



الضوابط والأدلة الفنية لتصميم وإنشاء وتشغيل المرادم

Technical Guidelines Design, Construction and Operation of Landfills

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LIST OF ACRONYMS

CQA	Construction Quality Assurance
DS	Dissolved Solids
GCL	Geosynthetic Clay Liner
GRI	Geosynthetics Research Institute
HDPE	High Density Polyethylene
K	Coefficient of Permeability
kPa	kilopascal
KSA	Kingdom of Saudi Arabia
LEL	Lower Explosive Limit
LLDPE	Linear Low-Density Polyethylene
LLS	Leak Location Survey
MSW	Municipal Solid Waste
MWAN	National Centre for Waste Management
NCEC	National Center of Environmental Compliance
PME	Presidency of Meteorology and Environment
SS	Suspended Solids
TS	Total Solids
TSD facility	Treatment, Storage and/or a Disposal facility
VS	Volatile Solids
v/v	volume to volume ratio

WAC	Waste Acceptance Criteria
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DEFINITIONS

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.

Backfill: Backfill is earth filling a trench or an excavation.

Biodegradable Waste: Any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and paperboard.

Borehole: A hole drilled as part of geotechnical investigation to collect soil and/or rock samples or in general to study the subsurface soils and for groundwater sampling and/or monitoring.

Bunds: Systems which contain waste in an embankment or secondary container to prevent the waste from travelling or escaping.

Cell: A waste cell is the basic structural unit of a landfill and is a clearly defined area that can facilitate incoming waste by eliminating the negative impacts on the environment and human health. Waste cells are formed by spreading and compacting incoming wastes in layers within a daily defined area. Individual daily waste cells must be compacted and placed as landfill develops and always following the filling plan to maximize the capacity.

Cell (Daily): This is the basic landfill unit of compacted solid waste which, when completed at the end of each day, is entirely capped by cover material. Cell width is determined by the manoeuvring requirements of vehicles depositing waste at the working face.

Closure: The act of terminating the operation of a landfill. Closure is preceded by remediation measures and followed by closure and aftercare monitoring.

Compaction: The process of increasing the density (densification) and hence the improvement of soil shearing strength and permeability characteristics by use of mechanical means such as rolling or vibration.

Competent Authority: The government entity responsible for operationally managing waste in accordance with a special regulatory provision.

Composite Liner: An assembled structure of geosynthetic materials and low permeability earth materials (clay or bentonite), placed beneath a landfill to form a barrier against the migration of leachate into the underlying soils and groundwater.

Conceptual Design: A design that addresses the principles of the intended design but does not include detailed specifications.

Cover: The layer used to cover waste for final closure. Cover layers may consist of both natural and artificial materials aiming to minimize landfill's impacts on the environment after closure. Final cover should be able to support vegetation if climatic conditions allow it to.

Cover (Daily): Daily cover is usually 0.15 – 0.20 m thick and consists of on-site soils or similar material obtained from nearby sources.

Dumpsite (or Open Dump): Any landfill failing to satisfy the requirements and criteria set in the current document is considered as a dumpsite or open dump. Any not engineered waste disposal site is considered as a Dumpsite or Open Dump.

Fault: A fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side.

Filling Plan: A plan indicating the phasing of the development of a landfill from the landfill preparation, through the operation (which is usually divided into area-based phases), to the final closure, rehabilitation and end-use. The phasing, and hence the Filling Plan, forms part of the design.

Floodplain: The lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands.

Gas collection system: All installations and equipment through which the landfill gas flows, from the waste body to the gas extraction well and transfer pipework during the operational and aftercare period.

Landfill gas: All the gases generated from the landfilled waste.

Geomembranes: Very low permeability synthetic membrane liners and barriers used with any geotechnical engineering-related material to control fluid migrations in a man-made project, structure, or system.

Geosynthetic Clay Liner: A manufactured composite barrier system comprising of layers of clay materials (e.g., bentonite) and geosynthetic materials (e.g., geotextiles and/or geomembranes) to form a single sheet for use as a liner.

Geotextile: A permeable, polymeric, woven, non-woven 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.

