applicable.

There is an important relationship between all aspects of the landfill process. Good landfill site selection provides for simple cost-effective design, which, provided the site preparation is correctly carried out, provides for good operation. This in turn ensures the environmental acceptability of the landfill. Environmental acceptability, in its turn, often relates directly to public acceptability. The Guidelines therefore **cover all technical aspects of landfill development, operation and closure**.

The Guidelines will be taken into consideration by the Department of Sanitation and Waste Management (DSWM) in setting licence conditions, they are thus implemented and enforced through the Landfill Licence system. **The Licence Holder is ultimately responsible and accountable for the landfill and any effect it may have on the receiving environment**. He may, however, appoint a suitably qualified Responsible Person, e.g. a consultant or manager, to ensure the application of the Guidelines on his behalf.

The first step in applying the Guidelines is to classify the landfill under consideration, whether it be proposed or existing. Thereafter all applicable Guidelines are based on this classification.

In the case of new landfills, site selection procedures are based on "negative mapping", whereby unsuitable areas for the location of landfills are eliminated. Site selection also requires the due consideration of alternatives in that more than one site must be considered. Site feasibility is then based on both technical suitability and public acceptance.

The extent and nature of site investigation will vary depending on the landfill classification and status. In most instances, however, it will involve a hydrogeological investigation and an environmental impact assessment (EIA). Based on this information, a site design will be prepared. This may be a new site design, an upgrade of an existing design, or closure design. In most cases, however, the basic design parameters, together with an end-use plan, must be addressed.

The results of the investigations and the design, together with certain additional information, must be collated and presented in a formal Licence Application. Based on this, the DSWM will grant a licence to operate a landfill, either as an operating site or with a view to closure.

Once a licence is granted, new landfill sites require to be constructed and prepared for waste disposal, while existing sites may require upgrading and/or restoration. Thereafter, landfills must be operated and monitored in accordance with the Licence Conditions which will reflect the Guidelines applicable to the class of landfill under consideration.
In the event of closure, the Licence Holder or landfill operator must inform the DSWM of his intention to close the facility. Once restoration and the closure design have been implemented to the satisfaction of the DSWM, the site may be permanently closed and an end-use plan may be implemented. Aftercare of the closed landfill site and ongoing monitoring must then continue until the DSWM accepts surrender of the licence when the landfill has stabilised, which may be after a period of many years.

Throughout the landfill development, operation and restoration, a close liaison must be maintained with the DSWM. At certain critical points, written consent must be obtained, before certain steps may be taken. In this way, and with the use of the Landfill Site Licensing Procedure, the DSWM will be able to enforce the Guidelines.
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1. INTRODUCTION AND OVERVIEW

1.1 LONG TERM WASTE MANAGEMENT OBJECTIVES FOR BOTSWANA

The Waste Management Strategy for Botswana is intended to enable the country to achieve a state of sustainable waste management within the next few years. It is based on three cardinal objectives:

- Protection of human health
- Protection of the environment (water, air, soil, biodiversity)
- Protection of natural resources - land, raw materials and energy

In addition, a fundamental tenet is the internationally accepted Waste Management Hierarchy, shown in Figure 1-1.

![Figure 1-1: Hierarchy of Waste Management](image)

Preventing waste from being produced is clearly the first goal. Waste minimisation, however, is not a simple technique which can be applied universally. It is an attitude of mind and requires commitment from all sectors of society. From industry much can be achieved by good housekeeping and materials management within the factory. Other techniques which may be used involve more fundamental changes - in input materials, product design and process changes.

In the household, waste minimisation can be achieved through better buying habits - only appropriate amounts and sizes of goods- and by re-using items.

Recycling and reuse of materials is supported by government as a long term aim to reduce environmental problems. Separation of materials at source, whether in industry or the home, makes the process of recovery and recycling easier. Recycling is a function of the economy. It is founded on the basic law of supply and demand. Recycled materials are of great economic importance. They are frequently less costly and more readily available than primary materials, and play a competitive role in keeping the price of those primary materials within manageable limits. They conserve world resources of both finite and renewable materials. They often reduce pollution and divert materials that would increase the burden of disposal from the waste stream. Furthermore, there are some costs incurred if recycling is not undertaken such as provision of litter control, medical costs of personal injury and the impact on the tourist industry.

Life cycle management is a wider concept than both waste minimisation and recycling, although it incorporates both of these issues. It is based on the principle that, in order to minimise the adverse environmental impact of the manufacture and use of manufactured products, it is necessary to manage what happens to the physical resources (i.e. materials and energy) of which such goods are made throughout the life of the product and beyond, i.e. over the five stages in the product’s life - manufacture, distribution, use, reuse and final discard.
Waste management facilities are required after all methods of preventing, recycling and controlling waste have been exhausted. The final waste product must be treated, if necessary, and disposed of. Special wastes should be treated, chemically, physically or biologically, to prepare them so that they may be deposited or discharged without harm to the environment. There are a range of processes available, including incineration, which depend on the nature of the particular waste stream. The technologies are relatively complex and need specific expertise.

Landfill sites are a central and essential component of any waste management concept. Despite active waste prevention and recycling, a residue will always remain which requires final disposal. Furthermore, landfill, if carried out properly, is an environmentally acceptable and low cost solution for the disposal of a wide range of wastes, including household waste which makes up the largest part of the waste produced in Botswana. Some countries oppose landfill because land availability is at a premium. Botswana has a low population density and, in relative terms, this is not a problem. Landfill will therefore be the most widely employed method of waste disposal for the foreseeable future.

The important objective is to ensure that landfill is carried out in such a manner that it does not cause harm to the environment. This can be done by ensuring that landfills are located, designed, constructed, operated and restored so as to ensure that ground and surface waters are not contaminated.

1.2 INTRODUCTION TO THE LANDFILL GUIDELINES AND LANDFILL LICENSING PROCEDURE

The purpose of these Guidelines for Landfills is to provide a basis for the policy and a minimum requirement on which the responsible body will issue Licences for landfills. It is anticipated, subject to the passing of the expected waste management legislation, that this body will be called the Department of Sanitation and Waste Management (DSWM) and this terminology has been used throughout the Guidelines. Every landfill is unique, however, and the DSWM will use its informed discretion in the implementation of the Guidelines. The Guidelines also provide practical information which will enable Licence Applicants, Licence Holders and their appointed advisers and managers to comply with the policy of the DSWM and with any associated legislative requirements.

The objectives of the Guidelines for Landfills are:

• To improve the standard of waste disposal in Botswana
• To provide minimum requirements for environmentally acceptable waste disposal for a Spectrum of landfill sizes and types, although according to individual site characteristics, at the discretion of the DSWM, the requirements in the licence could be more stringent
• To provide a framework of sustainable waste disposal standards within which to work and upon which to build.

The Guidelines are designed to protect public health, the environment and local amenities, using appropriate and cost effective methods.

Since landfills differ from one another, the Guidelines use a classification system whereby landfill types are differentiated according to size of operation, waste type and potential threat to the environment. Graded standards are then applied to the different classes of landfill. Once a landfill has been placed in a class, only the standards appropriate to that class need to be met. In this way the Guidelines ensure environmental acceptability for the full spectrum of landfills, from a small communal pit to a regional hazardous waste landfill, in a cost-effective way.
It must be emphasised that **The rule rather than the exception decides the Guideline.** This is fundamental to the approach used in the formulation of the document and must be borne in mind when applying it. The principles involved in the Guidelines cannot address every situation. The Guidelines therefore represent a reference framework of standards, which as a rule should be adhered to. In exceptional circumstances, however, deviations from the Guidelines are permissible. Where exceptions exist, these must be identified, and increased or relaxed standards must be based on defensible scientific research at the discretion of the DSWM.

Under the proposed new legislation, the Guidelines will be implemented through and enforced by the Landfill Site Licence. The granting and the retention of a Licence will depend on the landfill meeting with specific conditions which will be imposed by reference to the Guidelines. The conditions appearing in the Licence represent enforceable standards for that specific landfill. Unlicensed operating landfill sites will have to follow the same licensing procedure as new sites. In instances where operating landfills are unable to comply with the appropriate requirements within an agreed period, they will have to be closed in accordance with the closure conditions incorporated in a Licence for Closure.

The licensing procedure will be detailed in a regulation according to the proposed new act for the licensing of any waste management facility. In general the procedure for landfill sites is indicated in Figure 1-2, but the regulation condition will take precedence.

Once a Licence has been granted, the Licence Holder will be legally liable to operate the landfill in accordance with the Landfill Site Licence, both during its operation and after closure. It is the responsibility of the Licence Holder to amend the site classification appropriately, should a change in circumstances affect the classification of a landfill site.

In executing his responsibility, the Licence Applicant or Holder may appoint staff or consultants, who are appropriately qualified to the satisfaction of the DSWM, to co-ordinate and supervise the different phases of landfill development. Different people may, therefore, be appointed as the Responsible Person for different phases or facets of the landfill development and be accountable to the Licence Applicant or Holder for ensuring that the work undertaken is properly and competently directed, guided and executed. The Licence Holder will retain ultimate liability for the actions of those he may appoint as a Responsible Person.

This document follows the logical sequence of procedures in the development of a landfill, which is shown in Figure 1-2. **Site selection, investigation, design, preparation, construction, operation, closure and monitoring are each addressed**, consecutively, in their respective sections.

Landfills have been divided into several classes, each representing a different order of magnitude of risk to the environment and public health. Table 1-1, which is based on the Landfill Site Classification System described in section 2, shows the typical format used in tabulating Guidelines.
Introduction And Overview

Figure 1-2: Procedure for Operating and New Landfills

OPERATING LANDFILL

1. Classify Landfill
2. Investigate site
3. Upgrade landfill design
4. Operate and monitor landfill according to Licence Conditions

NEW LANDFILL

1. Classify Landfill
2. Rank candidate landfill sites and select
3. Assess feasibility
4. Investigate site
5. Design landfill
6. Prepare site and construct facility
7. Operate and monitor landfill according to Licence Conditions
8. Close landfill and restore site

DSWM = Division of Sanitation and Waste Management

Carry out monitoring and aftercare as prescribed in the Licence Conditions
Introduction And Overview

Table 1-1: Format of Tabulating Guidelines

<table>
<thead>
<tr>
<th>WASTE TYPE</th>
<th>I Inert Waste</th>
<th>G - General Waste</th>
<th>Sp - Special Waste</th>
</tr>
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<tr>
<td>LANDFILL SIZE</td>
<td>V Very small</td>
<td>S Small</td>
<td>M Medium</td>
</tr>
<tr>
<td>Environmental Impact Assessment</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Groundwater Monitoring</td>
<td>N</td>
<td>N</td>
<td>D</td>
</tr>
<tr>
<td>etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LEGEND

C: Compulsory
D: Discretionary - Opinion to be given by DSWM
N: Not compulsory:

A "C" on the Guidelines Table indicates that the requirement is **compulsory** for the class of landfill under consideration.

An "N" indicates that the requirement is **not compulsory** for that class of landfill.

A "D" indicates that special consideration is required at the discretion of the DSWM. The Licence Holder must therefore obtain the opinion of the DSWM.

At the end of each section, a table in the above format is provided which defines the applicability of each guideline to each landfill class.

1.3 OVERVIEW OF THE GUIDELINES

The term "landfilling" refers to waste disposal on land, whether it be the filling in of excavations or the creation of a landfill above grade, where the term "fill" is used in the engineering sense.

In contrast the term "site" only refers to the particular piece of land upon which the waste facility is planned or situated. It should be noted that landfills are frequently referred to as "landfill sites" and in this document the word "site" may at times be used to refer to a landfill.

Historically in Botswana, all wastes have been disposed of on land, because landfilling is the cheapest and most convenient method of waste disposal. No matter what volume reduction or resource recovery is implemented, waste will continue to be generated and some residues will always ultimately have to be disposed of in landfills.

Landfilling is environmentally acceptable if properly carried out. A landfill may be regarded as a construction project, carried out over a period of time, to build a desired landform using waste materials and incorporating appropriate environmental protection measures. Unfortunately, if
Introduction And Overview

not carried out to sufficiently high standards, landfilling has the potential to have an adverse impact on the environment. Such impacts may be divided into short term impacts and long term impacts:

Short term impacts, such as flies, odour, unsightliness, windblown litter, are nuisances which are generally associated with a waste disposal operation. They can be minimised, however, by effective management and should cease with the closure of the landfill.

Long term impacts, such as pollution of the water regime and unacceptable final profiles, are generally associated with incorrect landfill site selection, design, preparation or operation. These, together with the problems of disturbed and degraded land, may persist long after the landfill site has been closed.

Environmentally acceptable landfilling therefore aims at avoiding the degradation of the environment, and especially at preventing pollution of the surface and ground water by any leachate produced.

An important relationship exists between the siting, the design and the standard of operation of a landfill. In essence, good landfill site selection provides for simple cost-effective design, which, provided the site preparation is correctly carried out, provides for good operation. For example, a site should not be selected if it does not allow for a proper drainage design to ensure that upslope run-off does not enter the waste body.

Several types of landfills are envisaged for Botswana according to the classification system proposed further in the document. Normally only General wastes are generated in the vicinity of villages and smaller towns, while Special wastes and General wastes will be generated in the more industrialised and larger towns and villages. These should be disposed of separately from the General waste because of their properties and quantities. Inert landfills will be required where considerable amounts of demolition rubble is produced, mainly in the vicinity of the few larger towns.

1.3.1 Selecting a Landfill Site

A landfill site should only be selected after appropriate candidate sites have been identified and given due consideration.

The criteria which influence landfill site selection will include economic, environmental and public acceptance considerations. Economic considerations include aspects such as distance from waste generation areas, site size, access and land availability. Environmental considerations relate to the potential threat to the physical environment, specifically to water resources. They include, inter alia, criteria such as site topography, drainage, soils, hydrogeology and adjacent land-use. No excavation that approaches or intersects the groundwater table may be considered for waste disposal. Public acceptance is established by the procedure of public consultation, which is undertaken through the land use planning process (Planning Permission).

1.3.2 Designing a Landfill

When the best available site has been identified during the site selection process, the subsequent landfill design must utilise appropriate engineering techniques. The objective is to reduce the risk to public health, or the impairment of any ecosystem or resource in the receiving physical environment to an acceptable level. The design must minimise the risk of water pollution by leachate and in most instances it should also make provision for sufficient cover to isolate the waste body from the environment.

Groundwater pollution must be prevented by a mandatory physical separation between the waste and the groundwater regime. No borrow pit created during cover or other excavation may therefore be used for waste disposal, if it approaches or intersects the groundwater.
Of particular importance in Botswana, is an **effective surface water diversion drainage system** which diverts upslope run-off water away from the waste body. These design elements represent the first steps in the prevention of water pollution by waste disposal. Since the proper landfilling of waste requires regular covering to isolate the waste, landfills should be so sited and designed that **sufficient cover material is conveniently available** for the duration of the operation.

### 1.3.3 Operating a Landfill

The concept of sanitary landfilling involves the **compaction** and **covering** of waste on a daily basis. This technique has been developed to abate impacts on the environment, such as the short term operational nuisances associated with badly managed landfills. Compaction reduces voids in the waste, discourages vermin, controls litter, reduces the amount of cover required, increases site life and makes the site sufficiently stable to support tipping vehicles. Cover also reduces litter, odour, water ingress and the risk of uncontrolled fire. In addition, it reduces uncontrolled reclamation and improves visual appearance.

While sanitary landfilling should be applied at Medium, Large, and Special waste sites, burning - **provided it is undertaken in a controlled manner** - may be permitted at Very small and Small General landfills provided this is specifically permitted in the Licence conditions.

### 1.3.4 Closing a Landfill

When a landfill ceases operation, restoration work will usually be required as part of the closure process. This will involve **shaping, final cover, topsoiling, vegetating and drainage maintenance**. A programme of **aftercare**, in which the site is **monitored and maintained**, will also be required, especially on larger sites. At an appropriate time, the landfill can be utilised in terms of its designed end-use. In instances of poor siting, design and/or operation of existing landfills, however, additional remedial work will probably also be required.

### 1.3.5 Monitoring a Landfill

**Monitoring is a control mechanism** which is applied throughout the development of a landfill. During site preparation, quality assurance and control are forms of monitoring. The landfill must also be monitored during the operation, restoration and after its closure. Considerations include monitoring the impact of the landfill on the receiving environment, for example, gas monitoring and water quality monitoring.

Both groundwater and surface water quality monitoring systems must be set up at the landfill site investigation stage. During the design, these may be expanded to address other facets of water monitoring. Water quality monitoring continues throughout the operation, and after the closure of a landfill.
2.1 INTRODUCTION

A village with a small population in rural areas cannot be expected to have the same waste disposal needs, or to comply with the same requirements, as a city with a large population. As a result, a landfill classification system is used, which takes into consideration different waste disposal needs, depending on the quality and quantity of waste involved. The Landfill Classification System is based on the following criteria:

- Waste type and potential for environmental pollution (of soil, water or air)
- Size of waste stream or landfill operation.

These landfill classes form the basis for the setting of graded requirements for waste disposal needs.

2.2 WASTE TYPES

Controlled Waste is defined as all waste which falls under the control of the Waste Act. It will therefore consist of solid household, commercial and industrial wastes. It will exclude waste waters and may also exclude certain other wastes, such as some agricultural, military and mining wastes.

For the purposes of these Guidelines, Controlled wastes are subdivided into three categories, according to the potential risk posed to the environment, on account of their potential to generate significant leachate and/or their inherent hazardous properties. These are, in order of their pollution potential, Inert, General, and Special wastes:

**Inert waste (I)**

Although no waste is totally inert, Inert is the term used for wastes which contain negligible amounts (generally less than five percent) of bio-degradable organic components and which are neither Wet nor Hazardous. If the waste supports combustion, it is not inert. Although such wastes can cause aesthetic impacts and cause minor changes to water quality, their overall environmental impact, if reasonably managed, is not significant. Such wastes would include builders’ rubble, excavation spoil, and material from the desilting of drains.

**General waste (G)**

General waste is a generic term applied to all Controlled waste that is not Inert, Wet or Hazardous. It may comprise garden, domestic, commercial and general dry industrial waste. This waste stream may contain greater than five percent of readily bio-degradable wastes, as well as small quantities of hazardous substances dispersed within it, for example, batteries, insecticides, weed-killers and medical waste discarded on domestic and commercial premises. If excess water is permitted to enter the waste body, General wastes may generate leachate with an unacceptably high pollution potential. Dry General wastes may sometimes be disposed of on Wet/Hazardous waste sites in order to soak up moisture (practice of co-disposal).

**Special Waste (Sp)**

Special waste is defined as waste that requires special treatment and/or disposal because of its properties and/or quantities. Special waste is divided into Hazardous and Wet wastes.
**Special: Wet waste (Sp:W)**

**High moisture content** General wastes have a particularly high leachate generation potential. For this reason, these wastes have been placed in a separate category and are termed Wet wastes. Wet wastes must be disposed of on Special waste landfills, where special consideration has been given to a leachate management system. Such wastes would include:

- liquid wastes
- sludges, such as heavy metal sludges and solutions (for example Cr$^{6+}$ from tanneries)
- certain high moisture content wastes, such as some abattoir wastes.

It is often preferable not to mix these wastes, but to create specific mono disposal cells if there is sufficient need.

**Special: Hazardous waste (Sp:H)**

Hazardous waste is waste (solid or liquid) which has the potential, even in low concentrations, to have a significant adverse effect on public health and/or the environment. This would be on account of its inherent chemical and physical characteristics, such as toxic, ignitable, corrosive, carcinogenic or other properties.

The following types of waste should be regarded as potentially Hazardous:

**Inorganic waste**

- Acids and alkalis
- Cyanide waste
- Heavy metal sludges and solutions, such as Cr$^{6+}$ from tanneries
- Waste containing appreciable proportions of fibrous asbestos.

**Oily waste**

- Primarily from the processing, storage and use of mineral oils.

**Organic waste**

- Halogenated and Non-halogenated solvents residues
- Phenolic and PCB waste
- Paint and resin waste
- Biocide and other organic chemical residues.

**Miscellaneous waste**

- Waste from the production of edible oils, slaughter houses, tanneries and other animal and vegetable based products.
- Infectious waste such as diseased human/animal tissues, soiled bandages and syringes
- Redundant chemicals or medicines
- Explosive waste from manufacturing operations or redundant munitions.

It must be emphasised that the mixing or the co-disposal of any significant quantities of Hazardous waste (liquid or solid) with General waste renders the product a Hazardous waste.

---

**2.3 SIZE OF WASTE STREAM OR LANDFILL OPERATION**

The ultimate physical size of a landfill will depend upon the amount of waste it receives over its lifetime. This is important when the landfill is regarded as a potential point source of pollution. The size classification, however, addresses the size of the waste stream and the consequent size of the daily operation. This is because the immediate impacts of a landfill on the receiving...
environment (e.g. increased traffic, noise, dust, odours, flies, etc.) and the resources required to control them, will be in direct proportion to the amount of waste delivered to the site each day. The Guidelines applicable to the site will therefore depend on the maximum estimated size of the operation on an average working day.

The size of a landfill operation is dependent on the daily rate of waste deposition, which, in turn, depends, inter alia, on the size of the population served. In order, however, to take time and growth into account and to ensure that, from inception, the Guidelines apply to the ultimate size of a landfill operation, landfills are classified using the Maximum Annual Rate of Deposition (MARD). This is simply the projected maximum average annual rate of waste deposition, expressed in tonnes per annum, during the expected life of a landfill. Annual rates, rather than daily rates, are used because individual daily rates fluctuate widely and also because the number of working days per year can vary from site to site. Appendix 2 gives further details on how to calculate the MARD.

However the ultimate physical size of the landfill is also a factor in determining its potential to pollute, and in the restoration and aftercare monitoring programme the final size of the landfill will be taken account of, and special conditions set where an initially small landfill is operated for many years until its final size could be classified as either a medium or a large landfill.

Table 2-1 presents the General waste landfill size classification based on the Maximum Rate of Deposition. From this table, it will be seen that General waste landfills are divided into four size categories; Very small, Small, Medium, and Large. In cases where the MARD provides a borderline situation, the higher class must always be used. Guideline population size criteria are provided as an indication only, in the event that waste quantities are not known, but the determining factor is the MARD and not the indicative population size.

Table 2-1: Size Classification Of Landfills

<table>
<thead>
<tr>
<th>LANDFILL SIZE CLASS</th>
<th>MARD Tonnes p.a.</th>
<th>Indicative Population Size(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very small</td>
<td>V &lt;500</td>
<td>2,000</td>
</tr>
<tr>
<td>S 500-6,500</td>
<td>26,500</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>6,500 - 65,000</td>
<td>150 000</td>
</tr>
<tr>
<td>Large</td>
<td>&gt;65,000</td>
<td>&gt;150 000</td>
</tr>
</tbody>
</table>

Notes

1. The derivation of population size is explained in the Supplement to this document. Population sizes are only valid in areas where little or no industrial or construction waste is produced.

2. Guidelines for population size are a guide only, are not always appropriate for larger landfills, and a detailed MARD calculation is required.

3. Maximum Annual Rate of Deposition.

2.4 LEACHATE GENERATION AND MANAGEMENT

Landfills are usually also assessed in terms of their potential to generate leachate, and where significant leachate is generated, leachate management is required. Significant leachate generation is seasonal, or continuous as opposed to Sporadic leachate generation which results from abnormal circumstances such as excessive precipitation. In Botswana, however, the climate is generally arid, so that leachate would not be formed on account of climate conditions.
as in the case of a humid climate such as Swaziland. The main possibilities for significant leachate generation to occur in Botswana, therefore, would be

- due to high moisture content of the incoming waste (Wet waste)
- the ingress of either ground water or surface water run-off into the waste body. This will only occur in sites which do not adhere to the Guidelines.

In Botswana, rainfall events may be of very high intensity. This could possibly lead to sporadic leachate generation on other sites.

Wet wastes are allocated to Sp:W landfills, where any leachate generated can be managed. However, ground and surface water ingress into the waste body can cause leachate generation in G landfills, because of poor siting, design and operation. Typical examples include:

- **Poorly selected sites**
  Significant leachate generation will occur in existing landfills sited either in excavations which penetrate the ground water or in areas of emergent ground water. Although leachate will not be obvious in the first case, in the second case it is likely that leachate will be observed emanating from the toe of the landfill.
  Significant leachate generation may also occur in existing landfill sites which are sited in water courses or across catchments. This is because unless there is effective diversion drainage, run-off water will dam up behind the landfill and infiltrate the waste body. Where run-off, damming and water encroachment has occurred, leachate emission from the toe of the landfill may continue long after the problem has been rectified by remedial design.

- **Poorly designed and operated sites**
  If the Guidelines for design and operation have not been adhered to, in the case of existing sites, significant leachate generation may result. Examples could include infiltration from surface ponding, the failure of drainage systems permitting run-off to enter the landfill and cover excavations which penetrate the ground water.
  Aspects relating to ground and surface water ingress into the waste body are addressed in the respective siting, design and operation sections in this document. Provided that the Guidelines in these sections are adhered to, significant leachate should not be generated at General waste sites.

### 2.5 APPLICATION OF THE CLASSIFICATION SYSTEM

#### 2.5.1 Landfill Classes

As seen from Table 1.1, the landfill classification system provides seven landfill classes, i.e. I, G: V, G:S: G:M, G:L, Sp:W and Sp:H. The prefix G: is used to describe the General Waste landfills, whereas the prefix Sp describes Special Waste.

Once the landfill site has been classified according to the Landfill Classification System, the Guidelines which apply to the class of landfill under consideration can be identified, using the Guidelines tables provided at the end of each section.

**Inert waste landfills (I)**

Inert waste landfills may be depressions or excavations that can be filled with inert wastes such as spoil or builders rubble, with a view to backfilling or levelling. Although the word “inert” creates the impression that such wastes would not adversely affect the environment and water quality, this cannot be guaranteed. Consequently, such sites must be chosen and operated with discretion and caution. Excavations containing water should be avoided, unless express permission is obtained from the DSWM. Furthermore, the operation of inert waste landfills
should be carefully controlled and monitored to ensure that only inert wastes are disposed of on such sites.

**General waste landfills (G)**

General waste landfills are sub-divided into four classes, based on magnitude of waste stream and size of operation. These classes are Very small, Small, Medium and Large. The larger the operation, the more stringent the Guidelines.

If the Guidelines tables indicate that a Guideline applies to all classes of site, the DSWM will ensure that the degree of application is commensurate with the class of site under consideration.

**Special Waste Landfills (Sp)**

Any landfill which receives Wet wastes (with the exception of small quantities of sewage sludge at Small and Very small sites), or significant quantities of Hazardous waste must be classified as a Special waste landfill. Because of the risk posed by Sp landfills to the environment and to public health and safety, they must be containment sites. Sp landfills must therefore all be separated from the environment by a liner and a leachate collection system. The standard of the liner system will depend on the particular waste that is disposed of. Generally lagoon type facilities for large quantities of wet waste will require more simple liners, whereas solid and liquid hazardous waste facilities will require complex lining systems.

**x.5.2 Amendment of Site Classification**

The Licence Holder must ensure at all times that the site is correctly classified. Should the class of the site change over time, the DSWM must be notified and the Licence reviewed.
3. SPECIAL CASES

There are a number of special cases which do not fit well into general guidelines as described in this document, and should be considered on a case by case basis according to their merits. These include:

- The disposal of pit latrine and oxidation pond/sewage treatment sludges, which are wet, but not hazardous and the "pre-dried" sludge requires land disposal.
- The disposal of large quantities of animal carcasses, which would generally fall under the definition of wet waste, but are a special problem in themselves.
- The disposal of hazardous wastes, where each hazardous waste may have its own unique characteristics which need to be investigated separately.

3.1 SEWAGE SLUDGES AND DOMESTIC SEPTAGE

3.1.1 Background Description

One of the main principles for waste landfill in Botswana is to keep water out. Sewage sludges and domestic septage are considered to be a problem in disposal due to their high water content. Water acts as a transport medium for pollution to migrate, and it is therefore important that these "wet" wastes are evaluated with care before disposal; as they pose a high risk to groundwater pollution.

Domestic septage includes the pumpings from pit latrines, septic tanks, portable toilets, etc., but not from commercial or industrial sources. They are generally disposed in trenches (monofills), ponds, or co-disposed with municipal solid waste.

Sewage sludges emanate from desludging treatment plants, and consist of the greyish-black thick liquid that has settled to the bottom of the anaerobic and facultative ponds which have been dried to an acceptable water content. Depending on the industrial activity in the area these sludges may contain heavy metals and other toxic substances. Before disposal to land, recovery for compost/fertiliser or co-disposal at a municipal waste disposal site, this sludge needs to be dried.

Sewage sludge which is considered to be hazardous and commercial and industrial septage (grease traps, etc.) would fall under Section 3.3, Hazardous waste, and would be treated as a hazardous waste to comply with the Sp:H requirements.

3.1. Treatment, Reuse and Disposal

The optimum method of disposal for sludges is for land/soil improvement (beneficial use). Sewage sludges are most often rich in nutrients and, particularly in low industrialised areas, do not contain significant quantities of hazardous materials. It is therefore economically and environmentally prudent to make beneficial use of sludges, for example in fields to promote crop production.

Should beneficial use not be a solution then a number of alternative disposal options are given in Table 3-1. The selection of a suitable disposal site for domestic sludges depends a great deal on the characteristics of the sludge, as well as the site selection criteria given in Section 4.

As a guideline, waste with a solids content of less than 20% (calculated wet) are not considered suitable for landfilling and should therefore be pre-treated to reduce the water content. The optimum and most cost effective drying system for sludges in Botswana is the air or sun drying bed. This is described in Chapter 10 of the "Water Supply and Wastewater Management Handbook for Urban and District Councils".
### Table 3-1: Summary of various sludge disposal methods

<table>
<thead>
<tr>
<th>Disposal method</th>
<th>Landfill type</th>
<th>Sludge solids content</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow trench</td>
<td>Monofill</td>
<td>15-28%</td>
<td>Sludge is placed in a trench &lt; 3 m wide and covered with soil</td>
</tr>
<tr>
<td>Wide Trench</td>
<td>Monofill</td>
<td>&gt; 20%</td>
<td>Sludge is placed in a trench &gt; 3 m wide and covered with soil</td>
</tr>
<tr>
<td>Area fill</td>
<td>Monofill</td>
<td>&gt; 20%</td>
<td>Sludge is placed directly on the ground and covered with soil. Soils are often mixed in as a bulking agent.</td>
</tr>
<tr>
<td>Bunded Containment</td>
<td>Monofill</td>
<td>&gt; 20%</td>
<td>Sludge is placed directly on the ground, but it is surrounded by a series of bunds.</td>
</tr>
<tr>
<td>Pile</td>
<td>Pile</td>
<td>&gt; 28%</td>
<td>A mound of dewatered sludge is placed on the soil surface without a cover, for final disposal.</td>
</tr>
<tr>
<td>Surface impoundment</td>
<td>Surface impoundment / lagoon</td>
<td>&gt; 2%</td>
<td>Sludge is placed in an excavated area (or constructed dam) without cover for final disposal.</td>
</tr>
<tr>
<td>Dedicated surface disposal sites</td>
<td>Dedicated surface disposal sites</td>
<td>&gt; 3%</td>
<td>Sludge is injected or ploughed into the soil after being spread / sprayed onto the land. Applications are repeated for final disposal.</td>
</tr>
<tr>
<td>Dedicated beneficial use sites</td>
<td>Dedicated beneficial use sites</td>
<td>&gt; 3%</td>
<td>Sludge is injected or ploughed into the soil after being sprayed or spread onto the land. Crops are planted on the land, or grass grown and grazing allowed.</td>
</tr>
<tr>
<td>Sludge/household waste mixture</td>
<td>Co-disposal</td>
<td>&gt; 20%</td>
<td>Sludge is deposited on top of, and mixed in with, municipal solid waste.</td>
</tr>
<tr>
<td>Sludge/ soil mixture</td>
<td>Co-disposal</td>
<td>&gt; 20%</td>
<td>Sludge is mixed in with soil and applied to the municipal solid waste as intermediate or final cover, usually over the completed areas.</td>
</tr>
</tbody>
</table>

The design of lining systems for the sludge disposal site depends on the vulnerability of the groundwater in the area to pollution, and on the concentrations of Arsenic, Chromium and Nickel in the sludge. For large sites a special investigation and design should be undertaken to the approval of the DSWM, but recommended guidelines for smaller volumes of sludge are to select either disposal into narrow trenches, or co-disposal with municipal solid waste. Volumes of sludge production are dependant on the sanitation system used, treatment facilities (if any) and the proportion of the population using the system, but the estimate of dry sludge from a sewered system is between 0.1 and 0.2 kg per person per day.

### 3.1.3 Monitoring

Three characteristics of sludge should be monitored or controlled to protect human health and the environment:

- the concentration of certain heavy metals - Arsenic, Chromium and Nickel
• the level of pathogens - i) monitor the levels of faecal coliforms, or alternatively ii) use a process to significantly reduce coliforms such as aerobic or anaerobic digestion, air drying, composting, or lime stabilisation, or alternatively iii) apply a daily soil cover.

• the attractiveness to disease vectors - this part requires that the sludge attractiveness to insects, rodents and birds, is reduced, and is mainly achieved through treatment and/or covering.

Reference is made to the EPA Process Design Manual "Surface Disposal of Sewage Sludge and Domestic Septage".

3.2 ANIMAL CARCASSES

Large scale mortalities of animals occur on an infrequent and unpredictable basis. Most events are of short duration, are dealt with in an emergency manner and lessons learnt are seldom retained from one event to another. As large numbers of animal carcasses pose both health and environmental risks, guidelines for the rapid assessment and disposal of animal carcasses are required to reduce the impacts and long term costs of protecting people and the environment.

3.2.1 Classification of Disposal Method and Minimum Requirements

This chapter follows a logical sequence of procedures in the identification of the available disposal methods and minimum requirements for carcass disposal problems. Figure 3-1 outlines the sequence of steps to be taken.

3.2.1.1 Data Requirements for Identifying Disposal Methods

The following information is required to identify the method of disposal: 3.