Hazardous Waste Classification: Classifying waste as waste with properties that make it potentially dangerous or harmful to human health or the environment. Hazardous waste can be liquid, solid, semi-solid or contained gases. A waste can be classified as hazardous if:

- i. It displays one or more of the hazardous properties listed in Annex 1 of the Law;
- ii. Wastes containing polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF), DDT (1,1,1-trichloro-2,2-bis (4-chlorophenylethane), chlordane, hexachlorocyclohexanes (including lindane), dieldrin, endrin, heptachlor, hexachlorobenzene, chlordecone, aldrine, pentachlorobenzene, mirex, toxaphene hexabromobiphenyl and/or PCB exceeding the concentration limits indicated in Article 6 of the Stockholm Convention ratified by the Kingdom;
- iii. Any waste identified as hazardous as per the Environmental Law; or
- iv. Waste classified as hazardous under any convention ratified by the Kingdom.

Inert waste: Waste that does not undergo any significant physical, chemical, or biological transformation. Inert waste will not dissolve, burn, or otherwise physically or chemically react, biodegrade, or adversely affect other matter that it comes into contact with, in a way likely to cause environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and not endanger the quality of surface water or groundwater.

Lagoon: A lagoon is a lined structure constructed to contain leachate.

Landfill: An engineered waste disposal site, comprising all established and recognized engineered control methods to protect the environment (air, water, groundwater, soil, ecological settings, etc.) for the deposit of the waste onto or into land (i.e., underground).

Landfill Operator: A Service Provider who operates a landfill.

Landfill Operation Monitoring: The auditing and assessing of a waste disposal operation to determine whether it conforms to the site design.

Leachate: Any liquid percolating through the deposited waste and emitted from or contained within the landfill.

Leachate Collection System: All installations where the leachate is collected at the bottom of the waste and transported to the installation of the transport / treatment.

Leakage Detection System: A system for detecting leachate mitigation at landfills.

Leachate Management: The collection and drainage of leachate to a point where it can be extracted for storage or further treatment. This requires a system of under-drains and liners.

Licence: A written permission issued by the Centre for the purpose of carrying out any activity related to waste management in accordance with the controls determined by the Law and Regulation.

Lift: A series of adjoining cells of the same height, and at the same level, in a landfill.

Liner: A layer of low permeability material 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.

Monitoring: Is the process to control on a regular basis if there is a negative impact to the environment from operations taking place inside the landfill site. The main areas of monitoring in a landfill site are leachate, gas, groundwater, surface water and settlements. This may be achieved by compiling successive audit or water quality analyses results.

Municipal Solid Waste: Includes Residential Waste, which is Waste resulting from the usual activity of households, whether or not they are collected mixed or separately, and also includes Commercial and Administrative Waste, which is Waste that is produced from other sources that are similar in nature and composition to Residential Waste.

Permeability: The rate per unit area 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 m/year, m/sec, or cm/sec, which is synonymous to hydraulic conductivity.

Permit: A document granted by the Centre to waste recycling facilities attesting that they fulfil the Centre's Controls and Requirements before they obtain the licences issued by the competent authorities in accordance with their Regulations. The Permit is issued by MWAN for the operation or closure of a landfill, in terms of the Law.

Permitting: The act of issuing a Permit.

Rehabilitation: The restoration of a landfill site to a state which is publicly and environmentally acceptable.

Remediation: The rectification of problems, caused by bad practices, through the implementation of remedial measures.

Risk: A risk is measured by the likelihood (probability) of an event occurring and the consequences (impact) it may have. In the context of a landfill this may be defined as a measure of the probability of dangerous substances contained in the waste, leached from, or released by emission, and resulting impact to the environment and human health by entering the air, the surface environment or the water regime in unacceptable quantities or concentrations. The consequences of such occurrences could be considered as a threat to public health and/or the environment.

Risk Assessment: The assessment of potential risks by considering their likelihood (probability) of occurrence and consequences (impact) on the environment and human health caused by a landfill. The identification and assessment of potential risks provides the opportunity to address those impacts in the design.

Seismic impact zone An area with a ten percent or greater probability that the maximum horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed $0.10g$ in 250 years.

Settlement: The downward movement of foundations of a structure or parts of a structure due to the applied loading causing compression of the soil.

Shear strength: The shear strength of a soil (or waste) is the sum of the frictional resistance between the soil grains (or particles of waste) and the cohesion imparted by the finer fractions (clay and silty).

Site Specific Factors: Factors peculiar to a specific site that must be taken into consideration when designing and constructing a landfill.

Sludge Waste, which is any of the following:

- a. Residual sludge from sewage plants treating domestic or urban wastewaters and from other sewage plants treating waste waters of a composition similar to domestic and urban waste waters;
- b. Residual sludge from septic tanks and other similar installations for the treatment of sewage.
- c. Any other residual sludge from sewage treatment plants or septic tanks or other similar arrangement that are similar to wastewater treatment.

Standard: A measure by which the accuracy of quality of others or degree of excellence is judged, or a model for imitation. (Not used in legal sense).

Surface water: Water (usually rainfall) which flows across the ground surface towards and in manmade and natural drainage features such as drains, rivers, streams, lakes, and ponds.

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.

Transportation: Transporting waste by approved means of transportation to transfer stations, treatment or sorting facilities, or approved landfills.

Treatment: It means the use of physical, biological or chemical means, or a combination of these means, or others to bring about a change in the specifications of waste in order to reduce its volume, or facilitate the processes of treating it when reusing or recycling, or extracting some products from it or to remove organic pollutants and others in order to reduce or utilize some of the waste components or eliminate the possibility of harm to humans or the environment.

Unstable area: A location that is susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all the landfill structural components responsible for preventing releases from a landfill. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and Karst terranes.

Waste: All materials that are discarded or disposed of, and that directly or indirectly affect public health or the environment.

Waste Producer: Every person who produces classified waste according to the provisions of the Law.

Waste Management: Organizing any activity or practice related to waste commencing from waste collection, transportation, sorting, storage, treatment, recycling, import, export, and safe disposal, including aftercare at waste disposal sites.

Waste Body/Mass: This refers to the body or mass of waste (and cover) that is contained in the landfill. Because it is subject to decomposition, it has the potential to generate leachate and gas and must therefore be adequately separated from the water inflow.

Waste Disposal (v): The act of disposing of waste.

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.

Working Plan: A site-specific document which describes the way in which the landfill is operated. The Working 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 Filling Plan.

1 Purpose, Scope, and Exemptions

1.1 Purpose

The purpose of this Technical Guideline is to establish a strict operational and technical framework for waste landfilling in the Kingdom of Saudi Arabia (KSA), to prevent as much as possible, the negative impact on the environment and human health, generated from landfilling of waste, throughout the life cycle of a landfill, in accordance with the provisions of the Waste Management Law and the associated Implementing Regulations.

This document is intended to provide a guideline for those involved in the design, construction, operation, monitoring, permitting, and licencing of Landfills in the Kingdom of Saudi Arabia, to:

- Implement the best practice requirements with respect to landfill design, construction, operation, monitoring, site closure and aftercare.
- Identify and determine all requirements for developing new landfill sites of different classes related to different types of waste, according to international best practices and latest available technologies; and
- Provide a sustainable closure and aftercare plan upon completion of landfill operations.

1.2 Scope

This Guideline applies to all landfills to be designed and / or that are currently in the design process. The types of waste disposed in landfills are presented in the Technical Guidelines of Waste Acceptance Criteria (WAC). However, existing Landfill Operators should, as best as they can, implement all relevant requirements contained in this Technical Guideline.

The provisions of this Technical Guideline are addressed to all involved parties in the design, construction, operation, monitoring, and licencing of landfills namely:

- The National Centre for Waste Management;
- The environmental protection Competent authorities;
- Public administration;
- Design and construction companies involved in landfill projects; and
- Landfill operators.

1.3 Exemptions

The current Technical Guideline does not apply to the:

- Management of radioactive waste;
- Management of liquid waste (except landfill leachate);
- Spreading of sludges, including sewage sludges and sludges from dredging operations for the purposes of fertilisation or land improvement; and
- Remediation of existing dumpsites /open dumps.

The current Technical Guideline may apply specific exemptions set by the National Centre of Waste Management.