2.1.1.1 Biomass to be disposed of

Classify the biomass to be disposed of according to Table 3-2. Biomass relates to the total biomass to be disposed of at a single site during the disease/control event or over a 3 month period, which ever is the greater mass. A biomass of less than one ton is not covered by these guidelines.
**Figure 3-1: Guide to Identifying the Correct Disposal Method for Animal Carcasses**

<table>
<thead>
<tr>
<th><strong>Do I need to apply these guidelines to my specific carcass disposal problem?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the size of the event (i.e., number of animals expected to die or be killed within a 3 month period) make it necessary to apply these guidelines?</td>
</tr>
<tr>
<td>Check Table 3-2. If weight of carcasses &gt; 1 ton (1000 kg) <strong>proceed to classification</strong>, If weight &lt; 1 ton then you only need to use the guidelines in an advisory capacity.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>How do I classify the event?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Three sets of information are necessary in classifying the event:</td>
</tr>
<tr>
<td>&gt; The cause of death (Table 3-3),</td>
</tr>
<tr>
<td>' The type of land use at disposal site (e.g., town or rangeland etc.), (Table 3-4), =&gt;</td>
</tr>
<tr>
<td>Groundwater pollution vulnerability</td>
</tr>
<tr>
<td><strong>Proceed to identification of disposal options</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>What methods of disposal should be used?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-section 3.2.1.2 outlines the available disposal methods, while Table 3-5 is to help identify the correct disposal options.</td>
</tr>
<tr>
<td>From the options, select a disposal method most suitable to your specific situation</td>
</tr>
<tr>
<td>If the required disposal method is composting or burial, the following <strong>Tables identify the minimum requirements</strong></td>
</tr>
</tbody>
</table>

**Composting**

<table>
<thead>
<tr>
<th><strong>Burial</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>See Table 3-6 to identify the If neither composting nor See Table 3-7 and Table 3-8, minimum requirements for burial is to be used, proceed Combine the results of the tables to your composting disposal site to management section, identify the minimum requirements below for your burial site.</td>
</tr>
<tr>
<td>Once the method of disposal and minimum requirements have been identified, proceed to the <strong>management section</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>How do I manage the disposal site?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The following sections are applicable:</td>
</tr>
<tr>
<td>Section 3.2.2 for site identification requirements,</td>
</tr>
<tr>
<td>Section 3.2.3 for design of the disposal site,</td>
</tr>
<tr>
<td>Section 3.2.4 for general management aspects,</td>
</tr>
<tr>
<td>Section 3.2.5 for monitoring requirements, Section 3.2.6 for documentation requirements.</td>
</tr>
</tbody>
</table>
Special Cases

BOTSWANA LANDFILL GUIDELINES

3.2.1.2 Cause of death

The cause of death is to be classified as in Table 3-3.

Table 3-3: Classification of Cause of Death

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>CLASS</th>
<th>SOME EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persistent diseases and/or highly virulent, highly contagious and/or zoonotic. Large scale deaths often the result of control programmes</td>
<td>I</td>
<td>Rinderpest, Newcastle, Fowl Plague, Anthrax, Foot and Mouth, Crimean Congo Haemorrhagic Fever, Rabies, Tuberculosis or associated control killings</td>
</tr>
<tr>
<td>Non persistent diseases after the death of the host, infectious but usually resulting in small numbers of carcasses, very mildly zoonotic. Large scale deaths usually caused by control programmes</td>
<td>II</td>
<td>CBPP, Botulism, or associated control killings</td>
</tr>
<tr>
<td>Large scale mortalities not related to disease. Usually occur in remote areas or widely spread</td>
<td>III</td>
<td>Starvation and thirst</td>
</tr>
</tbody>
</table>

Note: poisoning has not been included as it usually results in relatively few deaths.

3.2.1.3 Land Use Classification

The land use is to be classified according to Table 3-4

Table 3-4: Land Use Type

<table>
<thead>
<tr>
<th>TYPE OF LAND USE</th>
<th>CLASS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protected Areas</td>
<td>3</td>
<td>Low risk except in wetland areas and where water is abstracted for tourist and domestic facilities</td>
</tr>
<tr>
<td>Extensive rangeland*</td>
<td>2</td>
<td>Relatively low risk</td>
</tr>
<tr>
<td>Rural settlement</td>
<td>1</td>
<td>High risk areas</td>
</tr>
<tr>
<td>Intensive agriculture plots</td>
<td>1</td>
<td>High risk areas</td>
</tr>
<tr>
<td>Urban areas</td>
<td>n/a</td>
<td>Extremely high risk - disposal through existing waste management authorities and facilities</td>
</tr>
</tbody>
</table>

* = rangeland includes commercial ranches and communal grazing areas (fenced and unfenced)

---

1 Veterinary (DAHP) policy is to condemn all animals that die of unknown causes.
2 Many of these diseases are not prevalent in the country but may occur in the future.
3 Zoonotic, defined as diseases communicable between animals and man (West, 1982).

BOTSWANA LANDFILL GUIDELINES
There are a number of disposal options available, these are:

- **Do nothing**: Carcasses are allowed to lie where they fall (except when in or near water resources used by people). This includes disposal by scavengers and natural decomposition on the soil surface.
- **Consumption**: The carcass is consumed and the bones either let lie or used for bone meal. With large numbers of animals it is necessary to meet veterinary public health requirements to ensure that the meat is fit for human consumption.
- **Burning**: Carcasses are fully burned using additional fuels such as wood, tyres or gasoline. Temperatures are relatively low.
- **Composting** (Aerobic decomposition): Carcasses are cut into pieces of less than 2 kg, combined with a bulking material and regularly turned to ensure oxidation.
- **Burial** (Anaerobic Decomposition): Carcasses are packed tightly and buried below ground. The top of the pit/trench is sealed with soil or other low permeable material.
- **Incineration**: Carcasses are burned at high temperatures in a purpose built incinerator.
- **Rendering**: Carcasses are rendered in an industrial process through pressure boiling, breaking into small pieces and incineration.

The identification of a suitable and acceptable method of disposal in a particular situation will depend on the cause of death and the mass of carcasses as indicated in Tables 3-2 and 3-3.

**Table 3-5: Identification of Acceptable Disposal Methods**

<table>
<thead>
<tr>
<th>CAUSE OF DEATH (Table 3-3)</th>
<th>LOW</th>
<th>MASS OF CARCASSEs (Table 3-2)</th>
<th>MODERATE</th>
<th>MEDIUM</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Do nothing⁴, Consume⁴, Burn⁴, Compost, Burial, Incineration</td>
<td>Do nothing, Consume, Burn, Compost, Burial, Incineration</td>
<td>Do nothing, Consume, Burial</td>
<td>Do nothing, Consume, Burial</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do nothing (wild animals only)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Do nothing Consume, Burn, Burial, Incineration</td>
<td>Do nothing (wild animals only), Consume, Burial, Incineration, Rendering</td>
<td>Do nothing (wild animals only), Burial, Incineration, Rendering</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burial, Incineration, Rendering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burial, Incineration, Rendering</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burial, Incineration, Rendering</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

⁴The do nothing option is limited to protected areas and extensive ranch land where the nuisance impact on people would be minimal.

⁵Consume = for human consumption (this can include the making of bonemeal)

⁶The burn option is limited to protected areas and extensive rangeland where the nuisance impact on people would be minimal.
### Table 3-6: Minimum Requirements for Composting (Aerobic Decomposition).
(Applicable only in areas of low nuisance value)

<table>
<thead>
<tr>
<th>LAND USE RISK (Table 3-4)</th>
<th>GROUNDWATER VULNERABILITY</th>
<th>MINIMAL</th>
<th>MODERATE</th>
<th>HIGH</th>
<th>EXTREME</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW (PROTECTED AREAS)</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td></td>
</tr>
<tr>
<td>MODERATE (EXTENSIVE RANGELAND)</td>
<td>Surface water diversion, ground surface seal,</td>
<td>Surface water diversion, ground surface seal,</td>
<td>Surface water diversion, ground surface seal, evaporation pond for runoff</td>
<td>Surface water diversion, ground surface seal, evaporation pond for runoff</td>
<td></td>
</tr>
<tr>
<td>HIGH (VILLAGES AND INTENSIVE AGRIC. PLOTS)</td>
<td>Surface water diversion, ground surface seal, evaporation pond for runoff, pest control</td>
<td>Surface water diversion, ground surface seal, evaporation pond for runoff, pest control</td>
<td>Surface water diversion, ground surface seal, evaporation pond for runoff, pest control</td>
<td>Surface water diversion, ground surface seal, evaporation pond for runoff, pest control</td>
<td></td>
</tr>
</tbody>
</table>

Note: documentation is required in all cases where sites occur in high or extreme groundwater vulnerability areas.
### Table 3-7: Minimum Requirements for Burial (Anaerobic Decomposition) in Relation to Groundwater Vulnerability

<table>
<thead>
<tr>
<th>LAND USE RISK (Table 3-4)</th>
<th>GROUNDWATER VULNERABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOW</strong> (PROTECTED AREAS)</td>
<td>Minimal: Siting</td>
</tr>
<tr>
<td><strong>MODERATE</strong> (EXTENSIVE RANGELAND)</td>
<td>Minimal: Siting, seal cover, documentation</td>
</tr>
<tr>
<td><strong>HIGH</strong> (VILLAGES AND INTENSIVE AGRICULTURAL PLOTS)</td>
<td>Minimal: Siting, liner, seal cover, water diversion, leachate extraction pipe, monitoring (D), documentation, insurance for compensation</td>
</tr>
</tbody>
</table>

C.* Compulsory, D: Discretionary (opinion to be given by DSWM), N, Not compulsory

---

7 Classification and mapping by the Department of Geological Survey, 1995 "Groundwater pollution vulnerability map".
### Table 3-8: Minimum Requirements for Burial (Anaerobic Decomposition) in Relation to the Scale of the Event

<table>
<thead>
<tr>
<th>LAND USE RISK (Table 3-4)</th>
<th>LOW (PROTECTED AREAS)</th>
<th>MODERATE (EXTENSIVE RANGELAND)</th>
<th>MEDIUM</th>
<th>HIGH (VILLAGES AND INTENSIVE AGRICULTURAL PLOTS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>Siting</td>
<td>Siting, seal cover, monitoring (D)</td>
<td>Siting, seal cover, monitoring (D)</td>
<td>Siting, liner, seal cover, water diversion, leachate extraction pipe, monitoring, insurance for compensation</td>
</tr>
<tr>
<td>MODERATE</td>
<td>Siting, seal cover, water diversion, monitoring (D), leachate extraction pipe, monitoring, insurance for compensation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIGH</td>
<td>Siting, liner, seal cover, water diversion, leachate extraction pipe, monitoring, insurance for compensation</td>
<td>No disposal on site</td>
<td>No disposal on site</td>
<td></td>
</tr>
</tbody>
</table>

*C: Compulsory, D: Discretionary (opinion to be given by DSWM), N: Not compulsory*

### 3.2.2 Site Identification Procedure

Site selection is the single most important activity in reducing environmental impacts from the disposal of carcasses by burial or composting. Refer to Chapter 4 with particular emphasis on sections 4.3 (elimination of unsuitable areas) and section 4.6.

Further site selection criteria, based on the biomass of carcasses requiring disposal, are listed in Table 3-9.

In any circumstance where the Unsuitable Areas Criteria (Section 4.3), or minimum buffer distances cannot be met, a full feasibility study is required. **3.2.3 Disposal Site Design**

The design of the disposal site relates directly to the minimum (mitigation) requirements (Section 3.2.1.3) and the results of the Hydrological and EIA investigations if applicable (see Section 3.2.2).
### Table 3-10: Definition of Terms Relating to Design and Management

<table>
<thead>
<tr>
<th>TERM</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siting</td>
<td>Correct geographical siting of disposal site (Section 4)</td>
</tr>
<tr>
<td>Surface water diversion</td>
<td>Divert surface water runoff away from the site (Sub-section 6.4.1)</td>
</tr>
<tr>
<td>Cover material</td>
<td>Cover material for burial sites refers to the material between the carcasses and ground level (excluding any form of mounding). Depth varies from 2m when closing a constant supply disposal trench to 4m when disposing of large numbers of whole animals.</td>
</tr>
<tr>
<td>Ground surface seal</td>
<td>Prevention of infiltrating water entering the carcass burial pit. (Sub-section 6.4.2/3)</td>
</tr>
<tr>
<td>Evaporation pond</td>
<td>Solar evaporation pond to collect leachate and runoff from the waste material (Compost)</td>
</tr>
<tr>
<td>Pest control</td>
<td>Control of flies and other pests (Sub-section 7.4.2)</td>
</tr>
<tr>
<td>Liner</td>
<td>Material at the base and on the sides of the disposal pit to reduce leachate entering groundwater (Sub-section 6.4.3)</td>
</tr>
<tr>
<td>Add bacteria</td>
<td>Addition of a commercial bacterial mix to speed up the rate of decomposition</td>
</tr>
<tr>
<td>Seal cover</td>
<td>Ensure that the capping material is impermeable and sheds water away from the carcass burial pit. The aim is to prevent leaching of the early products of decomposition which are more toxic than the final products (Sub-section 7.3.7)</td>
</tr>
<tr>
<td>Leachate extraction pipe</td>
<td>In areas where leachate may pollute potable aquifers, a leachate extraction system is needed. See Section 6.4.4. Note that the aim of the leachate extraction system is not to drain the site (as moisture is needed for decomposition), but to enable extraction of leachate: if monitoring indicates pollution is occurring.</td>
</tr>
<tr>
<td>Venting</td>
<td>Anaerobic disposal sites in which the cover material is sealed must have venting pipes to ensure constant methane and carbon dioxide release</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Monitoring of groundwater (Section 10 in particular Sub-section 10.2.2) and site condition. Monitoring of gases to identify the stage of</td>
</tr>
</tbody>
</table>
Special Cases

<table>
<thead>
<tr>
<th>TERM</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>decomposition occurring at sites. Monitoring is essential to pinpoint pollution problems as soon as they occur, allow management decisions to be made, and ensure that compensation claims are legitimate.</td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td>All private disposal sites that require insurance (Sub-section 3.2.1.3) must take out an insurance policy to ensure that, in the case of pollution, legitimate compensation claims can be settled.</td>
</tr>
</tbody>
</table>

3.2.4 Management

There are two management scenarios i.e.,

i. long term in which there is a constant supply of carcasses such as in intensive agriculture (feedlots etc.) and,

ii. a one-off event.

In both cases the carcasses need to be managed in such a way as to reduce nuisance impacts (smell and pests), health impacts (pests and pathogens) and environmental impacts.

3.2.4.1 Constant Supply

This problem arises in intensive agriculture such as chicken farming (broilers or egg production), pig farming and livestock feedlots. Generally there is a constant stream of carcasses with irregular changes in numbers due to minor (often unidentified) disease outbreaks. Disposal is generally by means of burial or burning.

Burial should follow the requirements laid down in 7 with some modification to allow for a small continuous stream of carcasses. A narrow (approximately 2m wide by 6m long) burial trench should be excavated to a depth as defined by the site investigation (but approximately 4-6m deep). The surface should be covered and provided with a disposal hatch. The hatch can either exclude light to prevent fly activity or, if it is transparent, allow light to enter the pit so that blue flies can breed in the carcasses and accelerate decomposition. Decomposition (both aerobic and anaerobic) could also be accelerated using a commercial bacterial mixture and by either cutting up or mashing the larger carcasses (such as pigs or goats).

Management requirements of sites established to deal with a constant supply of carcasses must be stringently adhered to and standards maintained through inspections by the District Health Inspectors and officials of the DSWM.

3.2.4.2 One-off Event Burning

The first option for burning is to use a purpose built incinerator. Smaller scale burning should take place following the safety requirements set out in Section 7.3.2. The equivalent of I cow will take approximately 5 hours to burn, and sufficient combustible material will be required to sustain the fire for this period of time. Combustible materials may include wood, straw, coal, or charcoal. The use of tyres and waste oil in large quantities and high density areas are discouraged due to the air pollution hazard.

The remains of all burnt carcasses need to be buried to reduce nuisance and health impacts from partially burnt carcasses. Burial requirements are outlined in Table 3-8.

Composting

Carcasses need to be small or cut into pieces (less than a kilogram wet weight per piece) and a bulking agent of humus, manure or vegetable waste (sawdust) needs to be incorporated.

---

*Partially after Kilner (Veterinary Adviser, Notifiable Diseases Section, Ministry. of Agriculture, Fisheries and Food, United Kingdom)*)
Special Cases

(approximately 75% of the volume). The entire mass being composted must be turned every two or three days until composting is complete. In dry conditions large amounts of water need to be added to maintain rapid decomposition. The operation needs to be well managed to limit problems with flies. Fencing of the compost area is necessary to exclude scavengers. A use for the product needs to be identified prior to commencement of composting. Minimum requirements for composting are outlined in Table 3-6.

Burial

Minimum requirements for burial are outlined in Tables 3-7 and 3-8. An explanation of terms used is provided in Table 3-10.

Trenches need to be excavated to a depth which varies in relation to groundwater and numbers of carcasses. In the case of large numbers of carcasses at least four metres of cover are needed i.e., the uppermost carcasses need to be at least four metres below ground surface level. When closing the site additional cover material to shed water from the site should be placed on top of the four metres of cover. In the case of small and moderate numbers of carcasses the cover should be at least two metres deep. Carcasses should be stacked as close together as possible to ensure that there is sufficient moisture for decomposition to occur. When closing the trench, the initial layer of cover material needs to be relatively coarse so as to allow escape of gases from the carcasses to the vent pipes (if required).

If the animals died of highly persistent disease organisms a site inspection, by a veterinary officer from DAMP, will be required during carcass disposal and site closure.

The maintenance of trees on a burial site and planting of tree seedlings after closure will help to reduce nitrate pollution.

3.U Monitoring and Aftercare.

The aims of monitoring are to ensure that decomposition of animal carcasses proceeds as expected thus reducing the chance of environmental impacts occurring. The types of monitoring required are:

- **Monitoring the stage of decomposition** (it is important that burial sites reach the methanogenic phase and that decomposition is not halted due to unfavourable site conditions). The most important gas to monitor is methane (on a once a year frequency). Methane production should commence approximately two years after burial and peak around year fifteen. When large volumes of methane are detected explosion warning signs need to be erected. If methane production is not detected by year three, a site investigation will be required and mitigations undertaken to promote anaerobic decomposition.

- **Groundwater monitoring** for pollution. The number and location of groundwater monitoring points needs to be identified by a hydrogeologist during site selection and design. Monitoring on an annual basis is required until five years after methane production has peaked (in village and intensive agriculture land use areas, biannual monitoring is required). Refer to monitoring of groundwater (Section 10 in particular Sub-section 10.2.2).

- **Monitoring of site condition** after closure. For example sign post legibility, site markers, condition of the ground surface to ensure that subsidence of cover material does not make the area a water catchment, and establishment of vegetation over the cover.

- When disposing of animal carcasses infected with a highly persistent disease organism, disease monitoring and monitoring of the organism's survival may be undertaken by DAHP. If requested by DSWM or DAHP, a monitoring device/structure allowing inspection should be installed.

For more details on site aftercare, refer to Sections 9.4 and 9.5.
3.2.6 Documentation Requirements

For all sites in which documentation is required (Sub-section 3.2.1.3) the following is to be recorded in duplicate and a copy lodged with the DSWM:

- reasons for disposal of animals,
- site selection procedures and reasons for final site selection,
- comments and concerns of IAPs,
- hydrogeological report (if applicable),
- EIA report (if applicable),
- site description and environmental parameters. This includes a photographic record of the site pre and post operation.
- number and type of animals disposed of (dates of event),
- site layout plan including vent and monitoring borehole locations,
- site aftercare (restoration, re-vegetation and warning signs),
- monitoring programme,
- record of complaints and incidents with IAPs.

3.3 HAZARDOUS WASTES

There is generally a low quantity of hazardous waste produced in Botswana, however because of its intrinsically high risk, a general landfill guideline incorporating details of all possible treatment and disposal variations would be cumbersome and generally not applicable. The landfilling of Hazardous waste has therefore been described in general below, but it is a requirement that all hazardous waste disposal facilities should be specifically investigated, designed and operated by a responsible person, based on the specific characteristics of the waste in question. Furthermore within the guidelines general references are made to requirements for hazardous waste sites, based on their general properties, but the recommendations of these guidelines with respect to hazardous waste should always be confirmed by the expert (responsible person).

3.3.1 Treatment Processes

The properties of certain Hazardous wastes are such that they cannot be safely deposited directly into a landfill. In such cases the wastes must be pre-treated in order to render them less toxic, mobile or reactive. A variety of process options exist. These are often interrelated but may be categorised generally into physical, chemical and biological treatment methods.

- Physical processes include incineration, blending and encapsulation.
- Chemical processes include neutralisation, precipitation, fixation and oxidation.
- Biological processes include aerobic and anaerobic degradation of organic materials.

Once a waste has been pre-treated, the residue is disposed of on the landfill. The conditions when pre-treatment is required will be determined on a case-by-case basis by the DSWM. Examples would be strong acids and alkalis or hexavalent chromium salts from tanneries.

3.3.2 Methods of Landfilling

Hazardous wastes must be disposed of in specially designed Sp:H containment landfills, with leachate management. Alternatively they may be disposed of within a cell designed to Sp:H specifications within the boundaries of a G landfill facility. It is a requirement that in investigating a G:L landfill site, the need for a hazardous waste disposal cell should also be investigated. This is because hazardous waste is usually generated in the larger municipal areas.
where industrial activity is growing, and there should be measures in place to care for these wastes.

For Sp:H landfills, documentation must be drawn up, describing the operating procedures to be used at the site and the Response Action Plan. Before the operation commences, these must be presented to, and accepted by, the DSWM.

There are two basic methods of landfilling hazardous wastes:

- mono-disposal, where the wastes are deposited in an unmixed state.
- co-disposal, where they are mixed with General wastes in ratios to optimise airspace utilisation and leachate management.

Either method may be most appropriate, depending on the individual circumstances, but of the two, mono-disposal is normally preferred. This is because the waste characteristics are more easily predicted if it is homogenous, and it also "preserves" or "stores" the material for potential recovery in future.

In mono-disposal, the hazardous wastes are placed in engineered containment cells (see Glossary), with each cell being reserved for wastes with similar chemical and physical characteristics. They are then covered in accordance with normal landfill practice and the cell is finally capped with an impermeable layer.

The term co-disposal may refer to the mixing of General and Hazardous wastes or to the mixing of liquid with dry wastes (see Glossary). In the case of Sp landfills, the Wet and Hazardous wastes may be co-disposed with dry General waste in order to soak up excess liquid and to avoid pond situations. Co-disposal may also be used to provide for advanced anaerobic decomposition of leachates and to dilute the toxicity of Hazardous wastes.

Co-disposal is achieved by mixing General and Hazardous waste at the working face, by spreading liquid waste on deposited General waste prior to covering, or by depositing liquids into trenches excavated into in situ waste, which has preferably been deposited for at least six months. Where trenches or engineered cells are used, they must always be suitably protected and off-loading must be such that persons or vehicles cannot accidentally fall into the cell.

Liquid Hazardous waste may also be end tipped into trenches and engineered containment cells and subsequently covered with dry general solid waste, which may also be end tipped. By the end of the operation, however, there must be sufficient dry waste in the trench or engineered cell to permit vehicle trafficability and covering activities. To achieve this, the exact proportions will vary according to circumstances but a volumetric co-disposal ratio of 9 units of solid waste to 1 unit of liquid waste is an example of what may be appropriate.

The optimum co-disposal ratio, however, should be determined using both environmental and economic criteria. By increasing the volume of dry waste, the leachate generation and hence liquid management costs are reduced. However the volume of Sp:H landfill airspace, which is costly to engineer, occupied by the dry General waste increases. By reducing the volume of dry waste, on the other hand, there is a saving in airspace utilisation but there is a greater need for liquid management, which is also costly. It is therefore in the interests of the design and operation of a Sp: H landfill to optimise the co-disposal ratio by minimising the sum of the airspace utilisation and liquid management costs.

Prior to and following the calculation of the optimum co-disposal ratio, which will involve a detailed water balance computation, the DSWM should be consulted.

It is a requirement that the off-loading of Wet or Hazardous waste and the co-disposal operations be executed under the jurisdiction of a suitably qualified responsible person (see section 7.2.4). The Responsible Person must ensure that appropriate standard operating procedures are adhered to. Aspects include:
• Ensuring the use of safety equipment (e.g. boots, gloves, goggles and breathing apparatus) by operatives.
• Ensuring that no incompatible wastes are co-disposed. It is particularly important to avoid mixing of certain chemicals which may react together with unfavourable results.
• Ensuring that an acceptable co-disposal ratio is adhered to.
• Ensuring immediate and/or daily covering.
• A wind sock should be flown near the point of deposit of hazardous materials and operatives must remain upwind, especially during discharge to avoid inhalation of vapours.

It is also essential that the Responsible Person and the workers know the content and the requirements of the Response Action Plan for the site, in case of an emergency.

In the event that more detail regarding co-disposal is required, the reader is referred to the document Landfill Co-disposal.

For further details on the handling and disposal of hazardous waste in the region refer to the South African Department of Water Affairs and Forestry publication "Minimum requirements for the handling and disposal of hazardous waste", First edition 1994, and any subsequent editions or publications.

3.3.3 Household Hazardous Waste

Small quantities of household hazardous waste (HHW) are very difficult to keep out of municipal landfills, and they may not be a problem if they are deposited in very small quantities (principle of co-disposal). Part of the operating procedure for a general waste landfill includes monitoring the incoming waste loads, which includes checking for the disposal of HHW. For convenience a list of typically produced HHW is shown in Table 3-11.
### Table 3-11: Typical Hazardous Household Waste (HHW)

<table>
<thead>
<tr>
<th>Product</th>
<th>Hazardous property</th>
<th>Product</th>
<th>Hazardous property</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Household cleaners</strong></td>
<td></td>
<td><strong>Automotive Products</strong></td>
<td></td>
</tr>
<tr>
<td>Abrasive scouring powders</td>
<td>Corrosive</td>
<td>Anti freeze</td>
<td>Poison</td>
</tr>
<tr>
<td>Aerosols</td>
<td>Flammable</td>
<td>Brake and clutch fluids</td>
<td>Flammable</td>
</tr>
<tr>
<td>Ammonia and ammonia based cleaners</td>
<td>Corrosive</td>
<td>Car batteries</td>
<td>Corrosive</td>
</tr>
<tr>
<td>Chlorine bleach</td>
<td>Corrosive</td>
<td>Diesel fuel</td>
<td>Flammable</td>
</tr>
<tr>
<td>Chemical drain openers</td>
<td>Corrosive</td>
<td>Paraffin/kerosene</td>
<td>Flammable</td>
</tr>
<tr>
<td>Furniture polish</td>
<td>Flammable</td>
<td>Gasoline</td>
<td>Flammable, Poison</td>
</tr>
<tr>
<td>Glass cleaners</td>
<td></td>
<td>Waste oil</td>
<td>Flammable</td>
</tr>
<tr>
<td>Outdated medicines</td>
<td>Hazardous to others in family</td>
<td>Paint products</td>
<td></td>
</tr>
<tr>
<td>Oven cleaner</td>
<td>Corrosive</td>
<td>Enamel, oil based, latex or water based paints</td>
<td>Flammable</td>
</tr>
<tr>
<td>Shoe polish</td>
<td>Flammable</td>
<td>Paint solvents and thinners</td>
<td>Flammable</td>
</tr>
<tr>
<td>Spot remover</td>
<td>Flammable</td>
<td>Batteries</td>
<td>Corrosive</td>
</tr>
<tr>
<td>Toilet cleaner</td>
<td>Corrosive</td>
<td>Photographic chemicals</td>
<td>Corrosive, Poison</td>
</tr>
<tr>
<td>Upholstery and carpet cleaner</td>
<td>Flammable and/or Corrosive</td>
<td>Pool acids and chlorine</td>
<td>Corrosive</td>
</tr>
<tr>
<td><strong>Personal care products</strong></td>
<td></td>
<td>Garden insecticides / pest killers</td>
<td>Poison, some are flammable</td>
</tr>
<tr>
<td>Hair waving/straightening lotions</td>
<td>Poison</td>
<td>Herbicides / weed killers</td>
<td>Poison</td>
</tr>
<tr>
<td>Medicated shampoos</td>
<td>Poison</td>
<td>Chemical fertilisers</td>
<td>Poison</td>
</tr>
<tr>
<td>Nail polish removers</td>
<td>Poison, Flammable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubbing alcohol</td>
<td>Poison</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. LANDFILL SITE SELECTION

4.1 INTRODUCTION

In the past, many of the landfill sites in Botswana were sited in unsuitable borrow pits, on an unscientific and *ad hoc* basis. Proper landfill siting is, however, fundamental to good waste disposal practice and the prevention of water pollution. In Botswana, where high intensity precipitation events can cause major run-off, landfills should be sited on topography which facilitates drainage control measures that prevent upslope run-off from entering the waste body and causing leachate.

When selecting a landfill site, the main aims are:

- To ensure a facility of **sufficient longevity** within an **economic haul distance** from the waste generation areas
- To ensure that the site to be developed is **environmentally acceptable** and that it provides for **simple, cost-effective design**. This in turn would provide for good operation
- To ensure that, because it is environmentally acceptable, the site is also **socially acceptable**.

The longevity or life of a landfill site should be determined by balancing the time required to write off investigation, design and construction costs, with the need for locally affected persons to see a realistic end to the operation and the perceived nuisances. This could be anywhere between 10 and 30 years, but the longer the life of the landfill the more chance there is for landfill technology to change.

The landfill site selection process begins in response to a defined need for a certain class of disposal site. Once the class, and hence the size and potential environmental impact, of the proposed landfill has been determined, sufficient alternative candidate landfill sites must be identified to allow for a choice.

All the candidate landfill sites identified must be evaluated and ranked according to economic, environmental and social criteria. The highest scoring sites are then subjected to a more detailed investigation to determine the best site.

For G:S, G:M, G:L, and Sp sites, a **Feasibility Study**, involving a preliminary hydrogeological investigation and a preliminary environmental impact assessment, should be carried out on the best site to determine whether it is environmentally acceptable. After this has been confirmed, the interested and affected parties and communities must be consulted for their input and acceptance of the proposed development. If, for some reason, development of the site under consideration is not feasible, the next best site is considered. When a site has been shown to be feasible, detailed site investigations and the licensing process can commence.

The Guidelines for each class of site are shown in Table 4-2 at the end of this section.

4.2 THE SITE SELECTION PROCESS

The first step in landfill site selection is to identify the size and the general location of the required site.

**Size of the site:** As mentioned in the previous section, it is necessary to determine the size of the waste stream to determine the classification of the required landfill. It will then be possible to estimate the physical size of the landfill, based on its intended life.

As an indication, for Very small sites, on which waste is unlikely to be compacted, a density in the region of 0.3 tonnes/m$^3$ may be used to compute the necessary airspace required. On Small
sites, which are likely to receive some compaction, a figure of about 0.5 tonnes/m$^3$ is recommended. If burning is permitted the density may be lower and a more detailed analysis will be required.

Equally, on larger sites it will be necessary to make more detailed estimates on the basis of the actual techniques proposed and a knowledge of the waste composition. Furthermore, as hazardous waste production is usually associated with industrial activity and large towns and cities, the need for a hazardous waste disposal cell should be evaluated for all large sites.

**General site location:** This is determined by the waste generation area(s) to be served. The proposed facility should be established as close to the generation area(s) as possible, to minimise transport costs, and existing or proposed modes of waste transport should be taken into consideration.

Thereafter, further steps in site selection are as follows:

- The elimination of all areas not suitable for waste disposal
- The identification of candidate sites, based on the site selection criteria provided in section 4.4
- The ranking of candidate sites
- The carrying out of a Feasibility Study on the best option(s).

### 4.3 Elimination of Unsuitable Areas

When selecting a location for a new landfill, it is important to eliminate those areas which are totally unsuitable. It is useful, where possible, to draw up map overlays indicating unsuitable areas. By use of this "negative mapping", it is possible to identify areas which are suitable for the development of landfills. It is in these areas that candidate landfill sites should be identified.

When having regard to these criteria, it must be remembered that the Guidelines have been developed on the basis that it is the rule rather than the exception that determines the Guideline. In the list below, **there are some criteria which may simply be unavoidable for Very small and even possibly Small landfills. In these cases, the DSWM must be consulted at an early stage and a waiver of the appropriate criterion must be formally obtained.**

No landfill site should be developed in the following unsuitable areas:

- Within 1,000m of an airport or airfield boundary. This is because landfills attract birds, creating the danger of birds striking aircraft.
- Below or within 100m of the 1 in 50 year floodline. This eliminates dry river beds, wetlands, swamps, pans and flood plains, where water pollution would result from waste disposal.
- Areas within 100m of the highest known level of significant surface water bodies, e.g. swamps, streams, rivers, water courses or dams.
- Unstable areas. These could include fault zones, seismic zones and dolomitic or karst areas where sinkholes and subsidence are likely.
- Sensitive ecological and/or historical areas. These include nature reserves and areas of ecological, religious, cultural or historical significance.
- Catchment areas for important water resources, e.g. a village water supply.
- Areas characterised by flat gradients that would not allow for the drainage control to prevent upslope run-off from entering the waste body.
- Areas characterised by shallow or emergent ground water, e.g. swamps, pans and springs, where a sufficient unsaturated zone separating the waste body and the ground water would...
not be possible. A minimum 5m unsaturated zone is compulsory for all landfill sites. This may, however, be reduced in the case of proven clayey, low permeability unsaturated zones.

- Areas of ground water recharge on account of topography and/or highly permeable soils.
- Areas overlying or adjacent to important or potentially important aquifers which are vulnerable to pollution from leachate. Such areas have in some instances been identified and presented in terms of vulnerability maps produced by the Department of Geological Survey (DGS).
- Areas characterised by shallow bedrock with little soil cover.
- Areas in close proximity to land-uses which are incompatible with landfilling and where the requisite buffer zones are not possible, or areas which may attract community resistance. Such areas would include residential areas, cemeteries, and nature reserves.
- Any area directly upwind of a residential area (see buffer zones, section 4.4.3).
- Areas where rights of way, such as those for water, electricity or roads, preclude the establishment of a waste disposal facility.
- Any area characterised by any factor that would prohibit the development of a landfill except at prohibitive cost.

4.4 IDENTIFYING CANDIDATE LANDFILL SITES

As many alternative candidate landfill sites as possible should be considered in terms of environmental and socio-economic criteria, before making a final choice. It should be noted that there are usually both economic and social implications when a landfill site is environmentally substandard.

4.4.1 Economic Criteria

Economic criteria would relate to the cost of obtaining, developing and operating a site to an acceptable standard:

- The distance of the landfill from the waste generation areas will be in direct proportion to transport costs, and distances should therefore be minimised.
- Wherever possible, landfills should be shared, because the economies of scale make larger sites less expensive to operate.
- The size of the landfill should cater for the disposal of the waste stream over at least the medium term (10-20 years) to justify the capital expenditure.
- Access to the landfill site will have cost and convenience implications, especially if roads have to be constructed.
- On the larger sites, on-site soil should be available to provide low cost cover material. Abundant on-site soil for cover purposes will make it more economical for the landfill operate in accordance with the Guidelines. Importation of cover increases operating costs. Furthermore, cover shortage may reduce site life.
- Where Sp sites are involved, low permeability clayey sands on site will reduce the cost of containment liners and leachate control systems.
- The price of the land and its reduced value on completion of the landfill may have a significant impact on the economics in certain circumstances.
### 4.4.2 Environmental Criteria

Environmental criteria relate to the potential threat to the physical environment, specifically to water resources. They include the following considerations:

- The greater the distance to ground or surface water bodies, the more suitable the site is in terms of lower potential for water pollution.
- The importance of ground or surface water bodies as water resources must be considered. The greater the resource value of the water body, the more sensitive the establishment of a landfill on account of the potential for water pollution.
- The geological should be such that there are no unfavourable conditions such as faults, dykes, secondary structures and zones of weakness.
- The depth and quality of soil on the site are important considerations for larger sites. Abundant on-site soil for cover purposes will facilitate landfill operations and will reduce nuisances such as flies, rodents, odours, wind blown litter, etc. Fine to medium grained soils with a high clay content and low permeability are also favoured as they reduce any pollutant migration.
- A landfill located on a steep slope will be very visible, and on a flat slope there will be difficulty in engineering the drainage. Therefore a gentle slope is preferable.
- Disturbed areas or areas which are naturally well represented in terms of flora and fauna are preferable.

### 4.4.3 Social Criteria

Social criteria relate to the possible adverse impact of a landfill on quality of life and to potential public resistance:

- Exposed sites with high visibility are less desirable than secluded or naturally screened sites.
- Prevailing wind directions must be taken into account. New landfills must be sited downwind of residential areas. The risk of windblown litter must be considered.
- The greater the distance from residential areas, the lower the risk of nuisance problems and hence resistance to the facility.
- The impact of additional traffic on the surrounding roads may be significant in the case of larger sites.
- The present and proposed land use should be of sufficiently low value.

In order to protect the public from any adverse effects of a waste disposal operation, Guidelines have been set for buffer zones around landfills. Buffer zones are separations between the registered site boundary and residential developments. The required buffer zone is usually 500m. In the case of G:L sites and Sp:H sites, however, the buffer zone is 1,000m. The implications of the existence of the landfill, for which Planning Permission will be required, should be recognised by the District Planning Authority, and no residential or commercial development may take place within the proclaimed buffer zone. At the discretion of the Planning Authority, however, industrial development may be permitted.

### 4.5 Ranking of the Candidate Landfill Sites

Having identified a number of candidate landfill sites using the above criteria, it is necessary to compare and rank them from best to worst using a matrix. The matrix would include environmental impacts, safety risks, social impacts and costs (acquisition, construction, operating and closure).
A typical matrix would be as shown in Table 4-1.

<table>
<thead>
<tr>
<th>CANDIDATE SITES</th>
<th>SITING CRITERIA</th>
<th>TOTAL SCORE (Score x weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Size</td>
<td>Distance</td>
</tr>
<tr>
<td>Weighting</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>SITE A</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>SITE B</td>
<td>etc.</td>
<td></td>
</tr>
<tr>
<td>SITE C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SITE Z</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The criteria shown in the table are not exhaustive. All the criteria discussed above should be evaluated. It may also be appropriate to give different weightings to the importance of different criteria. These must be appropriate to the local situation and may vary from region to region. For each site, each criterion is evaluated and assigned a score on an appropriate scale, e.g., 0 to 5 (worst to best). The evaluation and scoring process is usually carried out by a multi-disciplinary team, who reach consensus through discussion. The assigned values are then totalled (each being multiplied by the weighting factor if used) to provide an overall score for each site and, thereafter, sites are ranked from the highest (best) to the lowest (worst) score.

The top ranking sites may then be considered in more detail to confirm the ranking and to establish the preferred site.

4.6 FEASIBILITY STUDY

Input from the DSWM may be desirable before subjecting the top ranking candidate landfill site to more detailed investigation, in the form of a Feasibility Study. The Feasibility Study is compulsory for all G:S, G:M, G:L and Sp sites.

The primary objective of the Feasibility Study is to ensure that the subsequent Licence application is not destined to failure, thus saving time and money on the part of the DSWM and the applicant. The aims of the study are:

- To confirm that the site is not in an unsuitable area
- To identify any problem areas and to address them to the satisfaction of the DSWM
- To provide the necessary information for a Planning Application to be determined
- To identify any preliminary concerns of interested and affected parties (IAP's).
- To establish that the DSWM is likely to consider the site suitable for development into the class of landfill envisaged.
- To confirm that the operation is economic and can be supported by the community for whom it is being provided.
- To document the selection process and reasons for decisions

A candidate site must be both environmentally acceptable and acceptable to the Interested and Affected Parties (IAPs) for it to be feasible for development. The Planning Permission, which is a precursor to the grant of a Licence, provides the basis for the consultation with IAPs.
The Feasibility study provides information which will be necessary for the Planning Application to be determined. The extent of the Feasibility Study and its presentation will depend on the class of landfill proposed, the physical complexity of the actual site and the sensitivity of the receiving environment. Components of the study are provided below:

4.6.1 Basic Information

Certain information is necessary in order to provide background; this should include the following:

Landfill classification

In this section, all the information pertaining to waste types, magnitude of waste stream and waste moisture content is presented. Based on this, the proposed landfill is classified, using the landfill classification system (see Section 2). Applicants should also indicate whether it is to operate as a sanitary landfill or controlled burning site and whether they intend to deposit sewage sludge, wet or hazardous wastes.

Indication of candidate landfill site selection procedure

The process of candidate landfill site identification and ranking must be described in the Feasibility Report, to justify the choice of site.

Site description

This would include all information relevant to the development, design, operation and any intended after use of the site, e.g. topography, drainage, aspect, wind direction, rainfall, existing vegetation, access, etc. It could also include observations forthcoming from the preliminary Hydrogeological Investigation and Environmental Impact Assessment and any intentions for after use.

4.6.2 Preliminary Environmental Impact Assessment (pEIA)

The preliminary Environmental Impact Assessment (pEIA) is considered to be the forerunner of the full EIA described in Section 5 and is therefore to be carried out in accordance with the same principles. This preliminary EIA must re-address all the environmental siting criteria used during the candidate landfill site ranking and it must confirm the suitability of the site. Problem areas must be identified and their proposed solutions discussed in the Feasibility Report, usually in terms of the conceptual design.

4.6.2.1 Preliminary Hydrogeological Investigation (pHGI)

The extent of the preliminary hydrogeological investigation (pHGI) will be commensurate with the class of landfill under consideration. Usually it would be confined to a desk study of existing information, such as maps and reports obtained from the Department of Geological Survey (DGS). This may, however, need to be confirmed in the field by test pits or by the drilling of a limited number of boreholes and, sometimes, by blow yield tests.

The pHGI is an important part of the pEIA because the results are relevant to the assessment of impacts on the soil and water media. Details on the extent of the pHGI are given in the Hydrogeological supplement in Appendix 1. This preliminary HGI must be seen as the forerunner to the full investigation and therefore must be carried out in accordance with the principles set out in Section 5.

The information required is as follows:
Landfill Site Selection

Geology
This would include regional and local geology (stratigraphy and bedrock) as well as any structures (faults, dykes and lineations).

Soils
The soil on the site should be generally described and classified in terms of type, estimated permeability, depth and volume available for cover material.

Ground and Surface water
All boreholes within a distance of 1 km from the site boundaries must be identified, with a view to recording ground water uses in the area. The purpose for which the water is used and, where possible, borehole characteristics such as ground water levels, ground water quality, borehole yields, borehole depth, abstraction rates, geological logs, casing/screen details and drilling date, should be included.

From the borehole census, an indication of the minimum depth to ground water in the vicinity of the site, the yield and the probable flow direction must be provided. Should this not be possible, drilling may be justified in the preliminary HGI.

Regardless of the source of information, the importance of the ground water in the vicinity of the landfill as a resource and its vulnerability must be indicated. This would also apply in the case of any surface water observed in the vicinity of the site.

4.6.2.2 Conceptual Design
The conceptual design addresses the size, height and layout of the facility, together with any problem areas identified in the preliminary EIA. It also provides an indication of the planned landfill design.

4.6.2.3 Maps and Plans
The Feasibility Report must be illustrated with relevant maps and plans (for example, 1:50 000 topographical maps and 1:10 000 orthophoto maps, if available). The maps should indicate the position of the disposal site and should show the surrounding area to a distance of 1 km. The I in 50 year flood line of any water courses, the positions of boreholes, wells, springs, dams and water courses, archaeological, palaeontological, cultural and historical sites, important roads and transportation corridors, surrounding land uses and the waste generation area served should be shown. Existing and proposed land use and residential development should also be shown.

4.6.2.4 Interested and Affected Parties (IAPs)
Interested and Affected Parties (IAPs), are people and communities who are or can be affected in some way by the development of the proposed landfill. They must be made aware of the need for a landfill and its potential impact on them. They must be allowed input into the selection process and all their concerns are to be addressed in the process. In dealing with the IAPs, an acceptable end-use represents an important issue. Often this is dictated by the IAPs and must be taken into consideration in the Planning Permission and also the design and closure of the landfill.

The feasibility of a candidate landfill depends on IAP acceptance of the proposed development being obtained. This will normally be obtained through the Planning Permission process (or procedures under the Tribal Lands Act) for the proposed development and its end-use, which must be obtained as a precursor to the Licence application.

It is noted that there is no specific provision in the Town and Country planning Act to ensure public consultation, although this normally takes place. The DSWM should ensure that appropriate public consultation has taken place before a Licence is granted.
4.6.3 Consultation with DSWM

Although the Feasibility Study is not a formal part of the Licensing process, the submission of the Feasibility Study to the DSWM is an important step, since it provides an opportunity for consultation before the detailed investigation and design which is necessary before a Licence Application is submitted. The information in the Feasibility Study, together with some parts of the detailed investigation (e.g. the EIA, where conducted) may also be required for the Planning Application.

The DSWM will also be consulted for their opinion by the local Planning Department before Planning Permission is granted.

4.7 LICENCE APPLICATION

Before a landfill may be constructed or operated, a Licence is required from the DSWM. The Licence Application must include all the necessary information for the DSWM to make a decision. During the consultation process, the DSWM will define the extent of this information.

It will include all the results of the investigations which are specified in Table 5-2, together with the design information specified in Table 6-1.

The DSWM will also ensure that appropriate public consultation has taken place through the Planning Permission or Tribal Lands Act procedures.

The Licence will contain specific conditions relating to all aspects of the landfill. Notable among these will be a specification of the types and quantities of waste which may be accepted at the landfill.
Table 4-2: Guidelines for landfill Selection

<table>
<thead>
<tr>
<th>GUIDELINES</th>
<th>CLASSIFICATION SYSTEM</th>
<th>I</th>
<th>G</th>
<th>S</th>
<th>M</th>
<th>L</th>
<th>W</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classify proposed site</td>
<td></td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Investigate need for Hazardous waste cell</td>
<td></td>
<td>N</td>
<td>N</td>
<td>D</td>
<td>C</td>
<td>N</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Eliminate unsuitable areas</td>
<td></td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Identify candidate landfill sites</td>
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<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Rank candidates</td>
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<td>C</td>
<td>C</td>
<td>C</td>
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</tr>
<tr>
<td>Confirm best site</td>
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<td>N</td>
<td>N</td>
<td>C</td>
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<td>C</td>
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<tr>
<td>Buffer zone</td>
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<tr>
<td>Minimum 5m unsaturated zone</td>
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<td>C</td>
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<tr>
<td>Feasibility Study</td>
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<tr>
<td>Preliminary HGI</td>
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<td>C</td>
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<td>C</td>
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<tr>
<td>Preliminary EIA</td>
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<td>D</td>
<td>C</td>
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<tr>
<td>Consult with IAP's</td>
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<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Identify and assess problem areas</td>
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<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Confirm no insurmountable problems</td>
<td></td>
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<tr>
<td>Submit Planning Application (IAPs)</td>
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<td>C</td>
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<tr>
<td>Consult DSWM</td>
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<td>C</td>
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<td>C</td>
<td>C</td>
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<tr>
<td>Submit Licence Application (with further</td>
<td></td>
<td>C</td>
<td>C</td>
<td>C</td>
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<td>C</td>
<td>C</td>
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<tr>
<td>information as specified by the DSWM)</td>
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<tr>
<td>including documentation of all decisions</td>
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<td></td>
</tr>
</tbody>
</table>

*C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.*
5 LANDFILL SITE INVESTIGATION AND CHARACTERISATION

5.1 INTRODUCTION

Once the preliminary investigation has been completed, further detailed investigations and reports are required as part of the Licence Application. The extent of the investigation required for each class of site is shown in 2 at the end of this section. The detailed site investigation and environmental impact assessment usually take place in parallel. These investigations form the basis for the landfill design. Details for the hydrogeological requirements of the site investigations are described in the hydrogeological supplement in Appendix 1.

The extent of these investigations would be commensurate with the class of landfill under consideration, the level of investigation already undertaken and the potential environmental impact associated with the site. The persons responsible for the investigations must be appropriately qualified and experienced in order to execute, direct and guide all aspects in a professional manner. Liaison with the DSWM must continue throughout the investigations. This is because the depth or extent of the investigations will vary, depending on the site classification. The right levels of investigation must therefore be ensured, to provide the DSWM with the information required for decision making. Finally, the DSWM must be kept informed of progress.

5.2 SITE INVESTIGATION

The aims of the detailed site investigation are:

- To ensure that no problem areas were overlooked in the preliminary site investigation
- To provide a sound basis for the design of the landfill by obtaining adequate geographical, geological, hydrogeological and geotechnical information for the site.

The following three areas are covered by the site investigation and the subsequent report:

- **Above-surface features** or physical geography, which are the observable surface features associated with the site and surrounds
- **Sub-surface features**, or phenomena situated underground, which have to be exposed by means of excavation or drilling before they can be assessed
- **Other features**, such as surface or underground mining, associated with the site.

Although aspects of the above three areas are discussed in this section, the DSWM may have further specific requirements under certain circumstances. For example, additional geophysical surveys, pump and recharge tests and even tracer studies might be required.

5.2.1 Above-surface features

This part of the investigation deals with what can be observed on the site, and on a defined area adjacent to and affected by the site.

**Topography and surface drainage**

Appropriate topocadastral data, including all significant topographic features, must be provided. Most important are the drainage patterns, including seasonal and perennial stream$, and the distances to the nearest important water courses, wetlands and swamps. Rock outcrops and surface soil must also be recorded here.
No landfill may be developed within 100m of the highest recorded level of a significant surface water body or within the 1 in 50 year floodline. Any surface water observed adjacent to a proposed or existing landfill site must, however, be investigated. A survey must be conducted to assess the purpose for which it is used and to assess its present or potential strategic or community value. Any surface water body that may be affected by the landfill should be sampled both upstream and downstream, and analysed to determine its quality. In the case of new landfill sites, such sampling will provide a background against which to compare future water quality.

Infrastructure and man-made features
Infrastructure such as roads, railways or airfields must be indicated. Of particular importance in the consideration of sites for landfill, are earthworks which affect the natural drainage system and/or result in spoil which could serve as cover. Features such as sewage works, cemetery or existing waste dumps, that could cause or are already causing water pollution should also be indicated.

Climate
Relevant climatic data must be provided. This will include monthly rainfall and pan evaporation figures, and wind speed and direction data, preferably in the form of a wind rose. These should be obtainable from the nearest meteorological station to the site.

Vegetation
The existing vegetation on the site must be described, whether it be indigenous vegetation, crops or fallow agricultural land.

Some of the above information can be obtained from published reports or maps. Published information should, however, be verified, updated and elaborated upon by on-site observation. The latest available information should always be used.

5.2.2 Sub-surface Features
As indicated, access to sub-surface features such as soil and rock profiles or ground water is usually gained only by excavation. This could include testpitting, auguring and percussion drilling.

Geophysical techniques may be used to guide the siting of test pits and boreholes. These give initial insight into the geological and hydrogeological characteristics of a site. Geophysical techniques, although not always appropriate, could be useful in the location of water-bearing features such as dykes, faults and geological contacts.

Background regarding the principles relating to the drilling of exploration boreholes, and aspects such as the location of borehole, the depth of drilling and the construction of permanent observation wells, is discussed in the hydrogeological supplement in Appendix 1.

Although numerous boreholes may be required to provide a full understanding of the site for design purposes, this is not always practicable. At G:M sites and above, however, at least one correctly sited borehole should be drilled, as this would provide a substantial amount of information which would otherwise not be available.

Where three dimensional information is: required, for example when determining the phreatic surface and ground water flow direction, three boreholes are recommended. This is because three boreholes would, as a rule, provide this information by triangulation. Generally, however, more than three boreholes would be necessary.

Information obtained from the boreholes would include accurate measurement of ground water depth and flow direction. It would also provide insight into the soils, geology, stratigraphy and
hydrogeology associated with the site. Boreholes also provide access to the ground water for both water quality monitoring and future extraction.

**Geotechnical Investigations (Soils)**

**Quality and quantity**

Soil on a site serves both to provide cover material and to separate the waste body from the ground water. Consequently, it has to be properly qualified and quantified for both the purposes of design and for the DSWM's information.

Access to the first 3m of the soil profile is usually gained by test pits. If greater depths are required, auguring may be used. Data from the test pits may be supplemented with information from the borehole profiles.

**In situ permeability and other geotechnical tests**

In the case of a Sp site where an underliner is required, any natural soil layer that appears to be suitable for use as a liner should be tested for permeability. Examples of suitable permeability test methods include double ring infiltrometer tests and tests such as the Guelph in-situ permeameter. The permeability of underlying strata can be determined using borehole infiltration tests of various types.

Other soil identification tests may include particle size analysis, Atterberg limits and clay content. Standard Proctor compaction tests may also be required and if trench systems involving cut slopes are to be used, it may be necessary to measure the shear strength of the soils.

**Geological investigations**

**Stratigraphy and lithology**

The site must be described in terms of the Regional Geology, to indicate where it fits into the regional stratigraphy, e.g., the Archean granites, the Dolomites or the Karoo Sequence. This background stratigraphic and lithological information is usually available from existing geological maps and reports. This existing information must, however, be supplemented and confirmed in all cases with field data, comprising borehole logs or profiles and the interpretation thereof.

The stratigraphic and lithological features adjacent to and immediately beneath the site must also be examined by means of boreholes. The boreholes must be examined and profiled by a suitably qualified expert, who should describe and report upon the findings using appropriate maps and cross-sections.

The depth and extent of the investigation should be sufficient to provide the necessary understanding of the basic geology and to identify any problem areas.

**Tectonics, lineaments and structures**

The presence and disposition of any geological faults, joints and fractures, and other linear features resulting from dykes or from steeply dipping strata must also be described and indicated on the maps and cross-sections referred to above.

**Hydrogeological investigations**

All available hydrogeological data and any factors affecting the ground water in the area must be identified and must form part of the site investigation report.

**Ground water morphology and flow**

The depth and, general flow direction of the ground water and its seasonal fluctuations, particularly its wet season high elevation, as well as the presence of any, perched water surfaces or any other relevant data, must be determined.
Investigation of aquifers
On account of the importance of ground water protection in Botswana, electromagnetic geophysical techniques are particularly useful for the detection of the fracture zones which act as water conduits in both the Archean granites and in the Karoo sandstone aquifers. Landfills should not be developed over strategic aquifers. Any aquifer associated with a proposed landfill therefore must be investigated in terms of its yield, quality and existing or potential usage, to ensure that it does not represent a strategic water source.

Yields
During drilling, blow yield tests should be carried out to provide an initial indication of yield. Where yield is considered to be significant, it should be determined more accurately using appropriate step tests, see also the Hydrogeological supplement in Appendix 1. If yields are in excess of 5 l/sec and the quality of the water is good, then the development of a landfill site is prohibited.

Quality
The ground water quality will be assessed by monitoring, to determine whether it is of strategic value or not.

Ground water usage
A survey of existing boreholes and wells (a hydrocensus) must also be conducted. Abstraction rates, yield, depth, age and the purpose for which the water is used must be obtained, with a view to assessing the strategic or community value of the water resource.

5.2.3 Other features

Areas where mining has occurred
Open-cast and underground mines must be identified, delineated and examined to establish the effect of their presence on ground water flows and potential subsidence. The possibility of future mining activities should also be assessed.

Sinkholes and surface subsidences
Dolomitic areas where sinkholes or surface subsidences occur should have been avoided during the site selection process, as this geology is unsuitable for landfilling.

5.2.4 Site Investigation Report

The Site Investigation Report documents all the information gathered during the site investigation. In most instances, a detailed Site Investigation will form part of the Licence Application. The report should define the scope and objectives of the site investigation and indicate the methodology used.

Because water is of utmost importance in Botswana, the primary objective of the site investigation is to demonstrate to the DSWM that the hydrogeology associated with the site is such that a landfill can safely be developed and operated. If it indicates areas of vulnerability which require further investigation or special attention, these would be addressed in the Environmental Impact Assessment and the Environmental Control Report.

5.3 ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

The aims of the Environmental Impact Assessment (EIA) are:

• To identify and evaluate the various ways in which an existing or proposed landfill will affect its receiving environment
Landfill Site Investigation and Characterisation

• To assist the designer in addressing any identified impacts by means of proper design. The EIA assesses the potential impacts of a project on the environment and the likelihood of these impacts manifesting themselves. Based on this, the Environmental Impact Control Report (EICR) is drawn up, to indicate how the identified potential impacts can be addressed or mitigated in the design, operation or upgrading of the landfill. The EIA, where required, will form part of the Licence Application and may also be required for determination of the Planning Application.

5.3.1 EIA Methodology

Many established methods of assessing environmental impacts (or risk) exist. Most of these depend on, or take as their starting point, a checklist of considerations that should form part of the design process. Appendix 3 provides a typical checklist of design and environmental considerations for the environmentally acceptable design of landfills. The checklist has been divided into a number of sections, dealing with the selection and investigation of the landfill site and possible adverse impacts to be eliminated or controlled by design or operation. It may simply be used as a checklist, or, depending on the level of investigation, it may be used in a risk assessment to identify interactions between the site characteristics, design and operation, and their potential impacts on the environment.

In order to identify interactions, use is often made of a two-dimensional environmental impact identification matrix (see Table 5-1). These matrices usually list the project phases along a horizontal axis and the possible impacts on various aspects of the environment on a vertical axis. A methodology has recently been developed by the NCSA for use at the University of Botswana. In order to be effective, the matrices normally have to be large and complex but a summary is also usually produced. An example of the summary is provided in Table 5-1. The impacts are scored using a ranking scale. More detail on the methodology can be found in the University of Botswana methodology.

The selection of the actions and impacts that make up the axes of the matrix must be undertaken by a team having multi-disciplinary representation and including, if possible, representatives of the local authority, of any party that will be affected by the proposed site. The matrix must also be scored by the team, with each rating being the result of consensus.

5.3.2 Identification of Potential Adverse Impacts

The main objective of the EIA is to identify and evaluate potential adverse impacts of the project on the environment well before the landfill is developed. Moreover, in the unlikely event that any problem areas were overlooked during the Feasibility Study, these should now become evident. Some of the more common impacts associated with landfills include:

**Short term Impacts**

Short term impacts, such as burning, smoke, flies, odour, unsightliness, windblown litter, are nuisances which are generally associated with a waste disposal operation. These generally cease with the proper closure of the landfill. They must, however, be identified as potential problems during the operation of the landfill.

**Long term impacts**

Long term impacts of the landfill may include explosion hazards, as a result of landfill gas, and the pollution of the water regime. These impacts persist long after the landfill site has been closed.
### Table 5-1: Environmental Impact Matrix

<table>
<thead>
<tr>
<th>RECEIVING ENVIRONMENT</th>
<th>IMPACT</th>
<th>Construction</th>
<th>Operation</th>
<th>Closure</th>
<th>Total Impact</th>
<th>Total Receiving Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICAL ENVIRONMENT</td>
<td>Ground water Pollution</td>
<td>0</td>
<td>-3</td>
<td>-2</td>
<td>-5</td>
<td>-9</td>
</tr>
<tr>
<td></td>
<td>Surface Water Pollution</td>
<td>0</td>
<td>-3</td>
<td>-1</td>
<td>-4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECOLOGICAL ENVIRONMENT</td>
<td>Water Cycle</td>
<td>-3</td>
<td>-5</td>
<td>-6</td>
<td>-14</td>
<td>-18</td>
</tr>
<tr>
<td></td>
<td>Fire regime</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>-4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAND USE</td>
<td>Resumption of arable land</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
<td>-4</td>
<td>-13</td>
</tr>
<tr>
<td></td>
<td>Resumption of grazing land</td>
<td>-6</td>
<td>-4</td>
<td>1</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUMAN HEALTH &amp; QUALITY OF LIFE</td>
<td>Production of toxic materials</td>
<td>0</td>
<td>-3</td>
<td>-2</td>
<td>-5</td>
<td>-9</td>
</tr>
<tr>
<td></td>
<td>Spread of disease</td>
<td>-1</td>
<td>-3</td>
<td>0</td>
<td>-4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECONOMIC ISSUES</td>
<td>Income opportunities</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Demand for health services</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ACTIVITY’S TOTAL IMPACT</strong></td>
<td></td>
<td>-12</td>
<td>-24</td>
<td>-12</td>
<td>-48</td>
<td>-48</td>
</tr>
</tbody>
</table>

**Explosion hazards**

During the process of waste decomposition, malodorous landfill gases are generated. These contain methane, which can be explosive in concentrations from 5% - 15% in air. The rate of decomposition and hence the rate of production of significant quantities of gas depends on the moisture content of the waste. On account of Botswana's arid climate and the prescribed buffer zones adjacent to landfill sites, landfill gas is not considered to represent a problem, except where Large or Special waste landfills are situated very close to residential areas.

**Water pollution**

Pollution of the water regime may be divided into surface water pollution and ground water pollution.

*Ground water pollution*

Ground water pollution may result from badly sited, designed or operated landfills.

The siting of a landfill where no unsaturated zone exists would permit the waste to come in contact with the ground water and pollution would result. Bad drainage design could permit run-off water in high intensity rainfall events to enter the waste body and form leachate. If there is inadequate control of the operation and Wet wastes are disposed of on General landfill sites, leachate may also be generated.

Any leachate formed may seep through the unsaturated zone into the ground water and pollute it. This is particularly relevant in Botswana, as the majority of potable water in the rural areas is BOTSWANA
derived from ground water. Furthermore, it is noted that once an aquifer is polluted, it is very
difficult to remediate and purify the water.

Surface water pollution
Mechanisms of leachate generation are described above. Leachate could equally well enter and
pollute surface water bodies associated with the landfill.

Degraded land
If a landfill is not properly restored and shaped, the resulting profiles and degraded land will render
the area unsuitable for the envisaged end-use.

Once the EIA matrix has been scored, the interpretation of the results must be documented in a report.
The report must describe each adverse impact and its implications. If a problem area or negative impact
identified in the EIA cannot be eliminated or suitably addressed by design at acceptable cost to the
project, it could constitute a "no go" situation. A "no go" situation, would be any impact that would, by
itself, invalidate the use of the site.

This EIA report will be included in the Environmental Impact Control Report, which will show how
each major adverse impact will be addressed or, preferably, eliminated by the design and operation of
the landfill.

5.4 ENVIRONMENTAL IMPACT CONTROL REPORT (EICR)

The Environmental Impact Control Report (EICR) will encompass the EIA matrix and report, and
elements of the Design, Operating and Closure Plans. The objective of the report is to explain the steps
that will be taken to ensure that the disposal site will not have an adverse effect on the receiving
environment.

In discussing the EIA matrix and the interpretation thereof, the potential pollution, aesthetic and safety
impacts of the landfill were identified. The design and management principles proposed for the
reduction of these adverse impacts would then be addressed. A description would be provided of the
construction and operation of the proposed site, with particular reference to environmental protection
measures. Finally, a description of the proposed monitoring strategy, intended to substantiate the
efficiency of the design and the management principles envisaged, would be included.

In the EICR, for G:L and Sp sites, the environmental consequences of failure of the proposed
environmental protection measures to be included in the design of the site should be evaluated. This is,
in effect, a Risk Assessment approach.

Such a risk assessment approach should, for example, address the risk and potential impact of failure of
the landfill lining system, where this is proposed. Risk Assessment involves identifying:

• The potential adverse impacts from failure of the protection mechanisms.

• The source of the impact.

• The receptors or targets of the impact, i.e. the persons or features affected by it.

• The pathways through which the receptors may be affected.

• The probability of the receptors being affected via each pathway.

If the result of this analysis indicates unacceptable risks, the proposed design should be amended
and a new risk assessment carried out on an iterative basis until a satisfactory outcome is achieved.
Thus this procedure may interact with the design process described in the next section.

Figure 5-1 illustrates the sources, pathways and receptors for a typical large landfill.
Where appropriate, a Response Action Plan could be included in the EICR. This is so that, in the event of failure in the design, e.g., the liner or leachate collection system at an Sp site, the situation can be dealt with rapidly and efficiently. Such procedures would also be addressed in the Operating Plan (see Section 7.2.3).

5.5 PUBLIC CONSULTATION

The support of communities and local leaders is a vital aspect of the development process for a landfill. It is necessary that the consultation process is maintained throughout the investigation phase to update the community on the investigation results. The method and process for involving the community is flexible but must be undertaken with the input and consensus of the IAP’s.

The consultation process starts with an initial scoping conference, where anyone with an interest is invited to voice his or her opinion. Later, in order to ease communication and make the consultation process more efficient and effective, the direct liaison should be restricted to include only the community elected representatives, who will then be required to further liaise with their respective communities. These representatives could include the Kgosi, members of the VDC, politicians, or any other democratically selected individuals who have an interest.
Figure 5-1: Sources/Pathways/Receptors
<table>
<thead>
<tr>
<th>GUIDELINES</th>
<th>CLASSIFICATION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>Appoint Responsible Person</td>
<td>N</td>
</tr>
<tr>
<td>Delineate physical area to be investigated</td>
<td>N</td>
</tr>
<tr>
<td>Describe topography and surface drainage</td>
<td>N</td>
</tr>
<tr>
<td>Determine surface water quality</td>
<td>N</td>
</tr>
<tr>
<td>Assess importance of water sources (1 km)</td>
<td>N</td>
</tr>
<tr>
<td>Describe man-made features</td>
<td>N</td>
</tr>
<tr>
<td>Wind direction</td>
<td>N</td>
</tr>
<tr>
<td>Existing vegetation</td>
<td>N</td>
</tr>
<tr>
<td>Test pits</td>
<td>N</td>
</tr>
<tr>
<td>Geophysics</td>
<td>N</td>
</tr>
<tr>
<td>One borehole</td>
<td>N</td>
</tr>
<tr>
<td>Three or more boreholes</td>
<td>N</td>
</tr>
<tr>
<td>Soil description</td>
<td>N</td>
</tr>
<tr>
<td>In situ permeability tests</td>
<td>N</td>
</tr>
<tr>
<td>Stratigraphy and lithology</td>
<td>N</td>
</tr>
<tr>
<td>Tectonics and lineaments</td>
<td>N</td>
</tr>
<tr>
<td>Ground water morphology and flow</td>
<td>N</td>
</tr>
<tr>
<td>Ground water quality</td>
<td>N</td>
</tr>
<tr>
<td>Ground water usage</td>
<td>N</td>
</tr>
<tr>
<td>Investigation of aquifers</td>
<td>N</td>
</tr>
<tr>
<td>Pump testing</td>
<td>N</td>
</tr>
<tr>
<td>Past and future mining and subsidence</td>
<td>N</td>
</tr>
<tr>
<td>Hydrogeological report</td>
<td>N</td>
</tr>
<tr>
<td>Investigate potential gas hazards</td>
<td>N</td>
</tr>
<tr>
<td>EIA/EICR</td>
<td>N</td>
</tr>
<tr>
<td>Risk Assessment/sequences of failure</td>
<td>N</td>
</tr>
<tr>
<td>Response action plan</td>
<td>N</td>
</tr>
<tr>
<td>Public Consultation</td>
<td>C</td>
</tr>
</tbody>
</table>

*C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.*
6.1 INTRODUCTION

The landfill design is based on the findings of the Site Investigation and the Environmental Impact Assessment. If the best available site has been found to be sub-optimal from an environmental or hydrogeological point of view, the design must compensate by means of appropriate engineering. Such compensatory design must be to the satisfaction of the DSWM. A summary of the Guidelines, for each class of site, for design is shown in Table 6.1, and for construction in Table 6.2 at the end of this section.

The Responsible Person for the design must have qualifications and experience that are acceptable to the DSWM. For example, in the case of a Sp site, a Registered Professional Engineer must be responsible for the design and must provide design details appropriate for the class of landfill under consideration.

The general aim of landfill design is to provide a cost-effective, environmentally acceptable waste disposal facility. The key issues are:

- The prevention of upslope surface water run-off from entering the waste body and generating leachate which could pollute adjacent ground and surface water
- The provision of sufficient cover material to ensure an environmentally and aesthetically acceptable operation.

There is, in addition, a wide range of other matters which need to be addressed at the design stage, such as:

- Profile of the final landform (slopes, void capacity, settlement and waste density)
- Phasing of the filling process
- Infrastructure layout (roads, offices, weighbridge, wheelwash, sorting areas for recyclables, etc.)
- Materials requirements (soils balance for cover, restoration, peripheral banks)
- Leachate management
- Landfill gas management
- Preparatory works prior to waste arriving (sealing layers, internal bonds).
- Monitoring provisions

There are two stages of design - Conceptual and Technical.