2 Legal requirements

The Technical Guideline on Landfills complements the information provided by the Waste Management Law and the corresponding Implementing Regulations, with a more step-by-step approach to guide users through the technical requirements for landfills. For legal requirements on waste classification, however, users should consult both the WML and the IR, particularly the following provisions:

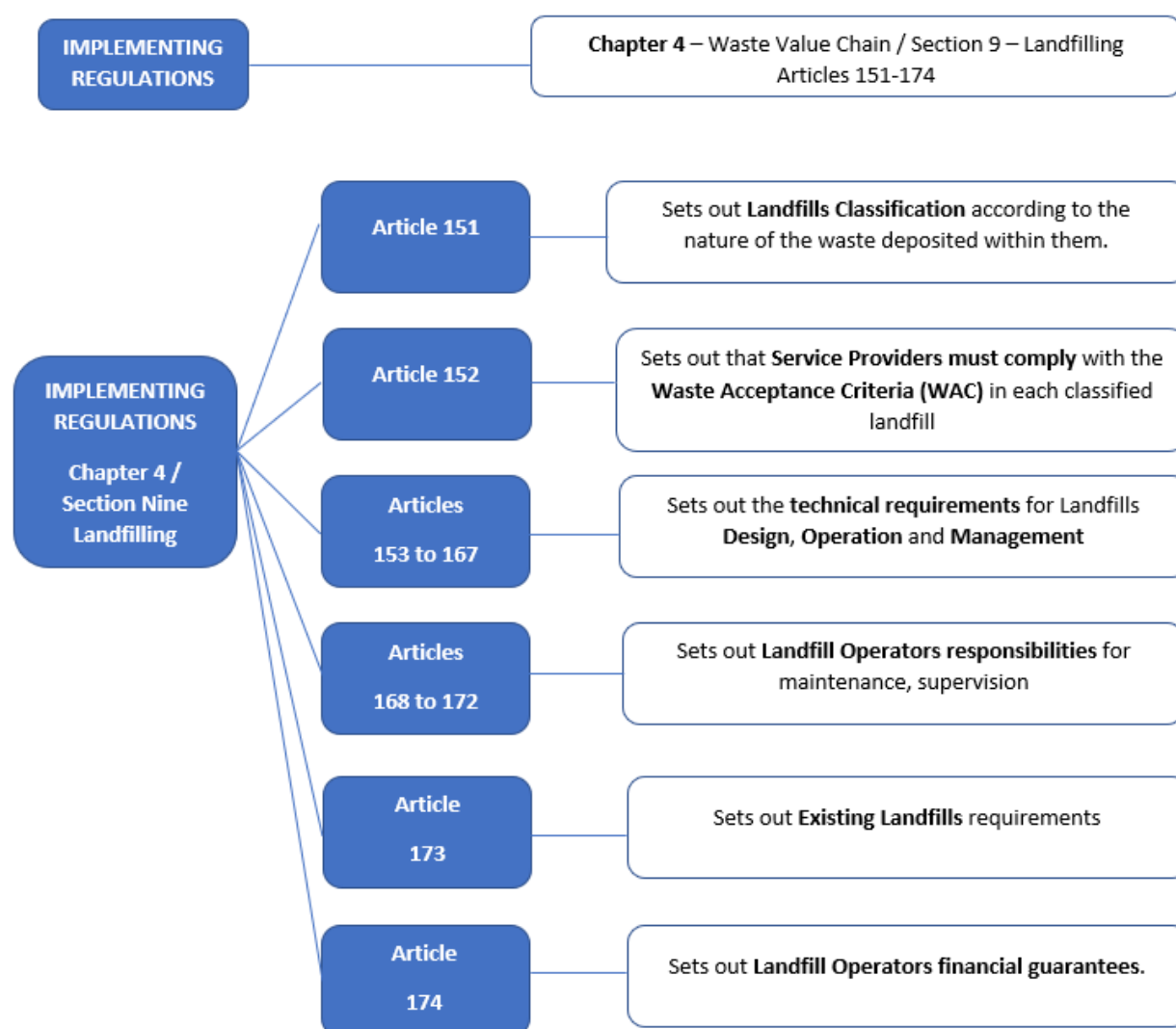


Figure 2-1: Overview of the main provisions from the legal requirements on licensing and permitting.