The Conceptual Design addresses the principles of the intended design, but does not include detailed specifications. A Conceptual Design is compulsory for all sites and is adequate for Licence application purposes in some instances.

The Technical Design is required as part of the Licence application in cases such as G:L and Sp landfills, where the design is more complex and requires the construction of features such as drains and underliners. The Technical Design is based on the Conceptual Design. Where necessary, it is also based on the results of tests on soils, construction materials and waste. The Technical Design includes detailed specifications of materials, measurements and procedures, as well as detailed drawings. The Technical Design, together with the associated Bills of Quantities, also forms the basis for contractual tendering and construction.
6.2 CONCEPTUAL DESIGN

Landfill classification, airspace and expected site life are common prerequisites to all landfill designs. They are therefore addressed under Conceptual Design.

6.2.1 Confirmation of Landfill Classification

Since the classification of a landfill site will determine the specific guideline requirements and the details applicable to its design, the classification, in terms of waste type and magnitude of the waste stream, must first be confirmed (see Section 2).

6.2.2 Filing Above and Below Ground Level

Landfills can be constructed in excavations and by raising the level above the virgin ground. Above ground disposal (landraising) is generally preferred over below ground disposal (filling of excavations), since it makes the management of surface water drainage easier and tends to result in less percolation of rainwater into the waste body. Nevertheless, filling of excavations sometimes performs a useful reclamation function and may be acceptable in many situations.

6.2.3 Airspace and Expected Site Life

Since the availability of cover material is a prerequisite for the sanitary landfill process, the supply of cover may be a limiting factor in the amount of airspace for the landfill. As a general rule, about 25% must be added to the waste volume to allow for intermediate cover, final cover and cell walls within the airspace. It is usually unsafe to assume that sufficient (or any) soil of adequate quality will be delivered to a general waste landfill. It is therefore greatly preferable to make reliable arrangements for on site excavation or an external borrow pit. Hence, for every 1 m$^3$ of cover available, 4 m$^3$ of waste can be deposited.

The calculation of required airspace volume from the weight of waste to be deposited involves assumptions about in-place density. This in turn depends on the kind of waste and the method of deposition. Some indicative densities have been suggested in section 4.2. The most reliable approach, however is to carry out volumetric consumption surveys on sites which are to be replaced and add allowances for future changes in the expected waste quantity.

In the case of controlled burning sites, plans should include arrangements for cover but it will be required less frequently and of a smaller volume. Burnt waste is likely to require about 20% of the equivalent volume required at a sanitary landfill. Because of the relatively low volumetric demand associated with controlled burning sites, the excavation of trenches is an economic method. Excavation brings with it the important advantage of creating a confined trench in which burning can be well controlled.

In considering the excavation of cover, careful attention must be given to the requirement that there must always be an acceptable minimum physical separation between the waste body and the highest seasonal level of the ground water (see section 4.3). The available airspace is also affected by the shape and height of the final landform, which, together with cover availability, must be taken into account.

Allowances for settlement must be taken into account. Often the final levels are not critical but it is important to allow for settlement at the edges if the landfill is in an excavation or trench, to prevent depressions forming which can collect surface water. As an approximate guide, a settlement of 20% to 30% can be expected for lightly compacted municipal waste during a 20 to 30 year period. These estimates cannot, however, be precise and the engineering plans must be tolerant and flexible.
6.2.4 Site Layout

The site layout design will typically comprise plans and sections indicating existing, excavated and final contours. The following aspects would be addressed and in many instances, would have to be indicated on plans:

Access
The requirements for road access to and within the site and other necessary infrastructure must be assessed.

Infrastructure
The infrastructure facilities at a landfill site will vary in accordance with the size of the operation. In the case of a G:V site, only access control would required. Larger sites will have a stronger infrastructure. In the case of Sp sites, convenient access to a laboratory is a requirement.

Matters that require consideration, especially for larger sites, include:

• Site accommodation - offices, plant maintenance facilities, staff facilities, enclosures for leasing to recyclers, etc.
• Weighbridge
• Fencing and security (see section 7.2.2)
• Signs and directions (see section 7.2.1)
• Services - Power, water and telephone.
• Laboratory for waste analysis.
• First aid facilities, possibly including emergency showers at Sp:H sites.
• Fire fighting equipment

Surface hydrology and drainage design
Because of the intensity of rainfall events in Botswana, the control of run-off water emerges as a major consideration in the design of landfills, if the generation of leachate and consequent water pollution are to be avoided.

Surface hydrology design will include surface drainage and storm water diversion drains, to direct upslope run-off water around and away from the landfill. Downslope drainage includes the separation of unpolluted from polluted surface water and the containment of any polluted water on the site. All drains must be designed to have a 0.5m minimum freeboard.

Containment and leachate management
In the case of Sp sites, the design must make provision for containment of Wet and Hazardous wastes. This implies the complete separation of the waste body and any associated leachate from the underlying soil or rock strata, by means of a liner, a leachate collection system and, where necessary, leachate treatment. This may take the form of diversion to sewer, re-circulation, or a dedicated treatment plant.

Monitoring systems
Monitoring systems for surface and ground water pollution should be indicated on the Conceptual Design Plan. This will include the position of both surface water sampling points and boreholes, if any (see details in the hydrogeological supplement in Appendix 1).
Gas monitoring is required if landfill gas is identified as a problem in the EIA. Any monitoring system should be indicated on the layout plan.

**Layout and Development Plans**

The Layout and Development Plans should have a scale of 1:1 000 and a contour interval of 1m. They should show the position and staging of the following aspects of the landfill operation:

- Site access and drainage
- Excavation and stockpiling of cover
- Screening berms and screening vegetation
- Cell construction sequence
- Deposition sequence and phases (including physical dimensions and timing for each phase).
- A Progressive Restoration Plan indicating final levels and restoration.
- A Preliminary Closure Plan, including an End-use Plan and possibly a Landscaping Plan. Figure 6-1 and Figure 6-2 show typical layouts which might be considered for small and medium landfills.

### 6.3 TESTING OF SOILS, CONSTRUCTION MATERIALS AND WASTE

Some *in situ* and laboratory testing of on-site soils and rock may have been done during the landfill site investigation, to assess the suitability of soils for cover and linings (see Section 5). In the design stage, more specific testing may have to be performed, to enable the technical design of the landfill to be carried out.

#### 6.3.1 *In situ* Permeability Tests

Since the unsaturated zone represents part of the geological barrier for ground water protection, it should be as thick as possible and its permeability should be known. *In situ* permeability testing, using double-ring infiltrometer tests or a Guelph *in-situ* permeameter, may therefore, in some instances, have to be performed on:

- The soil and/or rock immediately underlying the landfill
- The unsaturated zone that will ultimately separate the waste from the ground water. This may require the testing of different soil strata.

In Sp sites, testing for compatibility of soils and leachate may also be necessary to assess the effect of leachate on permeability. Such tests would be performed in a laboratory.

#### 6.3.2 Compaction Properties

For Sp and possibly G:L and G:M sites, the compaction properties for any soil, or modified soil, proposed for use in lining or capping layers, must be established according to the Standard Proctor compaction test.

#### 6.3.3 Shear Strength Tests

Where trench systems are envisaged and the excavation is more than 1.5 m, shear strength testing of soils may have to be performed, with a view to ensuring the overall stability and safety of cut slopes.
Figure 6-1: Small Landfills

- Access route (min. 500 m to nearest housing)
- 10 m wide fire break around site perimeter
- Wastes for recycling
- Cover stockpile
- Stock proof fencing
- Small Landfill - no burning permitted
- Small Landfill - burning permitted

Figure 6-2: Medium Landfills

- Access Road
- Screening by planting or earth berm
- Cut off drains at high side
- Cover and restoration stockpile
- Outer berm to tipping area
- Tipping area
- Cell wall
- Enclosures to lease to recycling entrepreneurs (fenced with concrete surface)
- Office and security control
- Machinery and equipment
- Contaminated water collection at low point
- Security fencing
- 10 m wide fire break around perimeter
6.3.4 Geomembrane and Geotextile Tests

In the case of Sp sites, it is possible that geomembranes and geotextiles will have to be tested for strength, durability and compatibility with identified components of waste and leachate, where adequate data are not available.

6.3.5 Testing of Wastes

For Sp sites, a representative sample of the anticipated waste stream should be tested for various specific parameters which may affect the design, such as compatibility of materials and reaction with the proposed lining.

6.4 TECHNICAL DESIGN

The Technical Design quantifies all necessary aspects of the Conceptual Design and may also indicate future performance of elements of the landfill. The Technical Design must be approved by the DSWM before a Licence is granted and construction may begin. The aspects of the design which follow are considered to require particular attention.

6.4.1 Design of Drainage Systems

Botswana has an arid climate, so that the overall climatic water balance is not such that significant leachate would be expected. It is possible, however, that high volumes of run-off can result over a short period of time with high intensity rainfall events. If such run-off is permitted to enter the waste body, significant leachate could be generated. On account of this, it is of the utmost importance to ensure that landfill drainage systems can adequately handle the run-off generated in high intensity rainfall events.

Drains must divert or contain a design storm of 50 year return period and 24 hour duration, with a minimum freeboard of 0.5m. The upslope cut-off drains must divert clean storm water around the site and into the natural drainage system. The system must also effectively separate unpolluted water, that has not come in contact with waste, from polluted water. Polluted water must be retained on the site, and disposed of separately from the unpolluted water or with any leachate that has been collected.

The main principles of landfill site drainage are therefore as follows:

• Upslope run-off and storm water must be diverted around and away from the landfill site by a system of berms and/or cut-off drains, to prevent water contamination and to minimise leachate generation.

• Contaminated water or leachate may not be allowed to leave the site and enter the environment. It must be managed by holding it in ponds from which it can evaporate or be used for dust control within the site.

• Clean, uncontaminated run-off water must not be permitted to mix with, and increase the volume of, contaminated water but must be allowed to flow off the site into the natural drainage system, under controlled conditions.

• The bases of the trenches and/or cells in which the waste is deposited must be designed and graded so that water drains away from the waste. The resulting contaminated water, together with all other contaminated run-off arising from the landfill, must be stored in a sump or retention dam, from where it may evaporate or be used for dust control.

6.4.2 Design of the separation between the waste body and the ground water

Whether cover excavations take place on site or not, there should, always be an acceptable physical separation between the proposed waste body and the wet season high elevation of the
ground water. The minimum permissible separation is 5m, except in the case of clayey soils where it has been proved that a sufficiently low permeability unsaturated zone exists. A substantially thicker separation is desirable in the case of more permeable, sandy soils. At this stage there is no set methodology for calculating the thickness of the separation between the waste body and the seasonal high elevation of the ground water. The ultimate thickness used must, however, be to the satisfaction of the DSWM.

It must be emphasised that the primary protection of the environment from the effects of a landfill arises from its proper siting (Section 4). However, cases may arise where siting of a landfill near an important aquifer is unavoidable. In such cases, the separation between the waste body and the ground water may need to be upgraded to provide additional protection. This may take the form of supplementing the thickness or constructing a liner.

6.4.3 Design of the Lining System

A mandatory physical separation between the waste body and the ground water regime is fundamental to all landfill designs. In addition to this, liner systems and leachate management are required where there is potential for significant leachate generation or where Hazardous wastes are involved. In Botswana, because of the arid climate and the decision to separate Wet wastes in Sp:W landfills, the only landfills which require leachate management and substantial liners are Sp landfills.

G:M and G:L landfills

Notwithstanding the above, and in order to provide the necessary degree of protection to the ground water system by facilitating the drainage of any sporadic leachate produced, the base layers for G:M and G:L landfills may require some engineering. In these cases, the in situ soil requires to be scarified, graded to a slope of at least 2%, and recompacted in a minimum of two 150 mm layers. The first layer should be compacted to 95% and the second layer to 100% of standard Proctor dry density at a water content between optimum and optimum + 2%. The soil used in these compacted layers should have a minimum Plasticity Index (PI) of 10 and a maximum particle size of 25 mm. Where the in situ soil is unsuitable or where additional protection is necessary, the DSWM may require that the recompacted layer be upgraded by adding clay or bentonite, or by increasing its thickness. In other instances, compacted clay layers, similar to those used in Sp landfills may even be required. A general indication of liner designs is given in Figure 6-3.

In many areas of Botswana, the soils are very sandy and there is little or no clay to be found. In these instances it may be appropriate to use calcrete for the layer construction. Calcrete forms a very hard surface, but is more permeable than clay, and due to its chemical nature, may react with certain wastes and leachate. For this reason specific testing will be required to determine its compatibility when specified for use in G:L and Sp landfills.

The construction of a pond to collect and temporarily store polluted water may also be necessary. Such a pond should also be appropriately lined with clay or a geomembrane to prevent infiltration of polluted water into the ground water.

Sp:H landfills

Botswana industries do produce some high risk hazardous wastes, even though the quantities are generally very small. In order to manage these wastes in an acceptable manner, it is necessary to have a detailed investigation carried out for each special case as referred to in Section 3.3. On the basis of this detailed investigation the DSWM will confirm the actual design required. It is envisaged that a composite liner consisting of compacted clay layers and a geomembrane lining, and incorporating leachate collection and leakage detection layers, constructed to international standards, would be a requirement.
6.4.5 Gas Management Systems

If landfill gas is identified as a problem during the site investigation (see Section 5) or subsequently during operation, a gas management system will be required. Such a system might
Compacted clay layers
Clay is normally compacted in 150 mm layers in order to ensure consistency and good compaction. These layers must be of low permeability so that a minimum outflow rate of 0.03 m/y is not exceeded. In situ permeability tests should be carried out on each compacted clay layer to confirm laboratory estimates of permeability.

Geomembrane liners
Even with bentonite addition the specified clay liners for an Sp landfill may not always be economical to construct. Substitution with Flexible Membrane Liners (FML’s) may also be considered, or alternatively a composite lining consisting of clay and an FML could be considered. In general a 2 mm thick FML will replace 2 x 150 mm compacted clay layers.

Leachate collection and leak detection
In Sp landfills it is required to install leachate collection systems, which are a series of pipes or channels situated above the liner, to collect any leachate flowing down through the waste. As no lining system is totally leak proof, a leak detection and collection layer should be installed below the liner to detect and collect any leachate flow through the liner

6.4.4 Leachate Management Systems
Leachate management involves leachate collection and treatment. Leachate will not normally be anticipated other than at Sp landfills, although a careful water balance study, possibly over short term periods, will be needed for G:L sites to confirm that leachate will not be produced.
The leachate collection system is a system of drains, bunds or trenches covered by the leachate collection layer beneath the waste (see Figure 6-4). Gravity flow of leachate from the upper collection layer (or from the leakage detection layer) is then directed to sumps, possibly using perforated collection pipes, from which it can be collected for treatment.
Figure 6-4 shows an example of how base slopes of landfills can be shaped to ensure that liquids flow to the edge of the landfill. Excessive liquid levels can be more easily dealt with by pumping from the edge of the landfill rather than near the centre where the thickness of waste is greater. Access for maintenance is also easier.

Leachate treatment systems will depend on the leachate composition and the most appropriate method of treatment. In Botswana, because of the arid climate, re-circulation of leachate through the landfill, which acts as an anaerobic reactor, is an attractive option. Other options include specifically designed on-site treatment facilities or, where appropriate, the use of a nearby sewage works.
The technical design of any of the above systems must be agreed by the DSWM, and specified in the Licence, prior to construction.
involve gas extraction by applying a suction to a system of perforated pipes within the landfill, or it might be a passive system.

No special measures need be undertaken for Very small, Small or Medium sites. At G:L sites, vents may have to be constructed if the capping is to be impervious. The amount of gas generation should be investigated before the capping is placed and this may justify the construction of passive vent trenches. Examples of some gas management systems are indicated in Figure 6-5.

Sp:H landfills should always be provided with gas venting systems. Passive gas venting using trenches, or even a network of perforated pipes, should be satisfactory for slow rates of generation. Flaring gas would only become necessary when the gas quantities are excessive and cause a nuisance or risk. For large quantities it may be possible to utilise the gas, but the economics of such a venture will need very careful consideration.

The technical design of any gas management systems must be approved by the DSWM, and specified in the Licence, prior to construction.

6.4.6 Final Cover

All landfill classes require a final cover layer of at least 300 mm in order to contain the waste body. If it is proposed to plant on the final surface a much greater thickness will be required and, to retain moisture, a clay layer should be included. This layer should also comprise topsoil, so that re-vegetation can be achieved. In addition, the final cover must maximise run-off of precipitation, prevent ponding and minimise infiltration of water into the landfill.

In the case of Sp sites, a more complex cover design is required. This is required to minimise the infiltration of water into the waste body, to better encapsulate the hazardous waste in the landfill, and to isolate it from the environment. The final cover requirements for each Sp site should be designed according to its particular characteristics.

0.4.7, Slopes

To maximise run-off of precipitation and prevent ponding, the "flat" surfaces of the landfill should have a gradient of about 3%, depending on soil quality, proposed use and erosion potential. The outer slopes of a landfill should not be steeper than 1 in 3 for erosion control. They should also be equipped with crest walls, and should not be too long, but should be broken by the incorporation of berms or step-backs.

6.4.8 Stability of Slopes

The construction of landfills usually involves excavating into natural soils. This can be unsafe, particularly with trench systems if they are greater than 1.5m in depth. In such cases, it will be necessary to analyse the stability of these cut slopes to ensure that they are safe against shear failure. This is achieved by applying the results obtained from the soil shear strength tests.

If no slope stability analysis is required on final slopes, a limit of 1 vertical to 3 horizontal is to be used.
Figure 6-4: Leachate Collection

Plan of landfill showing leachate collection systems

Section A-A through landfill

Inspection holes for drainage pipes

Stormwater cut off drain

Leachate collection sump

1 System of collection drains directing leachate, or leakage, to the leachate collection sump

Perforated pipes in leachate collection drains

Stormwater diversion

Landfill

Typical waste cell
6.5 LANDFILL PREPARATION AND CONSTRUCTION

Construction of the site to the stage that it is ready to receive and dispose of waste and to operate for a pre-determined minimum period, must ensure that the facility will conform to the intended design, operational requirements and end-use, as stated in the Licence.

The development of the site is a process that will continue throughout its operating life, with construction or preparation and commissioning representing the first stages of this development.

The need for site preparation exists at all new sites, but the degree and complexity will vary from site to site. In general, the G:L and the Sp sites will require the most preparation, as indicated in Tables 6-1 and 6-2.

All site preparation procedures must be approved, in the Licence conditions, by the DSWM.

6.5.1 Design Drawings, Specifications and Bills of Quantities

The design drawings, specifications and bills of quantities must be produced, as specified in the Guidelines shown in Table 6.1, and submitted with the Licence application to the DSWM.
Together, these form the basis for the site preparation, and none shall be read independently from the others.

### 6.5.2 Contractor
Where a contractor is appointed, he must be competent and able to carry out all the works in full conformity with the design, specification, drawings and bills of quantities. Suitably qualified specialist sub-contractors may also be appointed to carry out any special works. The contractor must be a registered employer and must be in good standing with the relevant authorities.

### 6.5.3 Quality Control Programme and Supervision
For larger sites, prior to the commencement of any construction, the contractor shall submit the quality control programme for all activities to be carried out on the site to the appointed Chartered or Professional Engineer, for his written approval. The programme, together with independent checks carried out by the Engineer, must be sufficient to ensure conformance with the design, specifications and drawings. The correctness of the facility and the quality of the construction must be attested to by the Engineer at the completion of the construction activities.

- The construction of leachate containment elements must be supervised on a full time basis by a Chartered or Professional Engineer or his delegated representative.
- The construction of all elements of a landfill must be supervised on a full time basis by a Chartered or Professional Engineer or his delegated representative.

- Particular attention must be paid to the quality control of any compacted soil liner.

The contractor must carry out a minimum of four density tests per 3,000m² of any compacted 150 mm thick layer. Sufficient Standard Proctor compaction tests must be performed to cover any variability of material that may arise. Density tests using a nuclear device will be considered acceptable, provided the results have been proved to be consistent with sand replacement tests. Sand replacement tests will be considered to be the absolute standard for measurement.

Because the permeability of a soil depends on both the density and the compaction water content, the results of all density tests must satisfy the following requirements:

- Dry density equal to or greater than Standard Proctor maximum dry density
- Water content within the range Standard Proctor optimum to Standard Proctor optimum plus two percent.

- Construction records must be kept of all such work. Such records must include records of materials used and the results of field tests.
- Other earthworks must comply with the requirements of the appropriate SABS 1200 or its international equivalent.
- Flexible membrane liners must comply with the requirements of SAGS 1526 (there is currently no international standard) and should be subjected to leak detection methods.

### 6.5.4 Boundaries and Extent of Site Preparation
The co-ordinates of the landfill site must be accurately indicated on a proper plan and, in certain instances, where warranted, the actual boundaries must be certified by a registered land surveyor. The works shall be set out according to the design drawings and specifications, and setting out shall be confirmed prior to the start of actual construction.

The site preparation will include the construction of the initial works, such as security, access and drainage, and sufficient development to allow for the effective commissioning and operation of the site for a pre-determined minimum period.
6.5.5 Health, Safety and Conservation of Natural Resources

The contractor must comply with reasonable Health and Safety standards and such legislation that may be introduced in Botswana.

The contractor must at all times also ensure the minimum of disturbance to the local flora and fauna, as well as the generation of minimum nuisance. Natural resources, such as topsoil and general cover, must be stockpiled and maintained for future use where necessary and as directed by the Engineer.

6.5.6 On completion of the construction phase, all the works shall be approved by the Engineer. The DSWM and other relevant authorities will then carry out a full inspection of the site and an examination of all relevant records. Provided all construction has been carried out in full conformity with the design specifications and drawings, and to the satisfaction of all the relevant authorities, a letter giving permission for the commencement of operation will be handed over by the DSWM.
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<th>GUIDELINES</th>
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<td>Indicate unsaturated zone after excavation</td>
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<td>Design drawings and specifications</td>
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C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.
Table 6-2: Guidelines for Landfill Construction

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<td>Approval of works by DSWM</td>
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*C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.*
7 LANDFILL OPERATION & MONITORING

7.1 INTRODUCTION

The aim of the Guidelines for landfill operation is to ensure that all waste is disposed of in an environmentally acceptable manner. The operation must thus conform to the conditions of both the Licence and also the Planning Permission or equivalent (under the Tribal Land Act). The Licence Holder or his appointed Responsible Person must therefore ensure that the Guidelines for the operation of a landfill site are applied to the degree commensurate with the class of landfill and hence to the satisfaction of the DSWM. The Guidelines for operation of the different landfill classes are shown in Table 7-2 at the end of this section. The Guidelines for monitoring, which is also covered in this section, are shown in Table 7-3.

7.2 FACILITIES AND RESOURCES FOR LANDFILL OPERATION

Sufficient facilities and resources are required for landfill operation to conform to both the landfill Licence conditions and the Guidelines associated with the site classification.

7.2.1 Signposting and Access

For larger sites, signs must be erected in the vicinity of the landfill, indicating the route and distance to the landfill site from the nearest main roads. A general notice board must be erected at the site entrance, indicating the names, addresses and telephone numbers of the Licence Holder, the hours of operation and an emergency telephone number. It is of particular importance that the sign clearly states the class of landfill and the types of waste that can be accepted. In the case of Sp:H landfills, clearly visible signposts warning of the associated hazards must be erected along the fence line at intervals not exceeding 100m. Suitable signs must also be erected on-site, to direct vehicle drivers appropriately and to control speed.

Road access to and within the site must be maintained at all times, in a manner suitable to accommodate the vehicles normally expected to utilise the facility. All roads, particularly onsite roads, must be so surfaced and maintained as to ensure that waste can reach the working face with the minimum of inconvenience. Two-way traffic flow must also be possible. Unsurfaced roads must be regularly graded. Dust may be controlled by watering but water is a scarce resource and watering is not normally justifiable.

7.2.2 Controls

Record Keeping

This issue is addressed in detail in section 8.

Waste acceptance

One of the purposes of the Site Classification System is to ensure the sites classified as G receive only the General waste for which they are designed and that all Wet or Hazardous waste is disposed of on Sp:W or Sp:H sites.

Prior to waste being accepted at G sites, it must be inspected and confirmed to be General waste.

The operator at the working face must also ensure that no Hazardous or high moisture wastes (even in sealed drums) are disposed of. Such controls are particularly important at G sites in the vicinity of industrial areas. In the event of Wet or Hazardous waste being intercepted at a G site, it must be diverted to a Sp site. The source, vehicle registration and a description of the waste must also be reported to the DSWM.
**Landfill Operation & Monitoring**

**Sp** sites must be operated in accordance with international standards. Consequently, all new enquiries regarding the disposal of Wet or Hazardous waste must be submitted with representative samples and a completed waste information sheet. Each load of such waste which subsequently arrives at the site must be sampled and tested for correlation with the original enquiry, prior to disposal. Waste which does not conform to the original specifications must be properly identified by testing in a laboratory, prior to its disposal on site. If a waste cannot be identified, the precautionary principle must be applied and the waste must be regarded as extremely hazardous and handled accordingly.

**Access Control**

In order to facilitate the above Waste Acceptance procedures, access to the site must be controlled. It is therefore a Guideline that vehicle access to a site must be limited to a single controlled entrance, to prevent the unauthorised entry and illegal dumping of waste on site. The site entrance must comprise a lockable gate which must be manned during hours of operation at the larger sites. At G:L and Sp:H sites, additional security is required after operating hours.

In addition to the gate, all sites must have the portion of the site currently in use adequately fenced and/or secured. For G:V sites and G:S burning sites post and wire fence is required. For sanitary G:S landfills and all G:M sites, fencing must be stockproof. In the case of G:L sites and Sp sites, fences must be 1.8m high with an overhang and must be constructed of sturdy and durable material. Where fencing is removed, or is not practicable because of continued theft despite security measures, barbed wire fences, earth berms and/or trenches must be used to prevent vehicle access. Painting of fences in identifiable colours may dissuade theft. In all events, however, the site boundaries must be clearly demarcated and measures must be taken to prevent unauthorised vehicle access.

**Security**

In addition to access control, suitable security must be provided to protect any facilities and plant on site.

Unauthorised pedestrian access must be strictly prohibited at Sp sites. Reclamation is forbidden at Sp:H waste disposal sites primarily for the purpose of protecting public health and safety. Controlled reclamation at other sites is discussed in section 7.3.1.

**7.2.3 Operating Plan**

An Operating Plan is a site-specific document that will be developed as part of the landfill Licence application procedure. It describes the way in which the landfill is to be operated and would include, *inter alia*, the following:

- Phasing
- Excavation sequence
- The provision of cells, site access and drainage.
- Methods of internal movement of waste and cover materials.
- Methods of waste discharge and emplacement (waste burning procedures and controls in the case of sites where burning is permitted).
- Working areas.
- Cover procedures and frequency of cover application.
- Procedures for handling and sorting recyclable materials.
- Procedures for difficult wastes (see section 7.4.3).
- Protection procedures for local quality of life (e.g. traffic, noise, litter, vermin etc.).
- Fire control procedures.
- Mobile plant and equipment.
Landfill Operation & Monitoring

• Operation monitoring procedures. Everything pertaining to the operation of a landfill should therefore be included in the Operating Plan, which is subject to regular update. The complexity of the Operating Plan will, however, vary with the class of site; varying from a very simple plan, in the case of a G:S site, to a very detailed and sophisticated document for a Sp:H site. In the case of all Sp:H sites, a Response Action Plan, detailing procedures to be followed in case of failure in the design or operation must be included (see Section 5.4).

7.2.4 Resources

To comply with the Guidelines for operation and to ensure environmentally acceptable waste disposal, sufficient suitable facilities, equipment and staff are required.

Infrastructure

Infrastructure has been addressed section 6.2.4.

Plant and equipment

The plant and equipment on site must be commensurate with the size and type of the operation. The type of equipment employed for all phases of the operation must therefore be of suitable capacity and construction. Typically, larger sites would have a combination of purpose-built landfill compactors, bulldozers, front end loaders and trucks to transport cover material. Such equipment should be fitted with reversing bleepers. The following is the minimum level of equipment recommended for each type of site:

Sp: For co-disposal the plant required will depend on the volumes of General waste but as a minimum there should be a tracked loader and equipment for leachate re-circulation. For specific mono-disposal requirements plant would have to be specified according to its design.

G:L Full time landfill compactor, tracked loader and possibly a tipper truck. G:M

Full or part time earth moving plant.

G:S Non-burning landfill - regular visits by earth moving plant. Controlled

burning landfill - occasional visits by earth moving plant. G:V

Occasional visits by earth moving plant.

I - Regular visits by bulldozer, and compaction plant.

The plant and equipment provide the means whereby the waste can be disposed of in accordance with the Guidelines. There should therefore be sufficient suitable equipment, drivers and backup to ensure environmentally acceptable waste disposal at all times. The availability of plant and equipment is an essential aspect of good landfill management. Equipment should therefore be adequately maintained, using a scheduled, rather than on-demand, maintenance system, especially at larger sites.

Staff

The operation of all landfill sites must be carried out under the direction of an appointed Responsible Person. In the case of G:V and G:S sites, the Responsible Person may be a representative of the District Environmental Health Department. In this case, visits to these sites should be made three-monthly and monthly respectively. In addition there may be a (part-time) gate controller in the case of a G:V site, a site foreman in the case of a G:S site, a site superintendent in the case of a G:M site and a landfill manager with a tertiary qualification in
the case of a G:L site. In the case of Sp:H sites, the appointed Responsible Person must have a BSc Degree with a Chemistry major, or equivalent. I sites should also have full-time supervision, to prevent the deposit of unacceptable materials.

The appointed Responsible Person must, in all cases, be supported by suitably qualified and competent staff. This staff complement would be commensurate with the size and type of the operation, as well as with the facilities and plant involved.

The requirement, therefore, is sufficient management and back-up to ensure that the Guidelines relating to the operation are met.

7.3 OPERATIONAL ASPECTS

Waste deposition is considered in terms of General waste (mainly involving controlled burning and sanitary landfill principles) and Special waste (including pre-treatment, co-disposal, lagooning and, possibly, encapsulation).

As indicated in Section 1, the majority of waste in Botswana is disposed of by landfill. Some 90% of this waste is general waste, and of this the majority is burned on the landfill site.

The principles of sanitary landfilling and the variations on this method thus apply predominantly to general waste. These principles are, however, also applied on Sp landfills in conjunction with other procedures, such as co-disposal, waste load allocations, pre-treatment etc.

7.3.1 Controlled Reclamation of Waste

At present, scavenging as opposed to controlled reclamation takes place at the majority of Botswana’s landfills. Following the Government strategy to follow the internationally accepted hierarchy of waste (i.e. first reduce, reuse/recycle or treat, before final disposal) the landfill operator is to provide assistance for reclamation activities with respect to the provision of separate reclamation areas and facilitating the sorting process. **Should this not be incorporated into the operations plan, the landfill operator should provide sufficient justification to the DSWM.**

While the ethic of reclamation from the waste stream is supported, scavenging at landfills can endanger the health and safety of the scavengers if not conducted in a proper manner. It is therefore necessary to provide guidelines for controlled reclamation. The following guidelines are provided:

**Off-site reclamation**

Since recovery at source (i.e. at the waste producer’s premises) is the most efficient way of reclaiming from the waste stream, generators producing reclaimable material should be identified and where possible reclamation should take place before the waste arrives at the disposal site. An area can be set aside within the site fence but outside the disposal area where the public can dispose of bulky wastes such as lounge suites, cupboards and white goods. Such an area will, however, have to be controlled and unwanted waste will have to be cleared to the landfill on a regular basis, for such an operation to be acceptable.

**Formalisation of on-site reclamation**

The reclamation operation must be formalised before it can be controlled. This will entail the identification of leaders or the formation of a committee with whom to communicate. Thereafter, all reclaimers must be registered and controlled by the leaders or committee, who are accountable to the Licence Holder.
Method of controlled on-site reclamation
Waste reclamation and sanitary landfilling are not compatible activities, as reclaimers require access to the waste while sanitary landfilling aims at confining it. Also, having reclaimers working in the vicinity of heavy machinery is unsafe. Waste reclamation should therefore be separated from waste compaction and covering activities.

To achieve this separation, the landfill can be operated using two working areas or cells. In one, waste can be deposited and spread for reclamation purposes, whilst in the other, waste remaining after reclamation may be either burned or compacted and covered. The size of the working areas and the frequency with which they are alternated would depend on numerous factors and will have to be optimised on a site specific basis.

Furthermore separate fenced off areas could be provided within the site, which can be made available for lease to small recycling entrepreneurs (see Figure 6-2).

Health and Safety Aspects
Reclaimers at all but G:V sites, should be obliged to wear suitable protective clothing, in particular industrial gloves and boots with protective soles. If this equipment is provided by the Licence Holder, this could become an effective method of ensuring that reclaimers were suitably registered.

Ongoing communication with reclaimers
In order for controlled reclamation to work in an efficient and safe manner, it is essential for the reclaimers to understand and to adhere to the system in operation at the landfill. Regular meetings should therefore be held between the landfill operators and the reclaimers or their representatives, in order to educate and negotiate where applicable. At this forum, health and safety issues should receive priority.

7.3.2 Code Of Practice for the Burning of Small Quantities of Domestic Waste
Waste management by either burning or by landfill entails environmental and health risks. The main problems relating to burning are the potential health and environmental impacts due to toxic emissions. Toxins may be either directly inhaled or ingested via the food web. There are three main types of toxin which affect our health:

- Carcinogens which are potentially lethal or debilitating due to frequent exposure throughout a person's life.
- Non-carcinogenic toxins affect health when a threshold level is exceeded even in the case of a single high exposure.
- Non-carcinogenic toxins which accumulate in tissue and eventually reach a threshold where they begin to cause significant ill health effects.

The risks associated with exposure of people via inhalation of emissions have been assessed in a detailed study. Risks from exposure to carcinogens via ingestion and the food-web were however not tested. As a result these guidelines may change as further information on the risks from this pathway become available.

The recommendations apply to waste disposal sites of class G:V and G:S.

3.2.1 Types of Landfills Where Burning is Permissible
- A community wishing to bum domestic waste needs to obtain a licence to burn waste as part of the procedures in registering the landfill. This permission is subject to acceptance by interested and affected parties and the local authorities. Two authorities in particular need to be approached i.e.,
1. The District Herbage Preservation Committee: to inform them of the proposed location of
the landfill, proposed fire frequency and the safety measures that will be undertaken to
prevent fires entering the surrounding land (in writing).

2. The Land Board: to request permission to clear a 10 metre wide fire break around the outside of
the landfill

7.3.2.2 Location of the Landfill

• Landfills should be located at least 500 m from human habitation and should not be located
on the windward side of the town (i.e., not north east of the village).

• In the case of a hilly area, the landfill should be situated down-slope rather than up-slope of a
village.

• As the impact of burning of waste on health via the food-chain is uncertain, the site should not be
situated within 500 m of arable lands.

• Landfills should not be situated within 500 m of surface water used for domestic or human
consumption.

7.3.2.3, Maximum Size of Village

The environmental costs and health risks from the burning of domestic waste exceeds those of
covering waste when a village size exceeds approximately 7,000 people. To allow for a safety margin
of 30 percent, villages with a population in excess of 5,000 people, should therefore not burn their
waste. The size of a village should be re-evaluated after each census (every 10 years).

If the village population is expected to exceed the maximum permissible level for the burning of
domestic waste before the next census, detailed plans for changes in management of waste
should be included in the District Development Plan.

7.3.2.4, Components of Rural Village Waste that Should Not be Burnt

Certain articles of waste that are generated in rural villages are considered too dangerous to burn.
The danger may be in terms of occupational risk to the landfill operator or in terms of
emissions. Items which must be removed from domestic waste which is destined for burning are
listed below.

Table 7-1: Types of Waste that should not be burnt

<table>
<thead>
<tr>
<th>Type of Waste</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosives</td>
<td>0 petrol</td>
</tr>
<tr>
<td></td>
<td>0 benzene</td>
</tr>
<tr>
<td></td>
<td>0 alcohol</td>
</tr>
<tr>
<td></td>
<td>0 thinners</td>
</tr>
<tr>
<td></td>
<td>0 paints</td>
</tr>
<tr>
<td>Herbicides and pesticides</td>
<td>0 Insecticide containers</td>
</tr>
<tr>
<td></td>
<td>0 herbicide containers</td>
</tr>
<tr>
<td>PVC/polyurethane plastics.</td>
<td>0 plastic vehicle parts</td>
</tr>
<tr>
<td></td>
<td>0 plastic guttering</td>
</tr>
<tr>
<td></td>
<td>0 plastic pipes</td>
</tr>
<tr>
<td>Chemicals</td>
<td>0 Chlorine</td>
</tr>
<tr>
<td></td>
<td>0 cleaning agents</td>
</tr>
<tr>
<td>Sealed containers</td>
<td>0 aerosol cans</td>
</tr>
<tr>
<td></td>
<td>0 gas bottles</td>
</tr>
<tr>
<td></td>
<td>0 other sealed containers</td>
</tr>
<tr>
<td>Vehicle Tyres</td>
<td></td>
</tr>
</tbody>
</table>
• Non combustible wastes
• Pharmaceuticals
• Re-useable material

7.3.2.5 Approach to Management

Separation at source

Once the waste has been placed in rubbish bags, the risks from occupational exposure relating to opening the bags and sorting for objects unsuitable for burning are high. Waste must therefore be sorted at source. The following procedure is recommended:

• All subscribers to the waste disposal system to be notified as to the types of waste which may not be burnt and must be sorted out from the general waste. Pamphlets must be posted in public buildings such as clinics and tribal administration offices on an annual basis by the Health Inspector for the area.
• For collection the items which may not be burnt must be placed apart from and adjacent to the rest of the waste
• The waste collector must keep a separate drum or bag for such items.
• At the site the items should be buried in an area separate from where burning occurs.

Fire Management

The risks from occupational exposure to burning waste are highest, so the persons at most risk are the operators of the landfills. Minimum contact with the waste and complete avoidance of the fire smoke and fumes is important. Operators and owners of a landfill should be aware of the fire management constraints laid out in the Forest Act (CAP. 38:04) and the Herbage Preservation (Prevention of Fires) Act (CAP. 38:02).

Burn Frequency

Burning should be carried out as frequently as possible to ensure that the volume of waste for burning remains relatively small and to prevent waste from becoming wet. This process will reduce the chance of wind borne litter occurring. Burning at the same interval as collection is recommended. The period between burns should not exceed one week so as to keep waste volumes to a manageable size.

Timing and Atmospheric Conditions Necessary for Burning

Burning should be undertaken between 8 am and 12 noon. This timing is important because:

• The waste can take up to 8 hours to burn fully. It is necessary to ensure that combustion is completed before evening temperature inversions occur.
• By 10 am there is usually enough air turbulence to ensure dispersal of the emissions.
• Burning during the hot period of the day will increase the rate and temperatures of combustion.
• Burning earlier in the day may be necessary during August and September to allow complete combustion to complete before the daily high winds develop.
• Waste should be left in plastic disposal bags for combustion so as to keep it dry and to avoid the spread of litter.
• Waste dumped after 12 noon should be burnt the following day.

Burning during high winds or when there is whirlwind activity should not be undertaken.
Management Activities

Disposal of Non Burnable Waste:
Non burnable waste is to be placed at a tip face which is not exposed to fire and covered with fill material at suitable intervals.

Burning
As the amount of oxygen available is important in the efficient combustion of waste, the following is recommended:

• Bags of waste should be stacked in a pyramid shape on top of a bed of tins or rubble near to the tip face which will allow oxygen to enter the waste from below. Waste should be ignited at the base, on the upwind side of the pyramid.

• Operators must stand upwind, well clear of the fire, and avoid inhalation of smoke. No manipulation of the fire or undertaking of activities near the fire is permitted as this will increase the occupational risk considerably.

• Operators must remain at the landfill site until combustion is complete.

• Compaction and covering of burnt waste is to be undertaken at the same frequency as in a landfill in which burning is not permitted.

• In the case of fire spreading into the surrounding area, under section 11. of the Herbage Preservation Act, the operator may require any person present to render assistance in extinguishing or preventing the spread of the fire, if the operator reasonably believes that the fire may become a danger to life or property.

Fire breaks:
All ground cover within the landfill site is to be removed and a 10 metre wide firebreak maintained outside of the perimeter of the landfill. The District Herbage Preservation Committee may, after inspection of the landfill site, require improvements to be made to the firebreak.

Safety Equipment
Site operators should have the standard safety equipment necessary for the handling of waste. Fire fighting equipment (beaters) must be available on site when burning waste.

Liability
The issuing of a permit by the DSWM allowing the burning of domestic waste shall not affect the right of any person aggrieved to recover damages by civil action for any loss sustained. The responsible parties are the landfill owners and operators.

3.3 Sanitary Landfilling
Wherever possible, landfills must be operated in accordance with the following sanitary landfill operating principles:

• Waste must be compacted

• Waste must be covered at the end of each day’s operations

Compaction is best achieved if the waste is spread in layers not exceeding 500 mm thick (uncompacted) and passed over a minimum of five times by a purpose built landfill compactor. The total compacted depth of the cell should be between one and two metres before covering. This procedure is recommended for G:L and Sp:H sites. At smaller sites, where less appropriate equipment is used, such as tracked or wheeled loaders, the best practicable compaction is required.
Landfill Operation & Monitoring

The sanitary landfill definition specifies daily cover, which is the recommended standard. In certain instances, however, such as existing, small or very small sites with a shortage of cover material or available plant, this Guideline may be appropriately relaxed. In such cases, the operation cannot truly be described as sanitary landfilling. It is noted that, in the case of new sites, the siting and design must ensure that there is sufficient cover for a sanitary landfill operation, throughout the projected life of the facility. Most sanitary landfill operations are based on a series of trenches or cells which are prepared to receive the waste. In either case, the general layout must be in accordance with the Operating Plan. Waste is deposited in trenches or cells, spread, compacted and covered, so that each day's waste is effectively isolated from the environment.

7.3.4 Methods of Landfilling: General Waste

As indicated, sanitary landfilling principles can be applied using the following methods:

**Trench System**

In G:V, G:S and G:M landfills, where relatively small volumes of waste are disposed of, trenches are often used in preference to cells. Such trenches may be excavated on an ongoing basis during the operation at frequent intervals. Nonetheless, this must always be done in accordance with the original design parameters and the Operating Plan. There must always be sufficient trench capacity on site to accommodate at least one week's waste but it will be satisfactory to provide trench capacity for up to 18 months at one time. Trenches must always be suitably fenced or protected, and off-loading must be such that persons or vehicles cannot accidentally fall into the excavation. Waste should be deposited into the trench, spread and compacted as much as possible, until it reaches a depth of between 0.5m and 1.0m. With the trench method, covering is more easily achieved (even by hand) using the spoil from the excavation.

**Standard cell operation**

The basic landfill unit is a cell within which waste can be deposited. Waste should be covered at the end of each day for G:M and G:L sites. A complete cell may be designed to last one to three months but, at larger sites a cell may last as little as one week. The sides are usually formed by 1.5m to 2.0m high berms, constructed from soil, rubble, or sloped waste covered by daily cover. In Botswana, large volumes of builders’ rubble are frequently set aside in piles adjacent to the landfill, instead of being used to create cells. Proper utilisation of builders’ rubble for the building of cell walls and for the covering of wastes in terms of sanitary landfilling is strongly recommended. The size of cell is determined by balancing the advantage of confining the area of exposed waste, the need for manoeuvring space by delivery vehicles and site machinery, the amount of cover required and limiting the frequency of constructing a new cell. The working face is the portion of the cell or trench where waste is deposited by incoming vehicles. The working face must be kept as small as possible for control and covering purposes. This is, however, determined by the manoeuvring requirements of the vehicles depositing waste. It should thus be sufficiently wide to avoid traffic congestion. There must also be sufficient cell capacity on site to accommodate at least one week's waste. Where the cell system is applied, waste must be deposited at the bottom of the working face and should be worked up a 1 in 3 slope, using available mobile plant. This is termed the Ramp Method.

**Special cells for putrescible waste**

With the permission of the DSWM, special cells may be constructed for the disposal of putrescible waste types, e.g., dead animals, at G landfill sites. Such waste should be deposited at the base of the working face and covered immediately with other waste. Alternatively, the waste

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BOTSWANA LANDFILL GUIDELINES
can be deposited and covered immediately with a layer of soil, at least 0.5m thick. The former method has the advantage of not disrupting the standard operation.

**Methods other than cell operation**

"End tipping" is where waste is pushed over the edge of an advancing face. This is not permitted on a normal landfill because it results in minimal compaction, slope instability and many other problems. Exceptions to this are at I, G:V and some G:S landfills, and also at Sp:W and some Sp:H sites, where waste is liquid and has to be end-tipped into trenches.

At certain waste disposal sites, and in particular at I landfills, where large volumes of non-putrescible dry general waste are disposed of or where compaction is not a critical factor, the Area Method may be used. This method involves the spreading of waste in a 0.5m layer over a large area. This method differs from End Tipping in that the waste is spread laterally in thin layers in a controlled manner, as opposed to being pushed haphazardly over an extended slope.

Sometimes the disposal of inert waste can be carried out as a single engineering contract. This is useful if it is intended to reclaim borrow pits or small mineral excavations within a short time such as a year or less. Projects of this brevity can often be tolerated within built up areas whereas a longer period might not be acceptable.

**Wet Weather Provisions**

In wet weather, it may not be possible for vehicle access across the site to reach the tipping area. In this event, at larger sites, a "wet weather cell", with about one week's capacity, should be provided at a point where access will be possible.

**7.3.5 Pre-treatment of Hazardous Waste**

The properties of certain Hazardous wastes are such that they cannot be safely deposited directly into a landfill. In such cases the wastes must be pre-treated in order to render them less toxic, mobile or reactive. A variety of process options exist. These are often interrelated but may be categorised generally into physical, chemical and biological treatment methods. Once a waste has been pre-treated, the residue is disposed of on the landfill.

The conditions when pre-treatment is required will be determined on a case-by-case basis by the DSWM.

**7.3.6 Methods of Landfilling: Hazardous Waste**

Hazardous wastes can be disposed of in specially designed Sp:H containment landfills, with leachate management. Alternatively they may be disposed of within a cell designed to Sp:H specifications within a G landfill. For Sp:H landfills, documentation must be drawn up, describing the operating procedures to be used at the site and the Response Action Plan. Before the operation commences, these must be presented to, and accepted by, the DSWM.

There are two methods of landfilling hazardous wastes:

- co-disposal, where the wastes are mixed with General wastes in ratios to optimise airspace utilisation and leachate management, and

- mono-disposal, where they are deposited in an unmixed state.

Either method may be most appropriate, depending on the individual circumstances, but of the two, mono-disposal is normally preferred as the landfill behaviour can be better predicted.

The element of hazardous waste operation are discussed in general in Section 3.3.
7.3.7 Cover Application
The sanitary landfill definition specifies daily cover. This is therefore a requirement unless the DSWM permits a relaxation.
The material to be used for cover may be soil, builders' rubble, ash or other approved covering. With the exception of I, G:V, and G:S landfills, a strategic stockpile of cover, enough for at least three days, should be maintained close to the working face for use in emergencies. Suitable equipment, resources, and cover material must also be available to ensure that no waste is left uncovered at the end of the working day.
The Guidelines for cover thickness are as follows:

**Daily or periodic cover**
This must be sufficient to isolate the waste from the environment. A minimum thickness of 150 mm of compacted soil or other appropriate material is required. This thickness may, however, have to be increased in the case of poor quality cover. Alternatively, if the area is to be left for
an extended period, but ultimately to be covered again with waste, the thickness of this intermediate cover must be increased to 300 mm.

**Final cover**

A minimum final cover of 300 mm is specified for all classes of landfill (refer to Section 6.5.6), with the exception of Sp landfills, which must comply with more detailed cover specifications to be designed according to the waste type. If the intention is to stimulate a good quality of natural growth or carry out planting then a much thicker cover is required. It should also include a lower level of impermeable soil to improve moisture retention.

All covered surfaces on the landfill must be so graded as to promote run-off to prevent ponding. Revegetation must commence as soon as is practically possible after the final cover has been placed, in order to restore the land on an ongoing basis. Revegetation should be undertaken with locally indigenous species, to ensure their future viability without maintenance.

### 7.4 OTHER ELEMENTS OF THE OPERATION

#### 7.4.1 Health and Safety

Any landfill is, by its very nature, a potentially dangerous place. For example, injuries may occur from glass and metal in the waste, from falling on uneven or unsound ground, from flying debris, from fires and from moving vehicles and plant, especially when reversing. Dangerous or infectious substances may sometimes be encountered, including leachate and landfill gas.

Operatives require protective clothing, first aid equipment and other suitable safeguards but, most of all, they require adequate training.

At all sites, a safe working procedure manual should be prepared. Such manuals for G:S and G:M sites could be prepared as a national standard. At all sites, operatives should receive some training, with formal training courses being offered at intervals for the larger sites (G:M and above).

Protection should be provided for visitors to the site, including DSWM and other inspectors, who should be provided with appropriate protective clothing. At larger sites, a visitors book should be maintained, with check-in and check-out procedures.

Additional procedures for Sp sites have been discussed in section 3.3.

#### 7A.2 Control of Nuisances

Nuisances resulting from the landfill operation should be controlled as follows:

**Fires**

Where burning is permitted, nuisances such as air pollution and odour must be avoided by ensuring efficient combustion as recommended in Section 7.3.2. At landfill sites where burning is prohibited or out of control, accidental fires must be extinguished immediately. Appropriate operational procedures, involving smothering with cover material, rather than the application of water, must be implemented.

At larger sites, an emergency tipping area should be provided for the discharge and extinguishing of loads that are delivered to the site whilst on fire.

All landfill sites should have a minimum 10 m wide firebreak graded around the perimeter, to both avoid waste from being ignited by veld fires, and to prevent veld fires from being ignited by burning waste.

**Litter**
It is a requirement that all litter be contained within the site. This may be achieved either by controlled burning of waste that could be windblown or by compacting and covering the waste on a daily basis. Windblown litter must be picked up and removed from fences and vegetation on a daily basis. On sites characterised by high winds, however, movable litter fences may also be required.

**Odours**

Good practice limits odour by such means as adequate compaction and cover, progressive capping and restoration and the rapid deposition of odorous wastes at depth and immediate cover. At larger and Sp sites, if gas generation is sufficiently great to cause nuisance it may be necessary to flare it. Compliance with the guidelines on protection distances, however, should avoid this problem. In the case of controlled burning sites, some smell is inevitable so that tolerance of it is dependent on the direction of prevailing winds and the distance to homes.

**Noise**

All equipment used on site must conform to the local authorities' by-laws concerning noise levels and hours of operation.

**Vermin and disease vectors**

It is a requirement that landfill sites be kept free of vermin. Appropriate measures, such as immediate cover of putrescible material, must be taken to eliminate or minimise disease vectors such as rats or flies.

Ageing household waste, especially if left uncovered can encourage insect populations to grow rapidly. At seasons when this occurs, covering more often will help. The application of insecticides by spraying and fogging is effective. Applications of insecticides should be carried out by trained personnel in accordance with manufacturers instructions.

**Dust**

Unsurfaced roads and other areas, which give rise to dust problems, must be appropriately watered to restrict dust to levels which do not pose a nuisance to workers or users of the facility.

### 7.4.3 Difficult Waste

Difficult wastes are those wastes which, whilst acceptable for disposal at a landfill on the basis of their overall properties, have some characteristics which require a particular method of handling which is not part of the general site operating procedure. Individual procedures are appropriate for these types of materials. Some examples are given below:

**Tyres**

Tyres, if deposited whole in a landfill can rise and cause void spaces which break the surface and encourage vermin. They also contribute to surface instability and represent a fire risk. In Botswana at present, there is ready market for some tyres for use on donkey carts and for reclamation in shoe manufacture. Unfortunately, in the larger towns, there are still surplus tyres.

It is not advisable to store them in large quantities, as this can present a fire risk with the potential for excessive black smoke. Ideally they should be quartered before landfilling. Shredded tyres may also have some potential for energy recovery. If they are to be landfilled in their whole state, this should be done in a controlled fashion, with individual being placed flat and separate from one another on the base of a cell before being covered with waste or, preferably, cover material. Each single layer should be covered before further tyres are added.

**Bulky waste and empty containers**
Bulky waste and empty containers should be separated and crushed by compaction equipment before being covered with further material, in order to avoid the creation of void spaces.

**Fine divided material (e.g. powders and dusts)**
Materials which may give rise to excessive dust when tipped should ideally be wetted before discharge and covered with general waste as soon as possible.

**Very light materials which may be easily windblown (e.g. expanded polystyrene)**
Light materials should ideally not be deposited during periods of high winds. They should be covered rapidly to prevent wind scatter.

**Animal carcasses (small amounts) and other putrescible and potentially malodorous materials**
Such materials should ideally be placed in excavations and should in any event be covered rapidly to minimise odour impacts. For large amounts of carcasses refer to Section 3.2.

### 7.4.4 Cover Excavation
Where cover is excavated on site, the Responsible Person must ensure that the separation between the waste body and the wet season high elevation of the ground water, as specified in the design, is maintained (see Section 6.5.2).

Excavations must also be properly drained to avoid ponding.

### 4.5 Drainage
The principles of landfill site drainage are presented in the site design (see Section 6.5.1). Site drainage is particularly important in Botswana because of its high intensity rainfall events. Most of the drainage system elements must be in place before the landfill is commissioned. As development, adaptation and maintenance of the drainage system are required during the operation of the site, certain of the elements discussed in Section 6.5.1 are repeated below:

- In addition to the main upslope drainage systems which prevent water entering the site, runoff and storm water falling on the site must also be diverted around and away from the waste by a system of berms and/or cut-off drains, to prevent water contamination and to minimise leachate generation.
- Where contaminated water or leachate does arise on a site, it must be managed. This means that it must be kept out of the environment and stored in ponds from which it can evaporate or be used for dust control.
- Clean, uncontaminated run-off water must not be permitted to mix with, and increase the volume of, contaminated water.
- The bases of all new trenches and/or cells in which the waste is deposited must be graded so that water drains away from the waste. The resulting contaminated water must be treated as above.
- A 0.5m freeboard, designed for the 1 in 50 year rainfall event, must always be maintained in the case of contaminated water impoundments and drainage trenches.
- All temporarily and finally covered areas must be graded and maintained to promote run-off without excessive erosion and to eliminate ponding or standing water.
- Clean, uncontaminated water, which has not been in contact with the waste, must be allowed to flow off the site into the natural drainage system, under controlled conditions.
- All drains must be maintained as an ongoing part of the operation. This involves, *inter alia*, ensuring that they are not blocked by silt.
7.4.6 Leachate and Gas Management

As with the drainage system, the leachate management system at a Sp landfill requires to be maintained, and continuously adapted and developed as the landfill develops, in accordance with the design.

Where a gas management system exists at a site, it must be correctly operated, maintained and monitored.

7.4.7 Progressive Restoration of Completed Areas

The progressive restoration of landfills by means of the placing of final cover and the establishment of vegetation is highly desirable, in order to prevent soil erosion and to improve visual appearance. Where feasible, revegetation should commence on all areas where no further waste deposition will take place. Figure 7-2 shows an example of how progressive restoration may be incorporated in the phasing of the landfill operation.

If possible, waste disposal operations should take place behind berms which are extended upwards in advance of the disposal operation to ensure continued screening. If this method is employed, the vegetation of these berms is a priority.

All final levels and slopes must be in accordance with the landfill design and the proposed end use.

Immediately on completion of an area, a minimum of 300 mm of final cover must be applied, or more in the case of Sp landfills. Final cover must comprise topsoil so that it can support vegetation. In order to prevent erosion and improve aesthetics, re-vegetation should commence as soon as possible.

7.5 INSPECTING AND MONITORING THE LANDFILL SITE OPERATION

Operating landfill sites must be inspected and monitored regularly to verify that the landfill is operated to the standards required by the Licence conditions, and that the licensed site design is properly implemented. Standards under consideration might include the proper compaction and covering of waste and monitoring the integrity of drainage systems.

Inspection will be undertaken by the DSWM, which is the regulatory authority. Monitoring must be undertaken by the Licence Holder, who may employ consultants for the purpose.

Monitoring is therefore a form of self-regulation. Inspection and monitoring may also quantify any effect of the operation on the environment, particularly on the water regime, and serve as an early warning system, so that any problems that arise can be identified and rectified. These would include problems such as malfunctioning drainage systems, cracks in the cover, leaking liners, and ground or surface water pollution.

The extent of inspection and monitoring will depend on the site classification and will be indicated in the Licence. For G:L and Sp:H sites, additional information required by the DSWM could include detail about airspace utilisation, cover volumes, waste stream data analyses and co-disposal ratios.

7.5.1 Landfill Inspection

The frequency of inspection of landfills by the DSWM will depend on the availability of resources. These resources will be concentrated on the larger sites and those which present the greatest risk to the environment. In general, the frequency will tend to be similar to that required for the site audits described in the next section.
7.5.2 Landfill Site Auditing

A landfill site audit is used to monitor the waste disposal operation. It may be undertaken and/or evaluated by an audit committee.

At Sp:H landfills, the audit committee must consist of the Licence Holder, the Site Manager, the DSWM and, where applicable, the relevant professional consultant(s). At other landfills, the audit committee may be reduced in consultation with the DSWM. The frequency of the audit must be agreed upon by all the parties concerned, but must occur at twelve month intervals for G:S landfills, six month intervals for G:M landfills, three month intervals for G:L landfills and monthly intervals for Sp:H landfills. G:V sites do not require an audit.

General aspects of a landfill site audit would include consideration of site security, site access, condition of roads and traffic control. The actual waste deposition would be addressed in terms of cell construction, waste deposition, spreading, efficiency of burning, compaction and covering. Operating procedures as specified in the Operating Plan would also be carefully appraised, as would aspects such as drainage, litter control and aesthetics. Similarly, all site specific Licence conditions and design requirements would be addressed. Where waste reclamation takes place, for example, this operation would be audited specifically for health and safety risks, as well as its aesthetic impact.

The audit programme should include the following:

- A checklist of items to be audited
- A comment on the findings of the audit
- A record of performance.

Any identified problem areas and the recommended actions to rectify these problems must be discussed with the landfill operators and, in the case of a Sp:H landfill a report must be submitted to the DSWM.

7.5.3 Other Monitoring

In addition to the landfill site audit, other data may be required to be recorded and retained. This would either be specified in the Licence conditions or requested subsequently by the DSWM. Most of the procedures outlined below would be included in the Operating Plan. The record keeping requirements are discussed in section 8.

Gate or weighbridge recording procedures

Landfill site operators, facility users and the regulatory authorities will all require waste disposal records for different reasons. Over and above the measurement of incoming waste for commercial purposes, records are also necessary for site management and control. Such records are obtained from record keeping at the gate or weighbridge.

Volume surveys

At all landfills, some idea of the remaining volumetric capacity (airspace) is required. This is achieved by assessing the volume by survey or other means.

Collection and processing of other data

In the case of Sp landfills, where high moisture waste is disposed of, it may be necessary to collect and analyse certain climatic statistics. These may include rainfall from rain gauges and A-pan evaporation rates, to provide insight into the site water balance.
Figure 7-2: Phasing of Filling and Progressive Restoration

- In Preparation
- Under Restoration
- In Operation
- Restored
- Site Entrance
- Haul Road
- Possible location of borrow pit / stockpile area
Landfill Operation & Monitoring

Leachate and water quality monitoring (see Section 10)
At Sp landfills, regular sampling of leachate, ground and surface water must be undertaken by the person responsible for monitoring the site. *Ad hoc* sampling must be carried out at all other landfills, so that any impact caused by the landfilling on the quality of the water regime in the vicinity of the site can be measured and recorded.

Gas monitoring
Where potential gas problems are identified, appropriate monitoring systems must be installed. These must be monitored at three monthly intervals during the operation and at the discretion of the DSWM after site closure. If the soil gas concentrations exceed 1% by volume at STP, the DSWM must be informed.

Air quality monitoring
Air quality monitoring at landfill sites mainly addresses odours, which could be related to gaseous emissions indicated above, and is usually undertaken in response to complaints. In the case of Sp:H landfills, however, there is the risk that dangerous wind blown contaminants could be emitted. At Sp:H sites, therefore, sufficient air quality monitoring must be undertaken where necessary to ensure that there is no risk to public health.

Climate monitoring
At Sp and possibly at certain G:L and G:M landfills, certain aspects of climate, notably rainfall and wind direction will need to be monitored.

Monitoring of restored areas (See Section 9)
Completed areas require ongoing inspection and maintenance. This includes the repair of cracks and erosion gullies which allow water to access the waste and from which malodorous gases escape, and the filling in of settlement depressions and/or cavities caused by fire. Damaged or dying vegetation should be replaced over a period of five years.
<table>
<thead>
<tr>
<th>GUIDELINES</th>
<th>CLASSIFICATION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>All-weather site roads</td>
<td>N</td>
</tr>
<tr>
<td>Waste acceptance procedure</td>
<td>C</td>
</tr>
<tr>
<td>Control of vehicle access</td>
<td>C</td>
</tr>
<tr>
<td>Site security</td>
<td>D</td>
</tr>
<tr>
<td>Operating plan</td>
<td>D</td>
</tr>
<tr>
<td>Landfill compactor</td>
<td>N</td>
</tr>
<tr>
<td>Full time earth moving plant</td>
<td>N</td>
</tr>
<tr>
<td>Part-time earth moving plant</td>
<td>C</td>
</tr>
<tr>
<td>Responsible Person</td>
<td>C</td>
</tr>
<tr>
<td>Full-time supervision</td>
<td>C</td>
</tr>
<tr>
<td>Compaction of waste</td>
<td>N</td>
</tr>
<tr>
<td>Daily cover</td>
<td>N</td>
</tr>
<tr>
<td>Wet weather cell</td>
<td>N</td>
</tr>
<tr>
<td>Immediate covering of putrescibles</td>
<td>-</td>
</tr>
<tr>
<td>Prohibition of end-tipping</td>
<td>N</td>
</tr>
<tr>
<td>Three days' stockpile of cover</td>
<td>N</td>
</tr>
<tr>
<td>Final cover</td>
<td>C</td>
</tr>
<tr>
<td>Nuisance control</td>
<td>C</td>
</tr>
<tr>
<td>Prohibition of burning</td>
<td>C</td>
</tr>
<tr>
<td>Wind sock</td>
<td>N</td>
</tr>
<tr>
<td>Draining water away from waste</td>
<td>C</td>
</tr>
<tr>
<td>Containment of contaminated runoff</td>
<td>N</td>
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<tr>
<td>Leachate containment</td>
<td>N</td>
</tr>
<tr>
<td>Storm water diversion measures</td>
<td>N</td>
</tr>
<tr>
<td>0.5m freeboard for diversion and impoundments</td>
<td>N</td>
</tr>
<tr>
<td>Grading cover/avoiding ponding</td>
<td>C</td>
</tr>
<tr>
<td>Landfill gas control</td>
<td>N</td>
</tr>
</tbody>
</table>

C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.
### Table 7-3: Landfill Monitoring Guidelines

<table>
<thead>
<tr>
<th>GUIDELINES</th>
<th>I</th>
<th>G</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>V</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Designate responsible person</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Landfill site auditing</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Records and data (see section 7)</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Waste stream analysis</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Sporadic leachate reporting</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Water quality monitoring</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Gas monitoring</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Air quality monitoring</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Monitoring of progressive restoration</td>
<td>C</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Ongoing maintenance</td>
<td>C</td>
<td>D</td>
<td>C</td>
</tr>
</tbody>
</table>

C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.
8. DOCUMENTATION AND RECORD KEEPING

8.1 INTRODUCTION

One of the most important methods of ensuring and proving compliance with Licence conditions is the keeping of adequate records. Such records will be of particular importance to the DSWM when considering the surrender of a Licence when the landfill has been completed and stabilised.

Since the Licence holder's liability continues until surrender of the Licence, these records should be regarded as an essential procedure by Licence holders.

Records cannot be prepared retrospectively and therefore plans for their organisation and maintenance should be made at an early stage in the site's development. Many records will be irreplaceable if lost or damaged. As a consequence, duplicate records for site with a major environmental impact (L, some M and all Sp sites) should be maintained at a separate location away from the site.

There are two types of records which should be maintained - static records, which do not change with time, and dynamic records, which do. The documentation discussed below is the maximum that might be expected and the smaller sites will have lesser requirements. The guidelines are shown in Table 8-2.

8.2 STATIC RECORDS

The static records consist of the documentation produced up to the point at which the site is licensed, constructed and commissioned. Naturally, the extent of this documentation will vary according to the classification of the site, but all documentation produced should be retained. Originals of these records can conveniently be held at a remote location, e.g. the Licence Holders main offices. The following is a list of documents which may be produced:

Key Documents
- Correspondence relating to initial consultations with the DSWM
- Site Feasibility Study
- Planning Application
- Planning Permission and conditions
- Site investigation report
- Conceptual design
- Technical design

Subsidiary Documents
- Preliminary hydrogeological investigation
- Preliminary EIA
- Maps and plans
- Correspondence and minutes of meetings with IAPs
- DSWM's opinion on site feasibility
- Detailed hydrogeological investigation
- EIA
- EICR
- Design drawings and specifications
8.3 DYNAMIC RECORDS

The dynamic records consist of those which document changes to the state of the landfill. The most obvious and important such document is a record of the type and quantity of waste received and deposited. The waste management legislation envisions the introduction of a documentation system (transfer note) for every consignment of controlled waste. It is likely, however, that this provision will not be introduced immediately and that documentation will be restricted to consignment notes for hazardous wastes. Any transfer notes or consignment notes relating to waste deposited at the site must be retained.

It is more likely that the records of type and quantity of waste deposited will be derived from records kept at the gate or weighbridge by the site supervisor or gate controller. The method of waste recording must be appropriate to the nature and the volume of the wastes entering the site. The degree of sophistication required will be dependent on the class of site involved. In the case of a weighbridge, actual records may be produced of the weight of waste deposited. If no weighbridge is available, the delivery vehicle registration number (if applicable), type and estimated volume should be recorded, together with the date and time of delivery. With the accumulation of records, a data base must be established and maintained at the landfill site. This would be compulsory in the case of Sp:H sites.

There are also many other types of dynamic record that should or may be maintained, namely the following:

- Stages of development and filling, accompanied by photographic records, showing the nature of materials deposited in different locations (where appropriate), and timing of filling.
- Results from annual survey of landfill volume usage. In the case of I and G:V landfills, this can be achieved by visual appraisal. In the case of G:S and G:M landfills, distances may be paced or tape-measured. At G:L and Sp:H landfills, however, survey instruments must be used. The entire site must be surveyed prior to commencement of waste disposal and annually thereafter. It is recommended that a scale of 1:1,000 is used with lm contours.
- Details of leachate and gas management practice, where this is undertaken.
- Environmental monitoring data.
- Register of accidents and incidents (incident book)
- Record of DSWM inspections (including a copy of any report produced by the DSWM) and any non-compliance notices, together with remedial action taken.
- Register of complaints from the general public and minutes of any consultative meetings.
- Visitors book.
**Documentation and Record Keeping**

- Weather and climate data, especially days of heavy rainfall and wind direction. At G:L and Sp sites, measurement and recording of rainfall and possibly evaporation rates would be required to assess the water balance.

Table 8-1 shows an example of how a site day book might be organised.