3 Roles and Responsibilities

3.1 Roles and Responsibilities

National Centre for Waste Management (MWAN)

The Centre aims to regulate and supervise waste management activities, stimulate investment in it, and improve its quality based on the principle of circular economy in waste management to achieve sustainable development goals. MWAN issues the licences and permits in accordance with the approved forms after fulfilling the conditions and requirements in accordance with the mechanism determined in relevant regulations and the specific requirements and technical controls issued by the MWAN.

No activity related to wastes, such as wastes collection, sorting, storing, treatment, recycling, import, export, and safe disposal thereof, including the aftercare of disposal site, shall be undertaken without obtaining the proper licence or permit out of the licences and permits set out in the Regulations of National Centre for Waste Management.

Competent Authority for Environmental Protection:

The Competent Authority together with the Centre, are supervising and controls the Landfill Operator and may:

- i) enter the premises for carrying out any investigation,
- ii) carry out such inspections, measurements and tests on premises entered, articles or records found on any such premises, and take away such samples of waste or articles, as may be considered appropriate for the purpose of enabling such investigation or
- iii) at any reasonable time require any relevant party to supply him with copies of, or of extracts from, any records kept for the purpose of demonstrating compliance with the landfill design standards.

Landfill Operator:

A Landfill Operator shall be responsible for the maintenance, supervision, monitoring, and post-closure control of the landfill site according to the relevant licence and/or other permits required by the Laws of KSA.

The Landfill Operator shall carry out the monitoring procedures on the Landfill after its closure for a period specified by the MWAN, and such period may be extended if the post-closure monitoring program finds that the landfill is not yet stable and poses potential environmental and/or health and safety risks.

The Landfill Operator shall promptly notify the Competent Authority for environmental protection of significant adverse effects on the environment and comply with the decision of the competent authority for environmental protection on remedial measures imposed in the post-closure period.

The MWAN shall determine the financial guarantees a Landfill Operator must provide to guarantee the fulfilment of their obligations.

4 Landfill Classification

4.1 Landfill Classes

The classification of landfills is based on the type of waste they are permitted to accept. Requirements differ regarding the type of incoming waste as the potential to harm the environment and human health differs. Each landfill must be classified in one of the following Classes:

Class 1 Landfills - Hazardous Landfills.

Hazardous Landfills which may only accept hazardous wastes which satisfy site specific acceptance criteria.

Class 2 Landfills - Non-Hazardous Landfills.

Non-Hazardous Landfills which may accept any wastes which are non-hazardous including municipal solid waste, non-hazardous industrial waste, stable non-reactive hazardous wastes, and others as demonstrated through appropriate investigation and risk assessment.

Sludges may be accepted for disposal only in Class 2 Landfills, and only if the following requirements are met:

- Non-hazardous waste other than household waste such as sludge should be disposed of only in Class 2 landfills;
- Disposed sludge is mixed with household waste in a ratio of 1:10 (1 part of sludge is mixed with 10 parts of household waste prior to disposal); and
- Sewage sludge can have a maximum humidity of 65%.

Class 3 Landfills - Inert Landfills.

Inert Landfills which may only accept waste which is known to be inert.

The type of waste to be disposed into the abovementioned Landfill Classes **must be in line with the Technical Guideline on Waste Acceptance Criteria (W.A.C)** developed for MWAN. All incoming types of waste must fulfil all criteria set in the relevant W.A.C. Technical Guideline.

5 General Requirements for all Landfill Classes

5.1 Introduction

The following paragraphs outline the main requirements to design a Landfill classified in any Class, including specific requirements for cell design, landfill liners, leachate management system, gas management, system, capping system, stability, environmental monitoring, and Construction Quality Assurance (CQA).

Articles (151) to Article (174) from Section Nine: Landfilling of the Implementing Regulations of the Waste Management Law must also be considered in Landfill design.

Moreover, guidelines related to special requirements for each Class, site infrastructure requirements, operation, record keeping, and site closure and aftercare are provided.