**Table 8-1: Landfill Day Book**

<table>
<thead>
<tr>
<th>Weather Conditions:</th>
<th>Opening Times:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staff on Site:</td>
<td>Signature of Manager/Foreman:</td>
</tr>
<tr>
<td>Plant Operating:</td>
<td>Significant events/incidents [e.g. Inspections, monitoring, visits, accidents, plant breakdown etc. - detailed report on separate sheet if required]:</td>
</tr>
</tbody>
</table>

**WASTE DEPOSITED**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Reg. No.</th>
<th>Driver Name</th>
<th>Arrival Time</th>
<th>Depart Time</th>
<th>Waste Type</th>
<th>Origin*</th>
<th>Weight/Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

* Waste producer (in the case of industrial waste) or Council (in the case of municipal waste)
### Table 8-2: Guidelines for Record Keeping

<table>
<thead>
<tr>
<th>GUIDELINES</th>
<th>CLASSIFICATION SYSTEM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>M</td>
</tr>
<tr>
<td>Static Records as available</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Dynamic records:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weighbridge records (type and quantity)</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Daily records of loads delivered (type and quantity)</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Weekly records of loads delivered (type and quantity)</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>3 monthly record of filling progress</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Annual record of filling progress</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Volumetric survey</td>
<td>D</td>
<td>N</td>
</tr>
<tr>
<td>Leachate and gas management records</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Monitoring records</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Incident book</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>DSWM inspections</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Visitors' book</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Complaints register</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Weather and climate data</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

*C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.*
9.1 INTRODUCTION

Closure is the final step in the operation of a landfill. In order to close a landfill properly, however, closure must be preceded by restoration, to ensure that the site is environmentally acceptable. The site must also be rendered suitable for its proposed end-use, as determined when Planning Permission was obtained. Once the operation has ceased, aftercare is necessary to ensure sustained acceptability.

Where it is intended to close a landfill, the Licence Holder must inform the DSWM of this intention. This is because certain procedures must be implemented and criteria met before closure. If the site is licensed, it must be closed and restored in accordance with the Licence conditions and closure guidelines appropriate to the landfill class under consideration. If, however, the site is not licensed, it must be licensed with a view to closure. In this event the emphasis of the application is on closure design and restoration.

Regardless of whether a landfill is licensed or not, it must be investigated before restoration and closure can commence, so as to identify any closure requirements that must be implemented. Based on the results of the above investigations, a closure plan must be prepared (for G:L, G:M and Sp sites), which must comply with the Planning Permission and the Licence.

When the landfill has been restored in accordance with the Licence conditions or Closure Plan, the Licence Holder will still retain responsibility for its aftercare and any environmental implications. When the site has stabilised, the DSWM may accept surrender of the Licence, whereupon the Licence Holder has no further liability.

Whether or not aftercare is required will depend on the site and its potential for effect on the environment. I, G:V and G:S sites are unlikely to have any such effects and therefore Licence surrender may be accepted relatively soon after closure, but it is possible that a programme of aftercare will be required for G:M sites. G:L and Sp sites will always be subject to aftercare and monitoring requirements and inspections.

The implementation of the intended after-use may commence before the surrender of the Licence, but the written permission of the DSWM is required in this instance.

The Guidelines for Restoration and Aftercare are shown in Table 9-1

9.2 END-USE AND CLOSURE REQUIREMENTS

The end-use of a landfill refers to its after-use, i.e. how it will be developed after closure to fit into the environment. The most common landfill end-use is open space, which may be used for sport and recreation. No structures, however, should be built on top of a closed landfill until it has completely stabilised. This is because of the problem of ongoing settlement and the possible generation of methane gas. Possible methane gas generation also precludes the development of structures immediately adjacent to the site. Furthermore, because of the hazardous nature of the waste contained within them, no public access should be allowed to closed Sp:H sites. The enduse requirements will depend on the Planning Permission requirements which will reflect the requirements of the IAPs.

The closure investigation must be carried out to identify the causes of any existing problems and to provide the basis for the closure requirements. The extent of the investigation will depend on

BOTSWANA LANDFILL GUIDELINES
the amount of investigation already completed, the existing problems and the potential environmental impact of the site.
Closure requirements are those restoration measures that must be taken to address the identified problems, and to render a landfill environmentally acceptable and suited to its proposed end-use. They include remedial work with regard to drainage, leachate management and cover integrity, and should be addressed in the upgrade or Closure Design.

9.3 CLOSURE PLAN

Where a Closure Plan is required it should include any remedial steps to deal with outstanding problems such as the correction of settlements, attending to drainage arrangements, improving or changing fences and gates, and the maintenance of vegetation. In the case of unlicensed landfills, it may represent the first landfill design submitted, while in the case of a licensed landfill it may involve amendment of an existing design. For a new landfill, the Closure Plan will be part of the initial design.
It may also be necessary to establish procedures for the removal of illegal deposits of waste and the maintenance of vegetation and drainage systems. In the case of Sp:H sites special attention must be paid to the possibility of gas migration and site security.
Aspects addressed in the Closure Plan would typically include the following:
• Remedial design to address identified problem areas
• Final shaping and landscaping
• Final landfill cover or cap design
• Permanent storm water diversion measures, run-off control and anti-erosion measures
• Any infrastructure relating to the end-use.
Finally, the objective of the design must always be to ensure that the closed landfill complies with the Guidelines.
Where the Closure Plan is not part of the Planning and Licence Applications it should be submitted to both the Planning Authority and DSWM for their approval.

9.4 RESTORATION

The restoration of the landfill will ensure that the final condition of the site is environmentally acceptable and that there will be no adverse long term effects on the surrounding areas, the water regime or the population. It includes final cover, capping in the case of Sp:H landfills, topsoiling and vegetating. Any long term leachate, gas, storm water and erosion control systems required should also be in place and in working condition before the landfill is closed.

9.5 AFTERCARE

The long term environmental impacts, public health, safety and nuisance problems associated with a landfill may persist long after the site has been closed. Ongoing inspections and aftercare are therefore required after site closure, to ensure that such problems do not continue unidentified and unabated.
Ongoing inspections must be carried out at regular intervals by the Licence Holder to monitor cover integrity, gas venting systems, subsidence, fires, vegetation, peripheral and surface drainage, erosion, and any other aspects of the closed site which could cause nuisances. These inspections should be carried quarterly during the first year after restoration and annually.
thereafter until the Planning Authority and DSWM are satisfied that there are no ongoing threats to the environment or danger to health.

Based on the findings of the ongoing inspections, aftercare of the landfill would address the following aspects:

**Integrity of cover**

The integrity of a landfill cover can be breached by several mechanisms, including settlement, fires and erosion. Settlement continuously takes place in a landfill. This is because the waste is subject to ongoing decomposition. Any uneven settlement will result in cracks or depressions in the cover. In landfills where fires have occurred, it is possible that smouldering fires can undermine areas which then either subside or collapse. Alternatively, erosion caused by surface water run-off can also expose waste.

In the event of the landfill cover being breached, three main effects may occur. First, flammable landfill gas may vent to the atmosphere, with associated odour problems and a danger of fire or even explosion. Secondly, exposed and/or undermined smouldering waste may create dangerous, unsafe situations. Thirdly, surface water may be channelled into depressions, where it may collect and infiltrate the waste, or it may gain access to the waste directly via the breaches. Both of these situations could result in the generation of leachate.

Post-closure monitoring must therefore address all the above aspects of landfill cover integrity. Wherever there are breaches, these should be identified, the cause investigated and the situation rectified by infilling.

**Drainage systems**

It is essential to ensure that drains are not excessively eroded or filled with silt or vegetation. They must function in order to ensure that excess surface water does not enter the waste body.

**Subsidence**

Any subsidence or cracks, due to settlement or any other cause, must be identified and rectified by infilling.

**Fires**

Any fires that result on the site should also be identified, exposed and smothered with soil as soon as possible.

**Vegetation**

Vegetation planted for the purposes of restoration, erosion control, beautification or the end-use must be maintained to ensure that it achieves its purpose.

**Security**

It is also essential to ensure that illegal access and dumping does not occur on the closed waste disposal facility.

### 9.6 ONGOING MONITORING

The existing systems for gas and for ground and surface water monitoring must be monitored on an ongoing basis, after the landfill site has closed. They are addressed in section 10.
9.7 LICENCE SURRENDER

The surrender of a Licence will only be considered once the DSWM is satisfied that the restoration of the site has been properly carried out and the site has stabilised. This will include the implementation of the Closure Plan as assessed at a final site inspection.

<table>
<thead>
<tr>
<th>Table 9-1: Guidelines for Restoration and Aftercare</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUIDELINES</td>
</tr>
<tr>
<td>Determine/reassess end-use requirements</td>
</tr>
<tr>
<td>Investigate to determine closure requirements and identify impacts</td>
</tr>
<tr>
<td>Confirmation of end-use by DSWM or Planning Permission</td>
</tr>
<tr>
<td>Design for upgrade/restoration</td>
</tr>
<tr>
<td>Design final shaping and landscaping</td>
</tr>
<tr>
<td>Design final cover or capping</td>
</tr>
<tr>
<td>Design permanent storm water diversion</td>
</tr>
<tr>
<td>Design anti-erosion measures</td>
</tr>
<tr>
<td>Closure Plan</td>
</tr>
<tr>
<td>Approval of Closure Plan by DSWM</td>
</tr>
<tr>
<td>Restoration and vegetation</td>
</tr>
<tr>
<td>Ongoing leachate control and treatment</td>
</tr>
<tr>
<td>Ongoing gas control or extraction</td>
</tr>
<tr>
<td>Ongoing inspection and maintenance</td>
</tr>
<tr>
<td>Implementation of Closure Plan</td>
</tr>
<tr>
<td>Inspection and monitoring:</td>
</tr>
<tr>
<td>(i) Frequency (in months)</td>
</tr>
<tr>
<td>(ii) Cover integrity</td>
</tr>
<tr>
<td>(iii) Drainage integrity</td>
</tr>
<tr>
<td>(iv) Control of ponding</td>
</tr>
<tr>
<td>(v) Fire control</td>
</tr>
<tr>
<td>(vi) Vegetation monitoring</td>
</tr>
<tr>
<td>(vii) Monitoring security and illegal dumping</td>
</tr>
<tr>
<td>Aftercare</td>
</tr>
<tr>
<td>DSWM approves surrender of Licence</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLASSIFICATION SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>I V      S      M      L      W      H</td>
</tr>
<tr>
<td>Determine/reassess end-use requirements          D N C C C C C</td>
</tr>
<tr>
<td>Investigate to determine closure requirements and identify impacts C C C C C C C</td>
</tr>
<tr>
<td>Confirmation of end-use by DSWM or Planning Permission D N C C C C C</td>
</tr>
<tr>
<td>Design for upgrade/restoration                   C C C C C C C</td>
</tr>
<tr>
<td>Design final shaping and landscaping             C N C C C C C</td>
</tr>
<tr>
<td>Design final cover or capping                    C C C C C C C</td>
</tr>
<tr>
<td>Design permanent storm water diversion           C C C C C C C</td>
</tr>
<tr>
<td>Design anti-erosion measures                     C C C C C C C</td>
</tr>
<tr>
<td>Closure Plan                                     C N C C C C C</td>
</tr>
<tr>
<td>Approval of Closure Plan by DSWM                 C N C C C C C</td>
</tr>
<tr>
<td>Restoration and vegetation                       C N C C C C C</td>
</tr>
<tr>
<td>Ongoing leachate control and treatment           N N N D D C C</td>
</tr>
<tr>
<td>Ongoing gas control or extraction                N N N D D D D</td>
</tr>
<tr>
<td>Ongoing inspection and maintenance               C N D C C C C</td>
</tr>
<tr>
<td>Implementation of Closure Plan                   C N C C C C C</td>
</tr>
</tbody>
</table>

* or more frequently

C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.
10. WATER QUALITY MONITORING

10.1 INTRODUCTION

Water quality monitoring begins before the construction of a landfill site and continues throughout and beyond its operation. Since post-closure water quality monitoring may continue for up to 30 years after the closure of a landfill, it can be seen to represent the final step in the landfill process.

Water quality monitoring is used to provide an early warning system to indicate any escape of leachate into the water environment. Once this is identified and quantified, appropriate measures can be taken. Where appropriate, the DSWM will therefore require a Water Quality Monitoring Plan, involving background, operation and post-closure monitoring, as a Licence condition. This ensures that the water quality in the vicinity of a landfill is regularly monitored and reported upon throughout its life so that, where necessary, remedial action can be taken.

Water quality monitoring is the responsibility of the Licence Holder, who must ensure that the level and the extent of monitoring is in accordance with the DSWM's requirements, which will be specified in the Licence. The Guidelines are shown in Table 10-3.

This section should be read in conjunction with the Hydrogeological supplement in Appendix 1.

10.2 DESIGN OF MONITORING SYSTEMS

Water quality monitoring must commence before any waste is disposed of. Monitoring will therefore start during the site investigation, when all accessible surface and ground water in the vicinity of the proposed landfill is sampled and analysed. The objective of this is to provide the pre-disposal background or datum against which future water quality can be measured.

Where appropriate, pre-operation monitoring sampling points must, together with any proposed monitoring points, be formalised and indicated as the monitoring systems in the site design. This plan would then be submitted as part of the Licence application.

It is at the investigation and design stages that the future monitoring systems are established and recorded. Pre-operation monitoring therefore forms the basis for water quality monitoring during the operation and even after closure.

It has to be remembered that the protection of water resources is, of all possible environmental impacts, the most significant. Consequently the greatest care is required and measures are justifiable to check the effect of waste landfills on the water regime.

10.2.1. Surface Water Monitoring System

During the site investigation, surface water quality in any associated drainage feature is monitored both upstream and downstream of the proposed landfill. Sampling points must be selected at representative, easily identified sites. While a single upstream sampling point may suffice, the size and complexity of the site, i.e. its class, will determine the number of downstream sampling points required.

The sample points upstream of the proposed landfill will provide ambient background values. The sample points downstream of the proposed landfill will ultimately indicate any significant pollution resulting from the site.
10.2.2 Ground Water Monitoring System

The ground water monitoring system, which comprises boreholes, is addressed in Sections 5 and 6. For more detail in this regard refer to the Hydrogeological supplement in Appendix 1.

10.2.3 Leachate Monitoring System

In Botswana, only Sp landfills are likely to require leachate management systems. In such cases, leachate collection systems would form part of the design and provision would have to be made for regular leachate monitoring.

10.2.4 parameters

For consistency, and for comparative purposes, the same water quality parameters are analysed for in both surface and ground water monitoring. Table 10-1 and Table 10-2 below set out the sampling parameters, which are different for determining the background water quality than for ongoing detection monitoring. Should one of the parameters in the detection monitoring programme be suspiciously high, then a process of investigative monitoring should be undertaken, where all the initial parameters from the background sampling exercise are analysed. Other parameters may, however, be added by the DSWM, should they be considered relevant at a specific site.

Table 10-1: Parameters for Background and Investigative Monitoring

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>Lead (Pb)</td>
</tr>
<tr>
<td>Alkalinity (M. Alk)</td>
<td>Magnesium (Mg)</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>Mercury (Hg)</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>Nitrate as N (NO₃-N)</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>pH</td>
</tr>
<tr>
<td>Chemical Oxygen Demand (COD)</td>
<td>Phenolic Compounds (Phen)</td>
</tr>
<tr>
<td>Chloride (Cl)</td>
<td>Potassium (K)</td>
</tr>
<tr>
<td>Chromium (Hexavalent) (Cr⁶⁺)</td>
<td>Sodium (Na)</td>
</tr>
<tr>
<td>Chromium (Total) (Cr) Cyanide</td>
<td>Sulphate (SO₄)</td>
</tr>
<tr>
<td>(CN)</td>
<td>Total Dissolved Solids (TDS)</td>
</tr>
<tr>
<td>Electrical Conductivity (EC)</td>
<td>Free and Saline Ammonia as N (NH₄-N)</td>
</tr>
<tr>
<td>Volatile Organic Carbons (VOC)</td>
<td></td>
</tr>
</tbody>
</table>

Table 10-2: Parameters for Detection Monitoring

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (M. Alk)</td>
<td>Nitrate as N (NO₃-N)</td>
</tr>
<tr>
<td>Calcium (Ca)</td>
<td>pH</td>
</tr>
<tr>
<td>Chemical Oxygen Demand (COD)</td>
<td>Potassium (K)</td>
</tr>
<tr>
<td>Chlorides (Cl)</td>
<td>Sodium (Na)</td>
</tr>
<tr>
<td>Electrical Conductivity (EC)</td>
<td>Sulphate (SO₄)</td>
</tr>
<tr>
<td>Fluoride (F)</td>
<td>Total Dissolved Solids (TDS)</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td></td>
</tr>
</tbody>
</table>
10.2.5 Sampling

The recommended ground water sampling methods and the treatment and storage of samples are those advocated by Weaver in the document "Groundwater Sampling". Surface water sampling methods are somewhat simpler, however, in that grab samples may be taken from the surface water sample points.

In the case of both surface and ground water sampling, clean bottles should be used. These should be rinsed with the sample water, prior to taking the sample. Sample treatment prior to analysis would be the same in both cases and is indicated in the above reference.

The analysis of the samples must be performed in accordance with the equivalent of South African Bureau of Standards (SABS) methodology.

10.2.6 Reporting

The ground and surface water quality results from the pre-operation monitoring, together with the annotated designs of the monitoring systems, must be submitted to the DSWM as part of the Licence Application, i.e. the Water Quality Monitoring Plan.

10.3 MONITORING DURING THE OPERATION

Once a landfill is operational, water quality monitoring must take place in accordance with the Licence conditions and any subsequent requirements of the DSWM.

Operation monitoring involves monitoring the water regime in the vicinity of the landfill, by means of the monitoring systems included in the design section of the Licence Application Report. These systems may have to be expanded.

A comparison between the upgradient, or ambient background, and the downgradient concentrations is used to assess the impact of the landfill on water quality. This is particularly the case where any contaminated surface water or leachate leaves the site.

The methodology for sampling both surface and ground water at an operating landfill would be the same as that used during pre-operation monitoring.

Operation monitoring may comprise two types of monitoring, i.e. detection monitoring and investigation monitoring.

10.3.1 Detection Monitoring

Detection monitoring is routine monitoring carried out every six months. The parameters used are limited to indicator parameters as listed in Table 10-2, to indicate the presence of pollution

10.3.2

If detection monitoring indicates possible pollution, with an increasing trend in the parameter concentrations with time, the DSWM may require further monitoring. This would be referred to as investigative monitoring and would involve monitoring the range of parameters included in Table 10-1, together with any other parameters deemed necessary. The sampling interval in the case of investigative monitoring would generally be monthly, or as determined by the DSWM.

10.3.3 Leachate

Where sporadic leachate is generated at an I or G site, the DSWM must be informed. If directed by the DSWM, the Licence Holder may have to have such leachate sampled and analysed. At Sp landfills, where significant leachate is generated, it should be sampled from the leachate collection system on a regular basis. Sampling frequency and the parameters analysed for
should be the same as for surface and ground water monitoring, unless otherwise stipulated in the Licence or by the DSWM.

10.3.4 Reporting
The above analyses must be presented in the format stipulated in the Site Licence, and the Licence Holder must maintain records of all analyses undertaken.

10.4 POST-CLOSURE MONITORING
Since a landfill can continue to pollute the ground and surface water regime long after the site has been closed, post-closure water quality monitoring must be ongoing. The approach and systems for ground and surface water monitoring described above should be used for this purpose.

The emphasis in the case of post-closure monitoring would be more on ground water monitoring, unless circumstances or the DSWM dictated otherwise. This is because the ground water in Botswana usually represents a strategic resource.

In the case of some G and all Sp:H sites, post-closure water quality monitoring may continue for many years after site closure. This will be specified by the DSWM at closure. Ongoing annual liaison with and reporting to the DSWM must continue throughout this period.

<table>
<thead>
<tr>
<th>Table 10-3: Guidelines for Water Quality Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUIDELINES</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Appoint Responsible Person</td>
</tr>
<tr>
<td>Submit Water Monitoring Plan in Licence Application</td>
</tr>
<tr>
<td>Pre-operation monitoring:</td>
</tr>
<tr>
<td>Surface water</td>
</tr>
<tr>
<td>Ground water</td>
</tr>
<tr>
<td>Background results in Licence Application</td>
</tr>
<tr>
<td>Water analysed per table 10.1</td>
</tr>
<tr>
<td>Sample/analyse</td>
</tr>
<tr>
<td>Operation Monitoring:</td>
</tr>
<tr>
<td>Surface water</td>
</tr>
<tr>
<td>Ground water</td>
</tr>
<tr>
<td>Leachate</td>
</tr>
<tr>
<td>Report sporadic leachate</td>
</tr>
<tr>
<td>Aftercare Monitoring:</td>
</tr>
<tr>
<td>Surface water</td>
</tr>
<tr>
<td>Ground water</td>
</tr>
</tbody>
</table>

C: Compulsory. D: Discretionary - opinion to be given by DSWM. N: Not compulsory.
Hydrogeological Aspects of Waste Disposal by Landfill

supplement to

Guidelines for the Disposal of Waste by Landfill

Final Draft 2.0 May 1996

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In Cooperation with the National Conservation Strategy (Co-ordinating) Agency and GTZ German Technical Cooperation
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1. Introduction

This supplement to the Botswana Guidelines For The Disposal of Waste By Landfill (herein referred to as the "Landfill Guidelines") covers all hydrogeological aspects that are to be considered during the different phases of a landfill development. The content of this supplement closely follows that of the guidelines and reference to the main body should be made where indicated or required. The relationships between the different development phases as laid down in the "Landfill Guidelines" and the different hydrogeological tasks associated with these steps are shown in Figure 1.

The ultimate goal of having "environmentally acceptable waste disposal facilities in Botswana " can best be reached when hydrogeological aspects are dealt with properly.

- The construction of a new facility for landfilling of wastes requires hydrogeological knowledge during the siting, operation and performance assessment. Proper site selection with regard to hydrogeological settings is the best provision for long-term safety of a landfill at a selected site.
- The upgrading of existing sites requires a thorough understanding of the hydrogeological site characteristics, because the implementation of new techniques to improve the standards of the facility in most often addresses the medium of groundwater.
- The closure procedures of sites that are no longer environmentally acceptable and/or are full, need to deal with the hydrogeological properties of the site. In most cases a site will be considered unacceptable because of existing or impeding impacts on the groundwater in the vicinity of the site.

It is understood that the extent and detail of hydrogeological investigations and installations, like monitoring wells, depends on various factors:

- the size of a landfill site
- the waste content of a landfill
- the complexity of the hydrogeological setting.

The sizes of landfills in the "Landfill Guidelines" are defined on the basis of waste generation, e.g. the amount of waste generated over a particular time interval by an indicative population. However, for the purpose of hydrogeological assessment of a potential impact of leachate on the groundwater below a site, the actual landfill disposal area that is covered by waste and its location with respect to the general direction of groundwater flow is more important (Table 1-1).

Table 1-1: Typical sizes of landfill disposal areas for Landfill Size Classes

<table>
<thead>
<tr>
<th>Landfill Size Class</th>
<th>Assumed depth of deposition</th>
<th>Landfill disposal area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very small (rural)</td>
<td>1 m</td>
<td>&lt; 1 ha</td>
</tr>
<tr>
<td>Small</td>
<td>2 m</td>
<td>1 to 5 ha</td>
</tr>
<tr>
<td>Medium</td>
<td>5 m</td>
<td>5 - 20 ha</td>
</tr>
<tr>
<td>Large</td>
<td>10 m</td>
<td>&gt; 20 ha</td>
</tr>
</tbody>
</table>

Characteristics of the waste are discussed in chapter 2 of the "Landfill Guidelines". The requirements for hydrogeological settings are dependant on the amount and quality of leachate the natural underground system has to cope with. Therefore, if a proper landfill operation can be maintained the risk of much leachate developing is quite low. Because of the high evaporation rates most moisture in the waste is evaporated before it can reach the subsurface groundwater regime. In general, the requirements for host rock selection, in a dry climate such as Botswana, do not need to be as strict as under humid climatic conditions. Furthermore, the lack of toxic constituents in most of the general waste justifies this procedure.
The complexity of hydrogeological situations depends on several features, such as hydrostratigraphy and tectonics. The simpler the underground is, the easier groundwater transport and flow processes can be assessed and monitored.
<table>
<thead>
<tr>
<th>Landfill Classification</th>
<th>G</th>
<th>Sp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>R</td>
</tr>
<tr>
<td>Geological Barrier Rocks</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

*Requirement:* C: Compulsory, D: Discretionary - opinion to be given by DSWM, N: Not compulsory

*Landfill Size Class:* I: Inert Landfill, G: General Waste Landfill (R: Rural, S: Small, M: Medium, L: Large),
Sp: Special waste Landfill (W: Wet, H: Hazardous)
For the ranking procedure it is necessary to have the distribution of potential barrier rocks mapped on a planning scale of 1:50,000 or even larger. These potentially suitable rocks are then reduced by the unsuitable areas as listed in the "Landfill Guideline" in an overlay procedure. The vulnerability map 1:50,000 is best suited for this purpose.

The Geological Map of Botswana is published in Quarter Degree Sheets and associated Bulletins in a scale of 1:125,000.

Table 2-2: Information Contained in Different Maps of Botswana

<table>
<thead>
<tr>
<th>Groundwater Resources Potential</th>
<th>Groundwater Quality</th>
<th>Aquifer Lithology</th>
<th>Surface Water</th>
<th>Groundwater Depth</th>
<th>Groundwater Flow Direction</th>
<th>Near Surface Geology</th>
<th>Groundwater Vulnerability</th>
<th>Pollution Sources</th>
<th>Topography</th>
<th>Boreholes</th>
<th>Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Resources Map 1:1,000,000</td>
<td>Groundwater Vulnerability Map 1:1,000,000</td>
<td>Hydrogeological Reconnaissance Map 1:500,000</td>
<td>Groundwater Vulnerability Maps 1:50,000</td>
<td>Geological Maps 1:125,000</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

2.3.2 Borehole Information

At the DGS borehole data of about 15000 boreholes are stored in a D-base database. For most of the holes only drilling logs exist, however, geological logs are also available for about one third of them. The National Water Borehole Archive contains information on most boreholes and wells that were drilled for groundwater exploration purposes. An example of this information is given in the appendix.

2.4 AQUIFER/ AQUITARD TYPES OF BOTSWANA

An aquifer is defined as a saturated geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients. Two types of aquifers are generally recognised, namely porous and fissured aquifers which include karst aquifers.

Geologic units that allow only minor or negligible amounts of water to be stored or to flow are called aquitards.

In line with the above outlined multibarrier concept aquitards are preferred as host rocks for landfills because these rocks have the best barrier properties.

With reference to Table 2-1 it is desirable to have aquitards at each landfill, however, in many instances, namely with rural and small facilities, these rocks might not be available. In cases where
landfill sites were chosen in the area of influence of an aquifer, special attention must be given to groundwater protection measures.

2.4.1 porous Aquifers
In porous aquifers the dominant groundwater flow is through pores around grains of sand, silt or gravel, which make up the aquifer. Porous aquifers in sand and gravel formations have generally a high groundwater potential. They contain up to 30 % water by aquifer volume. Some of the porous aquifers contain a certain amount of clay which would indicate some attenuation potential of pollutants and a locally reduced permeability. Examples of porous aquifers in Botswana are:

- Sands and gravel beds along major rivers (such as the Limpopo, Molopo, Shashe, Thamalakane, Boteti and Chobe)
- Unconsolidated sediments of the Kalahari Group and the Okavango Delta and the Makgadikgadi Pan.

On some of the hard rocks, like the Pre-Cambrian granite complex deeply weathered and decomposed portions exist, which behave as porous aquifers.

2.4.2 Fissured Aquifers
The term, fissured aquifer, is used for those rock units where groundwater flows through a variety of secondary structures, such as joints, fissures, fractures and faults. Hard rocks, such as quartzite, more readily develop fractures than softer rocks, such as shale and mica schist. The degree of fracturing in an aquifer generally reflects the degree to which the aquifer can transmit water. However, in some instances the fractures are closed by secondary cementation or are tight at deeper depths (about 60 meters and more) because of compression forces.

Exceptions occur in fault zones, where significant yields are possible even at greater depths. Near the surface the degree of fracturing normally increases because of pressure relief and the influence of weathering processes. Fissured aquifers usually have a low to fair groundwater potential. They contain only a few percent or even less water by aquifer volume. Characteristics of the aquifer vary greatly over short distances, and contaminant transport through fractures is comparatively fast along preferential pathways. In most hard rock aquifers there is hardly any attenuation of pollutants due to the lack of clay content within the rock matrix.

Sandstone has a primary porosity; depending on the degree of cementation, however, this porosity is negligible compared to the fracture porosity, where the dominant flow mechanism occurs. Major aquifers in the sandstones and quartzites of the Waterberg Formation are developed in the Molepolole-Mochudi escarpment and in the Tswapong Hills near Palapye. Other aquifers in the sandstones of the Karoo Formation are found near Serowe and Ghanzi.

Karst aquifers develop where groundwater flowing through fractured carbonate rocks dissolves material along fractures or bedding planes, which are widened, sometimes into larger dissolution channels. Karst aquifers generally tend to have a rather high permeability with a high groundwater potential. They are particularly vulnerable to pollution, because the retardation capacity of the rock matrix as such is low and groundwater can flow very fast along fractures and dissolution channels.

Karst aquifers in Botswana are only found in the Pre-Cambrian dolomite complex of southern Botswana near Lobatse, Ramotswa, Kanye, Jwaneng and Sekoma. Dolomite as a magnesium limestone is not dissolved as easily as pure limestone, nevertheless, karst phenomena are found within these rocks. Because major groundwater resources in Botswana are found within the dolomite sequence, these rocks in general are unsuitable for landfill siting. In cases where landfills exist upon these rocks, utmost care must be given to avoid any groundwater contamination.
2.4.3 Aquitards
As stated above aquitards are considered to be the best host rocks for landfills. Especially if these rocks contain clay minerals within the rock matrix their retardation capacity is high and pollutants that might enter the subsurface will not be transported far, but reduced to the immediate vicinity of the site. Also, because of the low permeability which in turn is caused by the low effective porosity, the amount of groundwater flow is very small and in most cases negligible. The groundwater thus has an insignificant potential for use.

Mudstones and shales, as well as basalts of the Karoo system can be regarded as aquitards. Other aquitards are developed within the volcanic, igneous and metamorphic rocks of the Pre-Cambrian system. Where this rock series are deeply weathered they have a secondary permeability and are therefore regarded as aquifers.

Granite, such as the Gaborone granite, like all other igneous rocks is generally regarded as an aquitard because of its low permeability. However, near-surface, granite weathers comparatively easily with open fractures and joints, eventually affecting large areas within the granitic mass. Therefore, fracture flow may dominate near surface. Associated with the granite occur gneiss complexes, namely in the east of Botswana, which also are aquitards.

2.5 PRELIMINARY HYDROGEOLOGICAL INVESTIGATIONS (PHI)

As the term indicates, Preliminary Hydrogeological Investigations (PHI) are a forerunner of those more Detailed Hydrogeological Investigations (DHI) to be undertaken once a site has been chosen and is prepared for operation. Most requirements for the PHI are laid down in the Landfill Guidelines. These include:

- local and regional geology
- soil cover description
- borehole inventory within a distance of 1 km
- assessment of groundwater resource value

Additional investigations might be necessary to complete the information on the following general geological data that should be available once the PHI has been completed:

- distribution of potential barrier rocks
- thickness of these rocks
- thickness of overlying rocks
- lithology (grain-size, texture)
- permeability, estimated
- stratigraphic age
- tectonic deformation
- faults, joints, fractures

With regard to hydrogeological properties the following characteristics should be described:

- general groundwater flow direction
- hydraulic gradient,
- depth to water table
- state of the piezometric surface(unconfined, confined)
- groundwater yield
- type of groundwater (hydrochemically)
- type of aquifer and soil cover
- vulnerability class
The results of the PHI are important for the Preliminary Environmental Impact Assessment, because major impacts of a landfill would affect the groundwater resources. It is important to recall, that these PHI are only required for small G:S, medium G:M and large sites G:L and Sp sites, whereas for the landfill classes I and G:R they are not necessary. In addition it must be pointed out that the full extent of the PHI is only required for large G:L and Sp sites. For all other cases the information level can be kept lower in accordance with the lower pollution potential of smaller sites. For these sites it is suggested to determine the particular hydrogeological standard setting for Botswana as discussed in the following chapter.

2.6 HYDROGEOLOGICAL SETTINGS

For the assessment of the pollution potential of a site, the setting (definition see Chapter 2) of its immediate surrounding rocks, e.g. the arrangement and properties of the underlying and adjacent hydrostratigraphical units, is most important, because these conditions determine whether any larger amount of leachate is likely to be transported away from the site into more regional aquifer systems. In order to visualise and to describe the suitability of different Hydrogeological Settings a set of standard types was developed (Figure 3 to Figure 5), which address up to three layers of three different types of hydrostratigraphical units:

- porous aquifers
- fissured aquifers
- aquitards.

With regard to the hydraulic situation these assemblages can be further classified according to the

- relation to the groundwater level (high, low)
- vicinity to receiving streams
- development of a multi-aquifer system.

Whereas the figures 3 - 5 give a complete overview of all possible combinations of these features, for the particular hydrogeological situation of an and country like Botswana the number of Standard Hydrogeological Settings can be reduced to a smaller number (Figure 6).
## Fissured Aquifers

<table>
<thead>
<tr>
<th>Fissured Aquifer</th>
<th>High water table</th>
<th>Low water table</th>
<th>several hydrostratigraphical Units</th>
<th>adjacent Receiving stream</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>below ground level</td>
<td>above ground level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FF undifferentiated</td>
<td>FFHb</td>
<td>FFHa</td>
<td>FFL</td>
<td>FFR</td>
</tr>
<tr>
<td>FA above Aquitard (fissured or porous)</td>
<td>FAHb</td>
<td>FAHa</td>
<td>FAL</td>
<td>FAU</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gunter Döhler 10/93
# Aquitards

<table>
<thead>
<tr>
<th>Aquitard (fissured or porous)</th>
<th>High water table</th>
<th>Low water table</th>
<th>several hydrostratigraphical Units</th>
<th>adjacent Receiving stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>AAHb</td>
<td>AAHa</td>
<td>AAL</td>
<td>AAR</td>
</tr>
<tr>
<td>AA, undifferentiated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>APHb</td>
<td>APHa</td>
<td>APL</td>
<td>APU</td>
</tr>
<tr>
<td>AP, above porous aquifer</td>
<td></td>
<td></td>
<td></td>
<td>APR</td>
</tr>
<tr>
<td>AF</td>
<td>AFHb</td>
<td>AFHa</td>
<td>AFL</td>
<td>AFU</td>
</tr>
<tr>
<td>AF, above fissured aquifer</td>
<td></td>
<td></td>
<td></td>
<td>AFR</td>
</tr>
</tbody>
</table>

Ganter Döthofter 1993
OP = Operational Phase
AP = Aftercare Phase

Evolution of site susceptibility to development of leachate
+
low

medium - high

±
medium - low

high

Elements of water balance
P = Precipitation
E = Evaporation
R = Runoff
L = Leachate, infiltrating
3. Landfill Site Characterisation

During the Landfill Site Characterisation process the Detailed Hydrogeological Investigations DHI are carried within the context of the entire Landfill Site Investigation program.