The design of a landfill shall include the following information as a minimum:

- The nature, origin, and quantities of the waste to be disposed of;
- The findings of relevant studies (as determined by the MWAN according to its discretion);
- Method utilised to seal the bottom of the landfill including protection of the sealing system and the drainage, collection, treatment, and discharge of the leachate;
- The system for the collection, storage, and recovery of landfill gas, as appropriate, or the system for the controlled combustion of landfill gas;
- Technical organization of the landfill (e.g., number of cells, administrative building, reception, parking, weighbridge, wheel washing, primary and secondary access roads, etc) and utilities;
- Infrastructure (i.e., road networks, utilities, etc); and
- Landfill control and monitoring system.

The following requirements are generic for all landfill Classes. Moreover, the expansion of existing Landfills of any Class, must meet the requirements and procedures set in the current document.

Expansion of existing Landfills must follow the exact same requirements, standards and procedures as set for new Landfills and in accordance with the content of the current document.

Where risk assessments reports and investigations identify that a lesser standard is required, for example for landfill Class 3 (Inert Landfills), then this justification will be considered during the Authorisation Process.

5.2 Location

The location of any Landfill facility must take under consideration the following criteria:

(Note: The Centre may provide exemption from some of these conditions depending on the nature of the project).

(1) Geological, hydrological, and socio-economic criteria:

- a. The characteristics and succession of geological layers;
- b. The risk of flooding, settlements and/or landslides on the site;
- c. The structure (physico-chemical and bacteriological characteristics), depth and direction of groundwater flow;
- d. The current and future land uses, their economic, financial, and social value for the population in the area;
- e. Avoidance of sites with very steep slopes; and

- f. Suitable backfilling soil must be adequate and in proximity to be used as a cover material or if suitable to be used as an impermeable sealing layer.
- (2) Climatic criteria:
 - a. The dominant direction of the winds in relation to the human settlements or other receptors; and
 - b. Anticipated precipitation.
- (3) Economic criteria:
 - a. The site should be able to accommodate the anticipated capacity of the facility;
 - b. The distance from source of production / collection of generated waste; and
 - c. The available infrastructure in the area (access roads, utilities).
- (4) Environmental criteria:
 - a. Distance from environmental and ecological settings;
 - b. Distance from sensitive receptors;
 - c. Distance from flora and fauna;
 - d. Risks of biodiversity loss due to the activities performed;
 - e. Distance from valleys, reefs, flood streams, beaches, bodies of water and water sources;
 - f. Avoidance of areas where the groundwater table is located close to surface; and
 - g. Avoidance of sabkhas.
- (5) Other criteria:
 - a. The distance from the boundary of the site to residential and recreational areas, waterways, water bodies and other agricultural or urban sites;
 - b. Site visibility;
 - c. Public acceptance;
 - d. Topography on the area;
 - e. Distance from utilities, electrical power lines, railways, airports, military facilities pipelines, and highways;
 - f. Availability of infrastructure and roads to the location and the impact of the facility on traffic in the area;
 - g. Distance from historical sites and nature reserves; and
 - h. Any other controls or requirements the Centre issues.

Table 5-1: Recommended main distances from Landfill site boundaries (Classes 1 to 3)

CATEGORY	DISTANCE
Aviation runways	≥ 3,5 km
Sensitive receptors such as recreation areas, residential properties, and associated community establishments (schools, hospitals, etc)	≥ 1,0 km
Coastal water resources	≥ 1,0 km
Agricultural areas	≥ 100 m
Pipelines and highways	≥ 30 m
Surface water	≥ 100 m
Inhabited buildings or structures	≥ 500 m

Landfills should not be developed on the following sites:

- a. Sites adjacent to planned land for development purposes such as urban, commercial, and agricultural expansion areas;
- b. Sites located in valleys, coastlines, and flood streams, where the treatment and disposal of waste may expose the water to contamination, because of leakage of fluids to the ground;
- c. Sites with high groundwater and/or geology which does not inhibit potential contaminants from entering groundwater, especially in areas where this water is used for agriculture or drinking or is considered a protected area;
- d. Sites on very steep locations;
- e. Sites on historical archaeological or natural areas or environmental reserves;
- f. Areas adjacent to airports and subject to the classification of the General Authority of Civil Aviation;
- g. Sites located in floodplains, wetlands, fault areas, seismic impact zones or unstable areas; and
- h. Any other area deemed by the competent authorities as invalid for the establishment of a facility for the treatment and disposal of waste.