3.1 HYDROSTRATIGRAPHY

Lithological (sedimentological) and stratigraphical data in connection with groundwater data are employed to describe the hydrostatigraphical situation of a landfill. The identification and correlation of sediments requires the synthesis of all available geological data. The following data are used to describe the location of the hydrostratigraphic units in space and their relationship to each other:

- Hydrostratigraphic cross-sections,
- Depth contour maps of the important units,
- Thickness maps of the important units.

These drawings and maps must clearly represent the hydrogeological interrelationships (e.g., through a suitable choice of cross-section lines and levels). Besides representing the immediate area of the landfill in detail, detailed representations of the regional hydrogeological environment are also necessary, along with evaluation of the results of contaminant transport forecast. A meaningful evaluation of the findings on the landfill site is possible only if there is a clear conception of the underground structure and the hydraulics of the wider surroundings. As a rule, consideration must be given to the entire partial surface water drainage and groundwater drainage area of the landfill’s receiving stream.

New data is obtained primarily through field surveys and studies (borings and ditches), and additional through borehole and surface geophysics. Before new borings are made, the survey data from available boring archives at the DGS or DWA should be consulted and evaluated.

3.2 HYDROGEOLOGICAL PROPERTIES OF THE SUBSURFACE

The following hydraulic parameters, needed to describe the groundwater flow system, must be collected through the field studies:

- hydraulic conductivity / permeability ($k_f$)
- transmissivity ($T$)
- storage coefficient ($s$)
- effective porosity ($n_e$).

3.2.1 Permeability

As a rule, field data on the permeability of the subsurface are needed for all the hydrostratigraphic units relevant to the evaluation. These may be supplemented with laboratory studies. To determine these data, the customary hydrogeological procedures for monitoring the hydraulic properties in wells and boreholes should be used:

- Pumping tests
- Infiltration tests
- Well permeameter tests
- Slug and bail tests
- Packer tests (drill stem tests, WD tests etc.)

For monitoring permeabilities within single boreholes and wells, slug and bail tests are the simplest and easiest to use and yield reliable results without water being pumped or otherwise handled.
Pumping tests are particularly suitable for determining the average (integral) values of the larger aquifer properties, while borehole tests (slug and bail tests, infiltration tests) are used especially to test the hydraulic properties of that part of the aquifer connected to the screened interval of the well. If the hydraulic properties of discrete areas of higher permeability must be determined, the various packer tests are appropriate. These procedures are particularly important for investigating zones of higher permeability in hard rocks where fissures, faults, fractures, concretional layers or other stratigraphic inhomogeneities occur.

In layered porous aquifers, the hydraulic properties of the various horizons may be determined through separate screening in well groups (chapter 4).

Field tests for permeability are necessary in the ground below the landfill in the waste disposal area down to a depth of at least 10 m into the groundwater beneath the landfill (classes G:L and Sp).

In the case of a deeper water table, special procedures may be employed within the unsaturated zone (e.g., infiltration tests, ring infiltrometer tests or other percolation procedures).

### 3.2.2 Transmissivity

The transmissivity is calculated as the integral of the hydraulic conductivity $k_f$ over the thickness $t$ of the groundwater body. In the case of pumping tests, for example, this may be determined directly by evaluating the type curves. The average hydraulic permeability is then calculated as the quotient of the transmissivity and the thickness of the aquifer.

$$T = t \cdot k_f$$

### 3.2.3 Effective Porosity

The effective porosity $n_e$ is the proportion of voids or interstices in the aquifer available for groundwater movement. It is expressed as the percentage or fraction of the total rock volume occupied by interconnected interstices. Knowledge of the effective porosity is necessary for calculating the velocity of the groundwater and for determining the retardation factors of pollutants in the groundwater. The effective porosity can be estimated from the grain-size composition of the sediments. In general, it is difficult to determine the effective porosity in fissured hard rocks. However, estimates can be obtained from the porosity proportion drained during pumping tests.

### 3.3 Groundwater Movement

The hydraulic pressure conditions must be quantitatively determined for all relevant bodies of groundwater in the vicinity of the landfill. For this purpose, the position and any alteration of unconfined or confined groundwater surfaces and of any perched groundwater bodies must be determined.

The hydraulic head (pressure head) describes the elevation at which the groundwater surface stands in an open well terminated at a specific point in an aquifer or aquitard.

The hydraulic gradient $i$ describes the hydraulic head differences over a given distance at given observation points. It is the driving force of groundwater flow from areas of higher topographic (i.e., recharge) levels to lower (i.e., discharge) areas.

Hydraulic heads should be measured and evaluated at a sufficiently large number of observation points (monitoring wells, other wells, river or lake gauges) over a long period of time (at least one hydrological year) at single-date intervals. The data is presented in the form of groundwater contour maps which show isolines of the groundwater potentiometric surface.

The objective is to determine the direction and strength of local and regional hydraulic gradients. The groundwater maps and isolines of groundwater head must be interpreted in accordance with the hydrostratigraphic situations (e.g., the influence of minor aquifers on groundwater movement) and with reference to their accuracy.
3.4 GROUNDWATER VOLUME AND GROUNDWATER VELOCITY

Using the determined basic hydraulic parameters as a basis, data are to be produced on the volume and velocity of the groundwater moving within the effective porosity in the vicinity of the landfill. The groundwater flow rate \( Q \) per cross-sectional area \( A \) is a measurement of the volume of maximally contaminable groundwater. It is found by calculating:

\[
Q = k_f \cdot i \cdot A
\]

The groundwater velocity \( v \) of the groundwater may be determined by computation from the basic hydraulic values: hydraulic conductivity \( k_f \), hydraulic gradient \( i \) and effective porosity \( n_e \):

\[
V = k_f \cdot i / n_e
\]

The groundwater velocity can also be determined directly through the use of tracer tests. The tracer dilution test (borehole method) for example, may be used for this purpose.

3.5 WATER BALANCE

Since the natural flow conditions will be altered due to the presence of a landfill, it is necessary to consider the water balance of the landfill under operating conditions and after it has been filled in order to evaluate its influence on the natural groundwater regime. For this purpose the groundwater recharge rates for areas outside the landfill are to be determined.

The leachate generation rate of the landfill must be calculated on the basis of the average precipitation over several years, the evaporation and transpiration rates and the volume of surface runoff. In addition, the modification in groundwater recharge by the landfill itself (mainly the increase in the infiltration rate) during operations and after final covering must be considered.

By calculating the volume and temporal increment of leachate generation, it is possible to assess what volumes of leachate are entering (or may enter) the groundwater and the receiving streams. The use of an infiltration model (e.g. the HELP model, Schroeder et al. 1988) is recommended for addressing the water balance at larger landfill sites.

3.6 GROUNDWATER PROPERTIES

In order to assess the effect of leachate leaving the landfill on water resources and also to deal with questions of documentation, the water quality must be characterised hydrochemically in advance. For this purpose it is necessary to perform a sufficient number of hydrochemical analyses of groundwater from all relevant hydrostratigraphic units and of water samples from surface water sources in the vicinity of the landfill.

Particular attention should be paid to any vertical differentiation of the bodies of groundwater so that near-surface effects, such as those on agriculture, for example, or the effects of upwelling deep salt water can be assessed. The depth of active groundwater movements can be determined through continuous monitoring of physical and chemical parameters (pH, temperature, conductivity etc.) in the borehole.

In the event, an existing landfill is expanded, the existing pollutant discharge situation should be given particular attention and recorded in detail. This makes it necessary to evaluate any existing analysis series from monitoring wells or to obtain new landfill-specific hydrochemical analysis data. The existing observation wells are frequently unsuitable for a detailed evaluation of the contamination situation (too far away, not in the downstream area, screened within a wrong aquifer section). In these cases it is necessary to establish new observation wells.
Table 3-1: Standard programs for the Detailed Hydrogeological Investigation DHI for the two groups of landfill size categories

<table>
<thead>
<tr>
<th>Methods</th>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geological cross-section (s)</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Regional geological map</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Local geological map</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Map of the distribution of barrier rocks</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Lithological columns of standard boreholes</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Soil map</td>
<td>N</td>
<td>D</td>
</tr>
<tr>
<td>Description of lithology and structure of host rocks</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td><strong>Hydrostratigraphy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrostratigraphical cross-sections (in groundwater direction and perpendicular to it)</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Survey of existing wells and boreholes (hydrocensus)</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Map of hydrostratigraphical units (local)</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td><strong>Hydraulics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In situ testing of permeability of unsaturated zone</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>In situ (borehole) testing of permeability of saturated zone (down to at least 10m below groundwater table)</td>
<td>N</td>
<td>C</td>
</tr>
<tr>
<td>Effective porosity</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Investigation boreholes (including borehole logging)</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Piezometer installation</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Construction of contour map of groundwater heads</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Determination of groundwater flow rate</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Determination of groundwater velocity</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Calculation of water balance</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td><strong>Groundwater Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrochemical analysis of observation well water</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Measuring of physical properties (pH, Temperature etc.)</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td><strong>Other subsurface features</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inventory of mining activities in the vicinity</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Inventory of surface subsidence in the vicinity</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td><strong>Groundwater Monitoring</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring plan &quot;Water&quot;</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Installation of A-wells</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Installation of B-wells</td>
<td>N/D</td>
<td>C</td>
</tr>
<tr>
<td>Installation of C-wells</td>
<td>N</td>
<td>D</td>
</tr>
<tr>
<td>Installation of D-wells</td>
<td>N</td>
<td>D/C</td>
</tr>
<tr>
<td><strong>Surface Water Monitoring</strong> ...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey of all surface water bodies within 5 km radius</td>
<td>N/D</td>
<td>C</td>
</tr>
</tbody>
</table>

*Requirement: C: Compulsory, D: Discretionary - opinion to be given by DSWM, N: Not compulsory*

<table>
<thead>
<tr>
<th></th>
<th>description of conditions</th>
<th>potential impacts</th>
<th>measures to avoid impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soil</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>soil distribution</td>
<td>soil maps, geological maps</td>
<td>use of valuable soils</td>
<td>proper site selection</td>
</tr>
<tr>
<td>soil quality</td>
<td>soil maps, geological maps</td>
<td>particle emission via air or surface water transport</td>
<td>daily cover, compacted and grown over final cover, efficient drainage of surface water</td>
</tr>
<tr>
<td>soil contamination</td>
<td>soil databases at DGS, information on contaminated sites</td>
<td>cross-contamination of different sources</td>
<td>proper site selection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Surface Water</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distribution of surface water bodies</td>
<td>hydrological maps, topographic maps</td>
<td>emission of leachate into surface water bodies</td>
<td>proper site selection</td>
</tr>
<tr>
<td>quality of surface waters</td>
<td>reports on surface water quality, database at DWA</td>
<td>pollution of surface waters in the landfill vicinity</td>
<td>efficient drainage of surface water, separation of landfill water</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Groundwater</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>groundwater properties</td>
<td>hydrogeological maps and sections, hydrochemistry data at DGS and DWA</td>
<td>contamination of valuable groundwater resources</td>
<td>proper site selection on barrier rocks, avoidance of aquifers, capture of leachate and contaminated surface water, efficient liner system</td>
</tr>
<tr>
<td>groundwater protection</td>
<td>hydrogeological maps, distribution of well protection areas, vulnerability maps (infiltration capacity)</td>
<td>contamination of valuable groundwater resources</td>
<td>siting outside of well protection areas</td>
</tr>
</tbody>
</table>
4.2 GROUNDWATER MONITORING

4.2.1 Monitoring Objectives
The purpose of monitoring is to determine if the landfill in its various elements is functioning as planned or forecast and if contamination of groundwater has already occurred. Efforts must be made through the monitoring program to gain early recognition of failures or malfunctions of individual components of the safety systems such as liners or drainages. If these elements are not functioning as planned, options for intervention should be available. Thus, for example, individual wells of the monitoring system can be positioned and designed in such a way that they may be used as remediation wells.

The specific targets for groundwater monitoring at waste disposal sites can be summarised as follows:

- Determination if the landfill is indeed polluting the groundwater (Detection)
- Determination of the discharge rate of pollutants into the groundwater
- Determination of the rate and direction of propagation of the pollutant plume
- Observation of the concentrations of specific pollutants
- Early recognition of an unexpected change in the size or direction of the pollutant plume
- Early recognition of the penetration of the pollutant plume into a heretofore unaffected aquifer (seepage into intermediate dividing layers)

For each landfill now being operated and for each one planned, the formulation and establishment of a monitoring plan “water” for both groundwater and surface water is required. Since the hydrogeological situation can have various degrees of complexity, each landfill must be treated as an individual case.

This plan must be based on the overall hydrogeological situation occurring at the landfill site. It must be compiled by the facility operator. For this purpose, the operator will usually make use of specialised technical consultants that have appropriate experience in dealing with hydrogeological, hydroeconomic and engineering questions relevant to landfills. The plan is to be submitted through the licensing authorities to DSWM for review and evaluation and, if necessary, must be reworked by the applicant. The monitoring plan, after it has been reviewed and licensed, then becomes part of the facility license. Upon request all the established data is to be made available to DSWM both as raw data and in processed form.

4.2.2 Monitoring Concept
The basis of the development of the monitoring concept is the recognition that leachate first contaminates groundwater in the immediate vicinity of a landfill and that reference values must be available in order to assess the relevance of the measured hydrochemical concentrations. Therefore, a defined zonal monitoring is considered necessary in the first place. In the second place, all the elements for a logical chain of documentation must be present. The basic principles of the zonal landfill monitoring concept are explained in Figure 7 to Figure 9.

The hydrochemical characterisation of groundwater that flows to the landfill and is largely unaffected by the landfill, is generally determined upstream. In exceptional cases data can also be drawn from the lateral surroundings of the landfill or from regional groundwater reports.
Groundwater monitoring at landfills - Plain view

groundwater observation zones

landfill

T1

T2

T3

groundwater travel time

2 a

200 d

groundwater flow
4.2.3.1 Monitoring Wells
Wells are primarily used for groundwater monitoring. A well is a hydraulic structure which permits withdrawal of water from a water-bearing formation. Well construction for monitoring wells normally involves the installation of casings and screenings in drilled boreholes. The use of open uncased boreholes for monitoring purposes is not acceptable, because they would not allow the collection of representative samples.

The following arrangement types of wells are used for monitoring (Figure 10): single wells, well groups, multilevel wells.

Wells that screen a single vertical section of an aquifer (single wells) are the most commonly used installations for water abstraction. Single wells that screen a long section of aquifer guarantee that contamination occurring in the groundwater of this area will be discovered. However, long screen sections also have significant disadvantages. The vertical differentiation of pollutants in the groundwater that is often present will not be detected. Moreover, any highly contaminated sections that are narrowly limited can be strongly diluted by the large water volumes that are removed during sampling, and subsequent analysis will not reveal important pollutants because of the lowered concentrations. The use of single wells for groundwater monitoring at landfills is suitable in the following cases:

- When mixed groundwater samples are to be taken from thin aquifers. For this purpose, the wells should screen the entire thickness of the aquifer (complete wells).
- When the main purpose of monitoring is directed at the uppermost section of the groundwater body (early recognition of seepage into the unsaturated zone).

Well Groups are primarily used for differential vertical monitoring of the groundwater. Each well group consists of closely placed wells of very small diameter, each of which screens a separate borehole at a different depth. The screen lengths and depths can be carefully determined only if the hydrostatigraphy, the hydraulic relationships and the pollutant discharge situation are known in detail. Well Groups are particularly appropriate for B-wells, which are intended to assure early recognition of pollutant discharge as close as possible to the landfill.

Multilevel wells allow the separate collection of groundwater samples from very short screens within one borehole, but at different depths. The great advantage of these wells is that the vertical distribution of pollutants and of the properties of the groundwater body can be differentiated particularly well.

A great disadvantage of the designs is that no water level measurements can be made in the thin pipes that lead upward from each screen level. In addition, the withdrawal of sufficient amounts of water for comprehensive study is very difficult. Multilevel wells are particularly suitable for the detailed study of already existing contamination and are therefore used chiefly as B and C-wells. For Botswana conditions this well design might only be considered if a large general waste or a hazardous waste landfill is to be constructed.

### Table 4-2: Suggested number of monitoring wells (A- and B-wells)

<table>
<thead>
<tr>
<th>Landfill size class</th>
<th>Waste accumulation rate (annual)</th>
<th>Number of monitoring wells/ holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>G: L large</td>
<td>&gt; 65,000 t/a</td>
<td>3-6</td>
</tr>
<tr>
<td>G:M medium</td>
<td>&lt; 65000 t/a</td>
<td>1 - 3</td>
</tr>
<tr>
<td>G:S small</td>
<td>&lt; 6,500 t/a</td>
<td>0-2</td>
</tr>
<tr>
<td>G:R rural</td>
<td>&lt; 500 t/a</td>
<td>0 - 1</td>
</tr>
</tbody>
</table>
should be screened. When the upper water bearing unit is very thick, specific depth intervals must be screened individually.

4.2.3.2.5 Sealing Material
A clean and well seated scaling of the screen section against influences from above or from other sections of the well is of great importance in assuring representative and undistorted samples. Only a material that swells after it is installed (e.g. bentonite) is suitable for this purpose. Attention should also be paid to the imperviousness of the individual pipe/screen connections. In general, all the materials used in boreholes (lubricants, flushing additives etc.) should be recorded in the boring record and tested in advance for their suitability. The use of adhesives and lubricants containing oils and fats is to be avoided if at all possible.

4.2.3.2.6 Well Development
After boring, the mud adhering to the walls („mud cake“) must be removed mechanically or by jet flushing to allow water to enter the well freely. Monitoring wells must provide water free of suspensions, in order to avoid bias of analysis.

4.2.3.2.7 Well Security
Wells, to the extent that hydrogeological requirements do not strictly prevent this, should be installed in such a way that they are as accessible as possible by street vehicles on a paved surface, especially in unfavourable soil conditions. In the case of sites on private land, access rights should be established contractually. As protection against vandalism and damage by vehicles the well top should be marked clearly and extend far enough out of the ground to allow easy sampling. The top casing must be cemented and should be constructed out of rigid metal. Installation of a well protector, a larger diameter steel casing around the well head as such, equipped with a lockable cap is highly recommended. If the site is fenced and the monitoring wells are located within the fence the risk of damage is quite low.

4.3 SURFACE WATER MONITORING

Surface water monitoring is only required for permanent bodies of water or ephemeral streams which flow for more than six months in a year in the immediate vicinity of G:L and Sp landfill sites. This applies in particular to bodies of standing and flowing water that:

• function as receiving streams for the near-surface groundwater in the immediate area of the landfill or receive precipitation or leachate directly from the landfill.
• function as receiving streams for water-treatment plants belonging to the landfill or for direct runoff from the area of the landfill.
• are situated downstream of the groundwater and receive inflow from the (contaminated) groundwater.

The entry of pollutants from a landfill can quickly lead to impairment or damage to water bodies. The most frequent pollution mechanisms are direct discharges of leachate from the slopes of highlying landfills and the resulting runoff, as well as near-surface seepage from the intermediate soil runoff or from the groundwater.

In order to assess the requirements to surface water monitoring, all bodies of surface water situated within a radius of 5 km should be taken into consideration. Normally, regular monitoring of surface water can be confined to the areas near the landfill.

Figure 9 shows a typical example of the possible influence of a landfill on flowing water and the monitoring concepts. In monitoring water quality and runoff amounts, it should be noted that the effects of the landfill can be determined only for small and medium-sized bodies of water.
sealed surfaces
Landfill

\[ \text{treatment} \]
\[ \text{direction of groundwater flow} \]

\[ R_l \]
\[ R_o \]

\[ \text{Reservoir for landfill water} \]
\[ \text{Reservoir for water from operating areas} \]
\[ \text{Sampling point} \]
The landfill water is to be treated using common waste-water techniques. The water from the operating areas comes from paved and covered areas (roof surfaces, streets, parking areas). As a rule it has relatively little pollution it can be introduced directly into the receiving stream after mechanical clarification in sedimentation ponds, which also should have a retention function. The upstream runoff gauge should be situated as close as possible to the landfill. The position of the downstream gauge must be below the point where the landfill and operating water is introduced and below the direct area of inflow of the landfill. In particular, the local relationships between the ground and surface water are should be considered in making this placement.

4.4 MONITORING PARAMETERS

The monitoring parameters are selected primarily on the basis of the composition of the landfill content. Existing sources of anthropogenic pollution (agricultural activities, effects of contaminated industrial areas) and existing special geogenic conditions should also be taken into consideration. The standard parameters which should generally be analysed in connection with landfill monitoring are given in the „Landfill Guideline“. In individual cases it may be necessary to collect data on additional parameters.

An existing geogenic hydrochemical anomaly, including possible anthropogenic pollution, is determined through the analysis of the groundwater in the upstream well. Its location is therefore of critical importance for evaluating the measurement results. A graduated zonal program for parameter selection, corresponding to the zonal arrangement of monitoring points is suggested.

For landfills containing special waste, the basic parameters presented in the „Landfill Guideline“ are to be supplemented in individual cases with landfill-specific parameters after agreement with DWA. A corresponding agreement with DGS is necessary where there are unusual existing geogenic groundwater conditions.

4.5 MONITORING FREQUENCY

The frequency of monitoring should be seen in connection with the zonal monitoring arrangement of wells. The establishment of additional wells in the further monitoring zones and the intensification of monitoring (in terms parameters and frequency) should take place in stages as a reaction to recognised pollution. The frequency of biological inspections in surface water is calculated individually on the basis of site conditions. They should generally take place at least once a year. After the shutdown of landfill operations post-closure monitoring data should be collected for at least five more years. During this time the recultivation will usually have been concluded. After this time, data collection measures should be arranged on an individual basis in the long-term monitoring program proposed and approved by DSWM for each landfill.

When pollution has been detected and verified, the following monitoring should be performed at the next highest monitoring level of the routine plan. At the same time, consideration should be given to whether the existing groundwater monitoring network should be extended to an appropriately greater distance (the C-area) in order to track possible expansions of the contamination. The monitoring frequency for the C-wells should be arranged as a function of an existing contamination. Depending on the availability of verified data (repeated measurements), the findings should be evaluated and, if appropriate, technical measures be taken to minimise discharges.
4.6 DATA PRESENTATION AND EVALUATION

The operator is obliged to supply the analytical data provided by technical laboratories in the monitoring of leachate, groundwater and surface water to DSWM. DSWM will determine on an individual basis the type and frequency of analysis of the data obtained at the landfill. In most cases, the data on underground condition should be presented in the form of groundwater maps and contour lines. The physical, chemical and biological data that are obtained should be analysed in such a way that the specific effects of the landfill on the water balance may be determined in a detailed and clearly understood manner.

For the representation of parameter concentrations and their alteration over time, the usual graphic, statistical and tabular procedures are suitable. Concentration diagrams (e.g. area, column and square diagrams) are the usual methods of graphic representation. They should be supported by tabular analyses and the use of statistical procedures (e.g. trend analysis).

For the analysis of data on leachate and surface water, volume and load balances should be compiled, in addition to concentration values.

In order to establish the effect of a landfill on the groundwater, the upstream concentrations are usually compared to the downstream concentrations. In order to simplify the presentation, the calculation of contamination factors (the quotient of the concentration in the B and C-wells and in the upstream A-wells) has proven to be satisfactory for the principal landfill-specific parameters produced by the leachate analysis. If the contamination factors are high, the significance of the measured data should be checked in the individual case and compared with reference data (e.g. the drinking water regulations). The following indicator parameters for general waste should be taken into consideration:

- general landfills: DOC, COD, ammonium, potassium, iron, manganese, boron, AOX
- rubble landfills: Conductivity, ammonium, calcium, chloride, sulphate, (AOX)

If there are differences in concentration in the upstream and downstream samples in only one or a few parameters, a landfill effect may be indicated. However, it must first be verified whether other causes (e.g. agricultural effects) are not also in play. Only in the case of downstream increase of several landfill-specific parameters, it is possible to conclude with certainty that there is groundwater contamination caused by the landfill. A time delay in the appearance of increased concentrations of various parameters may be observed in a-well, depending on the retention capacity of the rock. Therefore, a landfill influence cannot be concluded with certainty as a result of the first occurrence of increased concentrations of one parameter.

The procedure of monitoring surface water can be analogous to that for groundwater. A comparison of concentrations of relevant parameters from upstream and downstream measurement stations can also be made through the use of contamination factors.

The analysis of monitoring data is to be presented by the operator to DSWM, compiled in an annual monitoring report and submitted for verification once a year, without DSWM having to request it.

4.7 QUALITY ASSURANCE

In general, sampling and analysis at landfills is carried out by the operator or its consultant, unless special regulations of DSWM provide to the contrary (self-monitoring). Regular outside auditing is arranged through the monitoring agency. Field blanks, standards and spiked samples should be analysed on a regular basis in order to assure laboratory efficiency. During sample storage and transport utmost care must be taken that no additional contaminations occurs. The chain of custody should be documented on a special form that goes with the sample all the way. For a sample for a chain of custody form see Appendix 2.
## BOTSWANA NATIONAL WATER BOREHOLE ARCHIVE

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HYDROGEOLOGICAL APPENDIX 2: Example of Chain of Custody Form for Landfill Monitoring in Botswana

LANDFILL SITE WATER MONITORING - BOTSWANA

CHAIN OF CUSTODY RECORD
(to be returned in copy to the operator)

Sampling Date Site Name

Well or Sampling Points

Sample Sets for Each: Inorganic, Organic, Both

Collector's Name Telephone

Date Sampled Time Started Time Completed

Field Information (Precautions, Number of Samples, Number of Sample Boxes, Weather etc.)

Chain of Possession (After samples are transported off-site or to laboratory):

1. Signature Designation (IN)
   Name printed date/time of receipt (OUT)

2. Signature Designation (IN)
   Name printed date/time of receipt (OUT)

3. Signature Designation (IN)
   Name printed date/time of receipt (OUT)

Analysis Information;

Aliquot Analysis Start Initials Analysis complete Initials
(Part of sample) date/time date/time

1. ...............................................................
2. ...............................................................
3. ...............................................................
4. ...............................................................

HYDROGEOLOGICAL ASPECTS OF WASTE DISPOSAL BY LANDFILL

Appendix 140 of Appendix

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The size of a landfill operation is dependent on the daily rate of waste deposition, which, in turn, depends, *inter alia*, on the size of the population served. In order, however, to take time and growth into account and to ensure that, from inception, the Guidelines apply to the ultimate size of a landfill operation, landfills are classified using the Maximum Annual Rate of Deposition (MARD). This is simply the projected maximum average annual rate of waste deposition, expressed in tonnes per annum, during the expected life of a landfill. Annual rates, rather than daily rates, are used because individual daily rates fluctuate widely and also because the number of working days per year can vary from site to site.

In order to calculate the MARD, the Initial Annual Rate of Deposition (IARD), must first be established. This is the measurement of the existing waste stream in tonnes per annum. Once established, the IARD is escalated at a rate which is usually based on the projected population growth for the estimated or design life of a landfill. The maximum annual rate of deposition, which usually occurs in the final year of the operation, then represents the MARD.

The LARD or existing waste stream can be calculated by applying *per capita* generation rates to the figures for the population served, making allowance for any wastes that are recovered and therefore not deposited at the landfill. It is necessary, however, to differentiate between household waste and industrial waste - the latter only arising in industrial areas. In general, the rates for generation of household waste vary with the socio-economic standing of the population, from 0.3 kg *per capita* per day in the low income areas, to 0.8 kg *per capita* per day in the more affluent areas. Industrial and construction wastes can increase the total generation rate to around 2 or more kg *per capita* per day. Discretion must be used in applying these factors to arrive at a single figure for annual tonnage or LARD.

The following formula provides the basis for calculating the MARD from the IARD. \[ \text{MARD} = (\text{IARD})(1+D)^t \]

Where (IARD)= Initial rate of deposition of refuse on site in tonnes p.a.
\( D = \) Expected annual development rate, based on expected population growth rate in the area served by the landfill together with any predicted growth in *per capita* generation
\( t = \) Years since deposition started at rate (IARD) \( (\text{MARD}) = \) Maximum rate of deposition after \( t \) years
APPENDIX 3 - E A Checklist

CHECKLIST OF DESIGN AND ENVIRONMENTAL CONSIDERATIONS

The following is intended to represent a general checklist, which is convenient when considering the Guidelines. The Responsible Person will, however, decide on items required for a particular site. 1.

Selection of landfill site

Access from refuse source
Availability of construction and cover materials
Buffer zones
Elevation relative to refuse source
Existing mineral rights
Geology, e.g. fault zones, seismic impact zones, dolomitic areas where subsidence is possible
Life of landfill site
Microclimate, exposure to wind, etc.
Pedology

Potential for:
Adequate cover material
Adequate screening
Agriculture Expansion
of system
Environmental reclamation or abandonment
Nature conservation
Industrial development
Ranching and grazing
Recreation
Reclamation of existing environmental damage
Silviculture
Urban development or human settlement
Use for other waste disposal

Proximity to:
Agriculture, ranching or silvicultural development
Airfields or landing strips
Existing or potential recreational areas
Existing or potential main transport routes
Existing or potential main utility routes
Existing or potential major surface water supplies, or aquifers
Existing surface or underground mine workings Historical, cultural or natural interest areas
Ground-water recharge areas
Recreational areas
Refuse generation area, i.e. economic radius
Urban development or human settlements
Seasonal and long term variations of hydrology
Scenic value of site
Sensitive ecology
Sub-surface hydrology and flow
Topography of site and area between site and refuse source
Underlying mineral resources
Unique natural resources: *Fauna, flora*, breeding grounds, etc.
Unique physical features: Archaeological or historical sites Unique cultural features: Religious association, etc. Visibility of site

2. **Geotechnical and hydrogeological exploration of landfill site**

Abandoned quarries
Abandoned underground workings
Abandoned utilities Anisotropy of soil
Aquifers - depth, yield, potential or actual exploitation
Artesian water
Cavernous dolomites
Collapsible soils
Depth to bedrock
Depth to water table
Dispersive soils Dykes
Erodability of soils Erosion channels or pipes
Expansive clays Faults
Filled areas
Ground water morphology and phreatic surface
Ground water quality
Ground water abstraction and use
Hard-pan layers (pedogenic horizons, e.g., calcrete and ferricrete)
*In situ* permeability of ground profile
*In situ* strength of soil
Mining - undermining rehabilitated opencast pits, potential for future mining
Seismic activity
Slaking mudstones or shales
Slickensided clays Soil profiles, rock profiles Soluble constituents in soils
Stratigraphy and lithology
Tailings and other mine waste deposits - presence, potential for exploitation
Tectonics, lineaments and structures
3. **Information for design of landfill** *Site-specific*

*Information:*
- Foundation and cover design data:
- Bedrock permeability
- Cation exchange capacity
- Coefficient of consolidation
- Compaction characteristics of *in situ* soil
- Compressibility or swell potential
- Dispersibility under influence of exchanged cations
- Effective stress strength parameters
- Erodability of compacted soil
- Ground water profile
- Ground water chemistry
- *In situ* horizontal and vertical permeability of soils'
- Permeability of compacted soil
- Stability of cut slopes
- Hydrological design data (annual and monthly):
  - Rainfall intensity and duration
  - Pan evaporation
  - Streamflow
  - Infiltration and run-off
  - Wind velocity and direction

*Information Relating to Closure or Possible After-Use of Site:*
- Agricultural land
- Game park
- Grazing land
- Playing fields (football, golf, etc.)
- Recreational site

4. **Possible adverse impacts to be eliminated or controlled by Design/Operation**
- Access
- Blowing litter
- Dust nuisance
- Fire hazard (and associated air pollution and danger to humans and animals)
- Gas generation and migration
- Interference with stream or spring flow
- Land sterilisation by siltation and/or salinisation
- Odour or smell
- Slope failures
- Soil erosion
- Visual intrusion
- Water pollution by leachate, erosion, siltation.

  *This should take into account the change in permeability that could result if leachate or some other liquid were used as the permeating fluid.*
APPENDIX 4 - G:V and G:S Landfills A summary,

CHECKLIST OF COMPULSORY GUIDELINES FOR G:V AND G:S LANDFILLS

Items marked * are at discretion of DSWM

G:V Landfills

Site Selection

Classify proposed site Eliminate unsuitable areas Identify candidate landfill sites Buffer zone
Minimum 5m unsaturated zone Site description Preliminary HGI* Preliminary EIA*
Identify problem areas Assess problem areas
Confirm no insurmountable problems Submit Planning Application (lAP's) Consult DSWM
Submit Licence Application (with further information as specified by the DSWM)

Site Investigation

Determine surface water quality* Assess importance of water sources (1 Ian) Wind direction
Test Pits*

G:V Landfills

Site Selection

Classify proposed site Eliminate unsuitable areas Identify candidate landfill sites Buffer zone
Minimum 5m unsaturated zone Feasibility Study Site description Preliminary HGI Preliminary EIA
Identify problem areas Assess problem areas
Confirm no insurmountable problems Submit Planning Application (AP's) Consult DSWM
Submit Licence Application (with further information as specified by the DSWM)

Site Investigation

Appoint Responsible Person Delineate physical area to be investigated Describe topography and surface drainage
Determine surface water quality Assess importance of water sources (1cm) Describe man-made features Wind direction
Existing vegetation Test pits One or more boreholes* Soil description* Stratigraphy and lithology*
Ground water morphology and flow* Ground water quality* Ground water usage Investigation of aquifers* Past and future mining and subsidence Hydrogeological report*
Appendices

G:V Landfills

Landfill Design
Appoint Responsible Person
Conceptual Design
Site layout
design
Fencing
Fire fighting equipment*
Surface hydrology and drainage*
Stability of slopes*
Notices

Landfill Construction
Compliance with Health and Safety Procedures

Landfill Operation
Waste acceptance procedure
Control of vehicle access
Part-time plant*
Responsible Person
Daily cover*
Three days' stockpile of cover*
Immediate covering of putrescibles
Final cover
Nuisance control
Draining water away from waste
Storm water diversion measures*
Grading cover/avoiding ponding
Sporadic leachate reporting
Windsock

G:S Landfills

Landfill Design
Appoint Responsible Person
Conceptual Design
Assess cover volume
Indicate unsaturated zone after excavation*
Determine available airspace
Estimate airspace utilisation and site life
Site layout
design
Fencing
Site office*
Notices
First aid equipment*
Fire fighting equipment*
Development Plan
Closure and Restoration Plan
Monitoring system*
End-use plan*
Technical Design
Surface hydrology and drainage*
Water quality monitoring system*
Stability of slopes*
Design Drawings and specifications

Landfill Construction
Compliance with Health and Safety procedures

Landfill Operation
Waste acceptance procedure
Control of vehicle access
Operating plan
Part-time plant*
Responsible Person
Full-time supervision*
Compaction of waste
Daily cover*
Three days' stockpile of cover*
Immediate covering of putrescibles
Final cover
Nuisance control
Permit/
Prohibition of burning*
Windsock
Draining water away from waste
Storm water diversion measures
Grading cover/avoiding ponding
Sporadic leachate reporting
G: V Landfills Landfill

**Monitoring**
Designate responsible person
Landfill site auditing* Records and data
Ongoing maintenance* 

**Record Keeping**
Static Records as available Weekly records of loads delivered Annual record of filling progress DSWM inspections 

**Restoration and Aftercare**
Investigate to determine closure requirements and identify impacts
Design for upgrade/restoration
Design final cover or capping
Design permanent storm water diversion
Inspection and Monitoring:
(i) Frequency - 12 months (iii) Drainage Integrity
(vii) Monitoring security and illegal dumping
(Water) Report Sporadic Leachate
Aftercare period* 
DSWM approves surrender of licence

G: S Landfills

**Landfill Monitoring**
Designate responsible person
Landfill site auditing* Records and data
Monitoring of progressive restoration
Ongoing maintenance 

**Record Keeping**
Static Records as available
Daily records of loads delivered* Weekly records of loads delivered
Annual record of filling progress
Volumetric Survey* Monitoring records* DSWM inspections

**Restoration and Aftercare**
Determine/reassess end-use requirements
Investigate to determine closure requirements and identify impacts
Confirmation of end-use by DSWM
Design for upgrade/restoration Design final shaping and landscaping Design final cover or capping
Design permanent storm water diversion
Design anti-erosion measures Closure Plan
Compare actual condition to required condition
Approval of Closure Plan by DSWM
Restoration and vegetation
Ongoing inspection and maintenance* 
Implementation of Closure Plan
Inspection and monitoring:
(i) Frequency - 6 months (ii) Cover integrity* (iii) Drainage integrity (iv) Control of ponding (v) Fire control (vi) Vegetation monitoring* (vii) Monitoring security and illegal dumping (water) Leachate* (water) Report Sporadic Leachate
Aftercare period* 
DSWM approves surrender of licence
The following is an example of a fictitious landfill licence, which has primarily been based on similar licenses in South Africa and abroad, and should be used to show the basic differences between a landfill licence and any other easily revocable licences such as a vehicle licence, trading licence, etc. To allow this example to be flexible, and where information needs to be inserted, or was not available at the time of drafting this document, it has been incorporated in italics between square brackets. Note that the actual length of the licence could be as short as a 3 page letter, or as long as a 200 page report, and depends on the waste characteristics, the site characteristics, and also on the detail supplied in the licence application.

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**APPENDIX 5 - LANDFILL LICENCE - EXAMPLE**

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**LANDFILL LICENCE ISSUED IN TERMS OF THE WASTE ACT [No.] OF [Year] SECTION [No.]**

By virtue of the powers delegated to me by the Minister [Minister responsible for the Waste Act], I, [name of person delegated with the responsibility of issuing the licence], in my capacity as [title / designation], hereby authorise [name of licence holder] to establish and operate the [name of landfill facility], subject to the conditions detailed below:
Appendices

 LICENCE CONDITIONS:

1 Location:
   1.1 In this section the exact location of the site is given according to Town and Regional Planning terminology. The surveyed boundaries of the site should be included.

2 Classification
   2.1 In this section the classification of the site is given (in this example General waste Medium landfill (G:M)).
   2.2 A description of permissible waste should be given (for example - only waste falling under the definition of General waste, and clinical waste which has been incinerated at a temperature $> 800^\circ$C for more than 1 second), and I or it could be by exclusion (for example - all wastes except those falling under the definition of wet waste and hazardous wastes)

3 Construction
   3.1 Construction shall be undertaken according to the construction drawings and specifications as submitted to the DSWM, reference [no. 007- refer to design report, tender document, specification, drawings, etc. submitted by the licence applicant]. The construction is to be undertaken under the [full-time /part time] supervision of the responsible person [name].
   3.2 The DSWM are to be notified in writing, prior to commencement of operation, of the intention to commence disposal operations. The site and construction records shall be inspected by the DSWM, for approval, within 30 days of such notification.
   3.3 Any further developments or extensions to the site are to be undertaken according to the conditions in clauses 3.1 and 3.2 above.
   3.4 According to the design the maximum height of the site shall be [5 m], and the side slopes no steeper than [1 vertical to 3 horizontal]
   3.5 Diversion drainage works are to be constructed to divert all runoff water flowing from areas adjacent to the site. The drains should be constructed to accept [the maximum discharge expected from a storm with a 1 in 50 year recurrence interval over a period • 24 hours]. The drainage from the site should not contravene the conditions of the Water Act.
   3.6 [any further construction requirements]

Access control

   4.1 Weatherproof signs, written in English and Setswana, indicating [Name of site, hours • operation, permissible wastes, name, address and emergency number of the licensee, and responsible person, and also indicating that unauthorised access is prohibited], are to be installed at the entrance to the site [and at strategic points along the access route to the site].
   4.2 [Fencing specifications] and [gate control procedures]
   4.3 [Maintenance of service roads]
   4.4 [any further access requirements]

5 Operation

   5.1 The landfill shall be operated according to the procedures indicated in the design report/ licence application, [alternatively, specify tipping procedure (height and width • cells, compaction), covering procedure, depth and frequency]
5.2 The plant operating on the site shall include a full time modified tractor (tractor with front blade) and occasional/part time bulldozer to excavate and stockpile soil for cover.

5.3 The staff on the site shall include a full time supervisor and 2 labourers with job descriptions as indicated in the licence application.

5.4 The landfill may not be operated between the hours of [20:00 and 07:00, this may be specified if the landfill is close to residential areas, and the noise from the landfill is intrusive]

5.5 [the landfill management are to hold bi-annual/quarterly meetings with representatives of the local residents to discuss concerns of the residents and methods of addressing these concerns - this may be specified if the landfill is close to residential areas]

5.6 The landfill manager will take all reasonable steps to ensure that nuisances or potential health hazards [for example odours, smoke, dust, litter, noise, rodents, flies, etc.] are minimised.

5.7 [any further operational requirements]

6 Monitoring

6.1 The groundwater quality monitoring holes shall be sampled [at a frequency and for the parameters indicated in the licence application] and the results submitted to the DSWM annually.

6.2 The site will be audited for compliance in terms of operation, health and safety, and environmental impact [annually], by an independent party, and the results of the audit submitted to the DSWM.

6.3 [Landfill gas emissions are to be sampled at a frequency and at locations specified in the licence application - note this will only be deemed necessary at sites where significant quantities of landfill gas are expected]

6.4 [any further monitoring requirements]

7 Closure and restoration

7.1 The landfill operator must notify the DSWM in writing within 60 days of intended closure of the landfill site.

7.2 Within 3 months of ceasing operations at the site, the entire surface of the landfill should be covered [according to the closure and restoration requirements in the licence application], so that rain water can freely run off without forming ponds.

7.3 The site will be restored according to the approved restoration plan.

7.4 [any further closure and restoration requirements]

8 General

8.1 This licence is not transferable

8.2 This licence should not be construed as exempting the licence holder from complying with any other applicable act, regulation or bye-law.

8.3 [any further requirements]
Appendix II

Section I
Categories of Wastes to be Controlled

Waste Streams
Y1 Clinical wastes from medical care in hospitals, medical centres and clinics
Y2 Wastes from the production and preparation of pharmaceutical products
Y3 Waste pharmaceuticals, drugs and medicines
Y4 Wastes from the production, formulation and use of biocides and phytopharmaceuticals
Y5 Wastes from the manufacture, formulation and use of wood preserving chemicals
Y6 Wastes from the production, formulation and use of organic solvents
Y7 Wastes from heat treatment and tempering operations containing cyanides
Y8 Waste oils/water, hydrocarbons/water mixtures, emulsions
Y10 Waste substances and articles containing or contaminated with polychlorinated biphenyls (PCBs) and/or polychlorinated terphenyls (PCTs) and/or polybromated biphenyls (PBBS)
Y11 Waste tarry residues arising from refining, distillation and any pyrolytic treatment
Y12 Wastes from production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish
Y13 Wastes from production, formulation and use of resins, latex, plasticizers, glues/adhesives
Y14 Waste chemical substances arising from research and development or teaching activities which are not identified and/or are new and whose effects on man and/or the environment are not known
Y15 Wastes of an explosive nature not subject to other legislation
Y16 Wastes from production, formulation and use of photographic chemicals and processing materials
Y17 Wastes resulting from surface treatment of metals and plastics
Y18 Residues arising from industrial waste disposal operations "Wastes having as constituents:
Y19 Metal carbonyls
Y20 Beryllium, beryllium compounds
Y21 Hexavalent chromium compounds
Y22 Copper compounds
Y23 Zinc compounds
Y24 Arsenic; arsenic compounds
Y25 Selenium; selenium compounds
### List of Hazardous Characteristics

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<tr>
<th>UN Class</th>
<th>Code Characteristics</th>
<th>Explosive</th>
<th>Flammable liquids</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H 1</td>
<td>An explosive substance or waste is a solid or liquid substance or waste (or mixture of substances or wastes) which is in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such speed as to cause damage to the surroundings.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>H3</td>
<td>The word “flammable” has the same meaning as &quot;inflammable.&quot; Flammable liquids are liquids, or mixtures of liquids, or liquids containing solids in solution or suspension (for example, paints, varnishes, lacquers, etc., but not including substances or wastes otherwise classified on account of their dangerous characteristics) which give off a flammable vapour at temperatures of not more than 60.5° C, closed-cup test, or not more than 65.6° C, open-cup test. (Since the results of open-cup tests and of closed cup tests are not strictly comparable and even individual results by the same test are often variable, regulations varying from the above figures to make allowance for such differences would be within the spirit of this definition.)</td>
<td></td>
</tr>
</tbody>
</table>

Corresponds to the hazard classification system included in the United Nations Recommendations on the Transport of Dangerous Goods (ST/SG/AC. 10/1 Rev.5, United Nations, New York, 1988)
### UN Class Code

<table>
<thead>
<tr>
<th>UN Class</th>
<th>Code</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>H4.1</td>
<td>Flammable solids&lt;br&gt;Solids, or waste solids, other than those classed as explosives, which under conditions encountered in transport are readily combustible, or may cause or contribute to fire through friction.</td>
</tr>
<tr>
<td>4.2</td>
<td>H4.2</td>
<td>Substances or wastes liable to spontaneous combustion&lt;br&gt;Substances or wastes which are liable to spontaneous heating under normal conditions encountered in transport, or to heating up on contact with air, and being then liable to catch fire.</td>
</tr>
<tr>
<td>4.3</td>
<td>H4.3</td>
<td>Flammable solids&lt;br&gt;Solids, or waste solids, other than those classed as explosives, which under conditions encountered in transport are readily combustible, or may cause or contribute to fire through friction.</td>
</tr>
<tr>
<td>5.1</td>
<td>H5.1</td>
<td>Substances or wastes which, while in themselves not necessarily combustible, may, generally by yielding oxygen cause, or contribute to, the combustion of other materials.</td>
</tr>
<tr>
<td>5.2</td>
<td>H5.2</td>
<td>Organic Peroxides&lt;br&gt;Organic substances or wastes which contain the bivalent-O-O- structure are thermally unstable substances which may undergo exothermic self-accelerating decomposition.</td>
</tr>
<tr>
<td>6.1</td>
<td>H6.1</td>
<td>Oxidizing&lt;br&gt;Substances or wastes which, in contact with water emit flammable gases</td>
</tr>
<tr>
<td>6.2</td>
<td>H6.2</td>
<td>Poisonous (Acute)&lt;br&gt;Substances or wastes liable either to cause death or serious injury or to harm health if swallowed or inhaled or by skin contact.</td>
</tr>
<tr>
<td>6.2</td>
<td>H6.2</td>
<td>Toxic (delayed or chronic)&lt;br&gt;Substances or wastes which, if they are inhaled or ingested or if they penetrate the skin, may involve delayed or chronic effects, including carcinogenicity.</td>
</tr>
<tr>
<td>8</td>
<td>H8</td>
<td>Corrosives&lt;br&gt;Substances or wastes which, by chemical action, will cause severe damage when in contact with living tissue, or, in the case of leakage, will materially damage, or even destroy, other goods or the means of transport; they may also cause other hazards</td>
</tr>
<tr>
<td>9</td>
<td>H10</td>
<td>Liberation of toxic gases in contact with air or water&lt;br&gt;Substances or wastes which, by interaction with air or water, are liable to give off toxic gases in dangerous quantities.</td>
</tr>
<tr>
<td>9</td>
<td>H11</td>
<td>Ecotoxic&lt;br&gt;Substances or wastes which if released present or may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems.</td>
</tr>
<tr>
<td>9</td>
<td>H12</td>
<td>Toxic (delayed or chronic)&lt;br&gt;Substances or wastes which, if they are inhaled or ingested or if they penetrate the skin, may involve delayed or chronic effects, including carcinogenicity.</td>
</tr>
</tbody>
</table>

### Characteristics

- Substances or wastes which, in contact with water emit flammable gases
- Flammable solids<br>Solids, or waste solids, other than those classed as explosives, which under conditions encountered in transport are readily combustible, or may cause or contribute to fire through friction.
- Oxidizing<br>Substances or wastes which, in contact with water emit flammable gases
- Chemicals which, by interaction with water, are liable to give off flammable gases in dangerous quantities.
- Organic Peroxides<br>Organic substances or wastes which contain the bivalent-O-O- structure are thermally unstable substances which may undergo exothermic self-accelerating decomposition.
- Poisonous (Acute)<br>Substances or wastes liable either to cause death or serious injury or to harm health if swallowed or inhaled or by skin contact.
- Toxic (delayed or chronic)<br>Substances or wastes which, if they are inhaled or ingested or if they penetrate the skin, may involve delayed or chronic effects, including carcinogenicity.
- Ecotoxic<br>Substances or wastes which if released present or may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems.
- Corrosives<br>Substances or wastes which, by chemical action, will cause severe damage when in contact with living tissue, or, in the case of leakage, will materially damage, or even destroy, other goods or the means of transport; they may also cause other hazards.
- Liberation of toxic gases in contact with air or water<br>Substances or wastes which, by interaction with air or water, are liable to give off toxic gases in dangerous quantities.
# LIST OF ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Compulsory</td>
</tr>
<tr>
<td>D</td>
<td>Discretionary - at the discretion of the DSWM</td>
</tr>
<tr>
<td>DAHP</td>
<td>Department of Animal Health and Production</td>
</tr>
<tr>
<td>DGS</td>
<td>Department of Geological Surveys</td>
</tr>
<tr>
<td>DSWM</td>
<td>Department of Sanitation and Waste Management</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EICR</td>
<td>Environmental Impact Control Report</td>
</tr>
<tr>
<td>G</td>
<td>General waste</td>
</tr>
<tr>
<td>G:L</td>
<td>General waste, large landfill</td>
</tr>
<tr>
<td>G:M</td>
<td>General waste, medium landfill</td>
</tr>
<tr>
<td>G:S</td>
<td>General waste, small landfill</td>
</tr>
<tr>
<td>G:V</td>
<td>General waste, very small landfill</td>
</tr>
<tr>
<td>HGI</td>
<td>Hydrogeological Investigation</td>
</tr>
<tr>
<td>HHW</td>
<td>Household hazardous waste</td>
</tr>
<tr>
<td>I</td>
<td>Inert waste</td>
</tr>
<tr>
<td>IAP</td>
<td>Interested and Affected Party</td>
</tr>
<tr>
<td>LSO</td>
<td>Live Stock Unit = 450kg</td>
</tr>
<tr>
<td>MARD</td>
<td>Maximum annual rate of deposition</td>
</tr>
<tr>
<td>N</td>
<td>Not required</td>
</tr>
<tr>
<td>NA</td>
<td>Not applicable</td>
</tr>
<tr>
<td>NCSA</td>
<td>National Conservation Strategy (Coordinating) Agency</td>
</tr>
<tr>
<td>PCB</td>
<td>Polychlorinated biphenyl - toxic substance found in old transformer oils</td>
</tr>
<tr>
<td>pEIA</td>
<td>Preliminary Environmental Impact Assessment</td>
</tr>
<tr>
<td>pHGI</td>
<td>Preliminary Hydrogeological Investigation</td>
</tr>
<tr>
<td>SABS</td>
<td>South African Bureau of Standards</td>
</tr>
<tr>
<td>Sp</td>
<td>Special waste</td>
</tr>
<tr>
<td>Sp:H</td>
<td>Special waste, hazardous wastes</td>
</tr>
<tr>
<td>Sp:W</td>
<td>Special waste, wet wastes</td>
</tr>
<tr>
<td>VDC</td>
<td>Village Development Committee</td>
</tr>
</tbody>
</table>
REFERENCES


Busch, K et al., Technical Guidelines for Groundwater Monitoring at Landfill Sites, DGS/BGR, Lobatse, November 1995

Weaver, J.M.C., Groundwater Sampling, RSA Water Research Commission Project No. 339 TT 54/92.


Tchobanoglous, G et al., Integrated Solid Waste Management - Engineering Principles and Management Issues, McGraw-Hill, 1993


Appendices

REFERENCES


Since the meaning of terms may vary in different contexts, the following list defines certain terminology as it is used in the context of this document.

**Aftercare**: Care of a landfill after closure, including monitoring and maintaining of cover integrity, subsidences, drainage systems, and, where appropriate gas and leachate management systems.

**Ambient background**: Ambient background water quality refers to surface water sampled upstream or ground water sampled upgradient of a landfill site. In both cases, these samples reflect water that has not been contaminated by leachate from the landfill.

**Aquifer**: Water-bearing strata of fractured or permeable rock, sand or gravel. When capable of sustaining community water or other needs, such strata may be considered to represent strategic water resources, requiring protection from pollution.

**Aquitard**: A geological unit that allows only minor or negligible amounts of water to be stored or to flow.

**Attenuation**: In this context, attenuation is the process of reducing leachate concentrations by means of natural physical, chemical and biochemical processes such as dilution, oxidation and cell synthesis. Natural systems have an attenuation capacity which may render small volumes of contaminants (leachate) insignificant. However, when this capacity is exceeded, pollution results.

**Bill of Quantities**: This is a list of the tasks involved and an estimation of the quantities of the materials needed for the construction of elements of the landfill design.

**Buffer zone**: A buffer zone is the separation between the boundary of a landfill site and residential development. It may vary between 500m and 1,000m in width, depending on the classification of the landfill. No residential development should be permitted within a buffer zone. At the discretion of the Planning Authority, however, industrial development may be permitted.

**Cell**: This is the basic landfill unit of compacted solid waste which, when completed at the end of each day, is entirely contained by cover material. The sides may be typically formed by 1.5m to 2.0m high soil or rubble berms, or sloped covered waste. Cell width is determined by the manoeuvring requirements of vehicles depositing waste at the working face. A cell will typically last for one to three months for low input sites but as little as one week at busier landfills.

**Closure**: The act of terminating the operation of a landfill. Closure is preceded by restoration and followed by end-use and post closure monitoring.

**Closure requirements**: Those measures that must be taken to address problem areas and to render a landfill environmentally acceptable once it is closed.

**Co-Disposal (General with Hazardous waste)**: The mixing and joint disposal of Hazardous waste (Sp:H) and General (G) waste in the same landfill. The co-disposal of general waste with Hazardous waste as a means of facilitating disposal on a Sp:H site is acceptable, whereas the co-disposal of any significant quantity of Hazardous waste with general waste on a G site is unacceptable.

**Co-Disposal (liquid with dry waste)**: The mixing of high moisture content or liquid waste with dry waste. This affects the water balance and is an acceptable practice on a Sp:W site, but is only acceptable on a G site that is equipped with leachate management measures and is confirmed as acceptable in the Licence conditions.

**Co-Disposal ratio**: This indicates the volumetric ratio of compacted solid waste to liquid waste. It may be about 9 parts solid waste to 1 part liquid waste.

**Compaction**: The process whereby the volume of waste is reduced, using a purpose built compactor or other suitable machine.
Appendices

Conceptual Design: A design that addresses the principles of the intended design, but does not include detailed specifications.

Containment: The separation of the waste body and any associated leachate from the underlying soil, rock and water regime, by means of a liner and a leachate collection system.

Contaminate: The addition of foreign matter to a natural system. This does not necessarily result in pollution, unless the attenuation capacity of the natural system is exceeded.

Controlled Burning: The burning of waste at a landfill site in a controlled manner in order to minimise its impact on public health and the environment. It may be undertaken in order to conserve landfill space, to reduce the attraction of the waste to vermin and livestock and to reduce the potential for leachate and gas generation.

Controlled Waste: All waste which falls under the jurisdiction and control of the Waste Act

Cover: The material used to cover waste. Cover material is usually soil, but may comprise builders’ rubble, ash or other suitable material. Daily cover is usually 150 mm thick, intermediate cover is usually 300 mm thick and final cover or capping is usually 300 mm thick. Final cover may form part of a special capping design and, as is the case with intermediate cover, must be able to support vegetation.

Detection monitoring: This is routine water monitoring carried out at specified intervals, using a limited number of indicator parameters, with a view to indicating pollution from the landfill.

Development Plan: A plan indicating the phasing of the development of a landfill from the landfill preparation, through the operation (which is usually divided into areal phases), to the final closure, restoration and end-use. The phasing, and hence the Development Plan, forms part of the design.

Duty of care: This requires that any person who generates, transports, treats or disposes of waste must ensure that there is no unauthorised transfer or escape of waste from his control. Such a person must retain documentation describing both the waste and any related transactions. In this way, he retains responsibility for the waste generated or handled.

Encapsulation: The procedure for disposing of Hazardous wastes not suitable for direct landfilling. This procedure involves the isolation of the wastes in sealed, reinforced concrete cells or capsules. The capsules are then located in a demarcated area of a SP class site.

End-use Plan: The purpose for which the area of the rehabilitated and closed landfill is used. This may be as a park, playing fields, or other suitable land-use.

End-use requirements: These are the measures required to upgrade or rehabilitate a landfill site to render it suitable for the proposed end-use.

Engineered containment cell: A cell which is designed and engineered to contain Hazardous waste. It is underlain by a liner to prevent the waste and any leachate from the waste from coming into contact with the environment. The leachate requires collection and subsequent treatment.

Environment: The associated cultural, social, soil, biotic, atmospheric, surface and ground water aspects associated with the landfill that are, or could potentially be, impacted upon by the landfill.

Environmental Impact Assessment (EIA): An investigation to determine the potential detrimental or beneficial impact on the surrounding communities, fauna, flora, water, soil and air, arising from the development or presence of a landfill.

Environmental Impact Control Report (EICR): A report which details how any detrimental impacts, identified in the Environmental Impact Assessment, can be prevented or ameliorated by means of landfill site design and operation.

Feasible: Acceptable, capable of being used or implemented successfully, without unacceptably damaging the environment.

Flexible Membrane Liner (FML): An impervious membrane made of plastic, rubber or bitumen compounds and designed to isolate waste from the environment.

GLOSSARY
G Landfill: A landfill designed to accept only general waste.

General waste: Waste that does not pose an immediate threat to man or the environment, i.e., household waste, builders' rubble, garden waste, dry industrial and commercial waste. It may, however, with decomposition, infiltration and percolation, produce leachate with an unacceptable pollution potential. (See Waste.)

Geomembranes: Very low permeability synthetic membrane liners and barriers used with any geotechnical engineering-related material so as to control fluid migrations in a man-made project, structure or system. Synthetic membranes include flexible membrane liners (FMLs).

Geotextile: A permeable, polymeric, woven, non-woven or knitted material used in geotechnical and civil engineering applications. A cloth or felt made of natural or synthetic fibres and designed to act as a drainage or filtration element.

Ground water: Water occupying pores in the soil and cavities and spaces in rocks. This water may rise from a deep, magmatic source or be due to the infiltration of rainfall (recharge).

Guideline: A standard by means of which environmentally acceptable waste disposal practices can be distinguished from environmentally unacceptable waste disposal practices.

Hazardous waste (Ref. Basel Convention Model National Legislation, January 1996): Substances or objects which are disposed of, or are intended to be disposed of, or are required to be disposed of, and which belong to any category contained in Section I of Appendix II, unless they do not possess any of the characteristics contained in Section II of Appendix II. (Sections I and II of Appendix II for the Basel Convention model law is reproduced in Appendix 6)

I Landfill: A landfill design to accept only inert waste

Inert Waste: Non-hazardous solid waste containing less than five percent of bio-degradable organic components.

Initial Annual Rate of Deposition (LARD): The initial waste stream or deposition rate for a landfill site, expressed in tonnes per annum. (See Maximum Annual Rate of Deposition.)

Interested and affected parties (IAP's): Interested and Affected Parties are those people who will be affected in some way by the development of the proposed landfill. They may be represented by adjacent residents or farmers, a whole residential community, or the public at large.

Investigative monitoring: Investigative water quality monitoring is monitoring which uses an extended range of parameters, in order to investigate any leachate pollution identified by Detection Monitoring.

Landfill (v): To dispose of waste on land, whether by use of waste to fill in excavations or by creation of a landform above grade, where the term "fill" is used in the engineering sense.

Landfill (n): The waste body created by landfilling. This may be above or below grade, or both.

Landfill development process: This is the development of a landfill from its inception or siting, through its investigation, design, licensing, preparation, construction, operation, closure and end-use. Monitoring takes place throughout the above process and may continue for up to 30 or more years after closure.

Landfill methods:

Area method: A method whereby non-putrescible waste is spread in layers not exceeding 0.5m in thickness. This method does not provide maximum compaction, but does have an application in certain industries.

End tipping: The practice of tipping or pushing waste over the edge of an extended slope and thus extending the landfill laterally. This is unacceptable in most operations, as little or no waste compaction is achieved. The resulting slopes are thus frequently unstable and subject to burning.
**Ramp method:** The practice of working waste up a 1 in 3 slope in thin layers not exceeding 0.5m in thickness. This is consistent with sanitary landfilling, using cells. Maximum compaction is achieved by passing over the waste at least five times with a purpose built landfill compactor.

**Trench method:** The practice of excavating a trench in virgin ground in which waste may be deposited. This method has the advantage that the excavation of the trench provides a supply of cover material. It also serves to contain the waste, prevent wind scatter and reduce visual intrusion.

**Landfill operation monitoring:** The auditing and assessing of a waste disposal operation to determine whether it conforms to the site design and to the Guidelines.

**Leachate:** An aqueous solution with a high pollution potential, arising when water is licensed to percolate through decomposing waste. It contains final and intermediate products of decomposition, various solutes and waste residues. It may also contain carcinogens and/or pathogens.

**Leachate management:** The collection and drainage of leachate to a point where it can be extracted for treatment. This requires a system of under-drains and liners and, in certain instances, is synonymous with containment.

**Licence:** The licence issued by the DSWM for the operation and/or closure of a landfill.

**Licensing:** The act of issuing a licence.

**Licence holder:** The person who, having obtained a licence to operate a waste disposal site, is legally responsible for the site, both during operation and after closure.

**Lift:** A series of adjoining cells of the same height, and at the same level, in a landfill.

**Lineament:** A long feature of the Earth's surface which may be structural or volcanic and may be related to movements involved in folding and faulting.

**Liner:** A layer of low permeability placed beneath a landfill and designed to direct leachate to a collection drain or sump, or to contain leachate. It may comprise natural materials, synthetic materials, or a combination thereof. (See also FML and Geomembrane.)

**Lithology:** The character of a rock expressed in terms of its mineral composition, its structure, grain size and arrangement of its component parts.

**Maximum Annual Rate of Deposition (MARD):** The projected maximum rate of waste deposition during the expected life of a landfill, expressed in tonnes per annum. (See **Initial Annual Rate of Deposition**.)

**Operating Plan:** A site-specific document which describes the way in which the landfill is operated. The Operating Plan commences at the level and detail of daily cell construction and continues through to the development and excavation sequence, access and drainage within a given phase of the Development Plan.

**Outflow rate:** The rate at which leachate will pass through a liner, taking account of the bead of leachate likely to accumulate over the liner. Outflow rate is measured in $\text{m}^3/\text{year}$, $\text{m}^2/\text{year}$ or $\text{m.}/\text{year}$.

**Permeability (primary):** The rate at which fluid will pass through a porous material under a unit flow gradient. The constant of proportionality $K$ in Darcy's Law is the permeability and is measured in $\text{m/year}$ or $\text{cm/sec}$.

**Permeability (secondary):** The rate at which fluid will pass through macro features of a soil, such as paleo-root canals, termite tunnels and rodent burrows, under unit flow gradient.

**Phreatic surface:** A surface defined by the levels at which the ground water will come to rest in a series of boreholes drilled in an area. The surface indicates the levels at which the pressure in the ground water is atmospheric.

**Pollute:** To add contaminants to a natural system, to the extent that its attenuation capacity is exceeded and it becomes significantly degraded.
Precautionary principle: Where a risk is unknown; the assumption of the worst case situation and the making of provision for such a situation.

Pre-disposal background: This is water quality monitoring which takes place before a landfill is commissioned and thus reflects the pollution status of the water regime prior to waste disposal. This monitoring includes upstream and downstream surface water, as well as upgradient and downgradient ground water. It may be used as a datum against which to compare all future water quality.

Restoration: The final process which restores completed portions of a landfill to an environmentally acceptable landform. Restoration should be undertaken progressively during the life of a landfill. It may precede or form part of Closure and precedes End-use. Restoration measures would include cover, topsoil, and the establishment of vegetation.

Response Action Plan: A plan intended to counter or minimise the adverse effects of any malfunction of a landfill design element with immediate effect. A Response Action Plan is usually associated with the disposal of Special: Hazardous waste.

Responsible person: A person(s) who takes professional responsibility for ensuring that all or some of the facets of any of the following are properly directed, guided and executed, in a professionally justifiable manner: investigatory work, design, preparation, operation, closure and monitoring.

Risk Assessment (in the context of these Guidelines): Assessment of the nature and probability of adverse consequences to public health or the environment resulting from dangerous substances contained in the waste, leached therefrom or released by emission entering into the air, the surface environment or the water regime.

Sanitary landfilling: A method of disposing of refuse on land without causing nuisances or hazards to public health or safety. Landfilling uses the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day’s operations or at such less frequent intervals as may be acceptable.

Septage: Pumpings from pit latrines, septic tanks, portable toilets, etc., which are pumped into a vacuum tanker for eventual disposal to land.

Sewage sludge: The greyish black thick sediment that has settled to the bottom of anaerobic, facultative or oxidation ponds in the treatment of sewage waste.

Shear Strength: The strength of soils and other geological features when submitted to shearing forces.

Significant: Factors or considerations are termed significant when they are important, because they are of consequence. For example, they will have a detectable influence on a process, the environment, or the end result.

Significant leachate generation: Seasonal or continuous leachate generation resulting mainly from climate and/or waste moisture content. In the case of existing landfills, significant leachate generation may also result from poor site selection and/or design. It is essential that significant leachate generation be managed by means of leachate collection and treatment if water pollution is to be avoided.

Special waste: Special waste is defined as waste that requires special treatment and/or disposal because of its properties and/or quantities. Special waste is divided into Hazardous and Wet wastes.

Sporadic leachate generation: Leachate generation resulting from abnormal circumstances, e.g., excessively wet periods, the temporary deposition of wet or saturated waste, or poor site drainage (where this can be remedied). Sporadic leachate generation is not considered to warrant the provision of a leachate management system.

Stratigraphy: The definition and description of stratified rock layers, their relationships and structure.
Technical Design: The Technical Design is based on the Conceptual Design. It includes detailed specifications of materials, measurements and procedures, as well as detailed drawings.

Tectonics: Study of the major structural features of the Earth's crust, especially in relation to movements involved in folding and faulting.

Unsaturated zone: The Unsaturated Zone is the portion of the soil or rock profile situated above the phreatic surface. In this zone the soil pores are filled with gas and water, as opposed to those in the saturated zone, where pores are filled with water.

Waste: (a) An undesirable or superfluous by-product,
(b) residue or remainder of any process or activity, (c) any gaseous (contained), liquid or solid matter, (d) or any combination thereof, which
   (i) is discarded by any person or
   (ii) is accumulated or stored by any person with the purpose of recycling, reusing or extracting a useable product from such matter.

Waste body: This refers to the body of waste (and cover) that is contained in the landfill. Because it is subject to decomposition, it has the potential to generate leachate and must therefore be adequately separated from the water regime.

Waste disposal (v): The act of disposing of waste. In the context of this document, only waste disposal on land is addressed.

Waste disposal site: The draft Waste Management Act defines a Waste Disposal Site as any facility used for the disposal of waste, normally a landfill, regardless of whether it has a licence. When a licence is granted, it becomes a Licensed Waste Management Facility.

Water balance: The balance of total inputs and outputs of water within the landfill system. Inputs may include precipitation, moisture inherent in the incoming waste, runoff from adjacent land, surface and ground water flows. Outputs may include evaporation, transpiration and leachate production. Water may also be stored within the landfill and augmented by water generated from biochemical reactions. Climatic Water Balance refers to a simplified calculation involving only figures for precipitation and pan evaporation. It is used only to indicate the climatic conditions under which leachate management is needed, on account of the generation of significant quantities of leachate.

Wet waste: Waste with a high moisture content, such as liquid wastes, sludges and some abattoir wastes.

Working face: The active part of the landfill; where waste is deposited by incoming vehicles, then spread and compacted on the sloped face of the cell by a compactor. The width of the working face is determined by manoeuvring requirements of the vehicles depositing waste.