Moreover, the location for the development of a new Landfill must consider and comply to the Site Location Criteria mentioned in Articles (95) to Article (98) of the Implementing Regulations of the Waste Management Law.

A new landfill site location may be approved by MWAN only when the site's characteristics are in accordance with the abovementioned requirements or corrective measures are foreseen such that the new landfill will not pose a serious environmental risk. A site selection study (part of the EIA procedure) should be undertaken to establish the most suitable location for a new landfill considering all of the above components.

5.3 Site Design Considerations

All new landfill sites (of all Classes) must be designed with the least possible impact on local environment and, where possible, they must blend in with the surroundings. Site factors which affect landfill design include (but are not limited to) the following:

- Local topography;
- Size and shape of the property area;
- Subsurface geological and hydrogeological conditions;
- Surrounding land use;
- Local availability of cover materials;
- Local ecological aspects;
- Seismic considerations;
- Access to the site; and
- Existence of public infrastructure (electricity, drinking water, sewerage network, roads etc.), or buffer zones.

5.4 Site Layout

Landfills and associated infrastructures must be designed to:

- Minimise potential environmental impacts;
- Minimise health and safety risks for landfill personnel and public;
- Comply with all relevant regulations and laws throughout its lifetime;
- Use onsite resources efficiently; and
- Meet the targets set and fulfil its purpose.

To assist meeting the requirements set along with the abovementioned considerations, a detailed site layout plan must be provided to MWAN as part of the site's Working Plan prior to the development of a landfill.

The detailed site layout will provide evidence that key concerns have been identified and addressed accordingly, prior to the initiation of construction works. Some considerations for the site layout include the following (with further details provided in Section 6):

- A manned gatehouse, along with weighbridge and wheel wash facility should be located at the entrance to the site in order to control incoming waste vehicles;
- A waiting area should be located near to the entrance to avoid traffic congestion; and
- A sampling area should be located near to the site entrance in order to allow for validation of the incoming waste type and potentially block entry for incorrect waste streams.

5.5 Soil and Groundwater Protection

All landfills must be designed to meet the necessary conditions for preventing pollution of soil and groundwater and ensure that efficient protection from generated leachate is provided.

Protection of soil and groundwater is achieved through the implementation of a suitable landfill basal lining and capping system prior to operations and after closure respectively (as defined in Section 7).

5.6 Surface Water and Leachate Management

Sufficient measures must be taken, with respect to the characteristics of the landfill and local climate conditions, to:

- Reduce and control water precipitation from entering the landfill body;
- Manage rainwater effectively without potential hazards to the landfill (such as flooding incidents);
- Prevent contaminated water entering the surface water drainage system;
- Collect any contaminated water;
- Transfer collected leachate to a leachate storage infrastructure for further treatment; and
- Treatment (via evaporation or any other suitable technology) of contaminated water and leachate from the landfill to an appropriate standard required for discharge or otherwise transport collected leachate to an authorized wastewater treatment facility with the approval of the Competent Authority.

Discharge of leachate or contaminated water to a receptor is forbidden unless the standards set for discharge are met and this is proven by laboratory analyses conducted by a certified laboratory and approved by the Competent Authority.

A suitable groundwater, surface water and leachate monitoring system will be installed to increase control measures against potential risks.

5.7 Gas Control

Appropriate measures shall be implemented to control the accumulation and migration of landfill gas at any gas generating landfill sites (this is a requirement for MSW Class 2 Landfills, and subject to project specific requirements for all other landfill types).

Landfill gas should be initially extracted by either a passive or active extraction system and then treated and utilised if feasible. If the quantity and quality of collected gas cannot be used for energy production, it must then be flared to a suitable flare unit installed on site. Passive venting shall be permitted only in the event that the risks of gas emissions and migration are considered low through a suitable risk assessment study.

The extraction, collection, treatment, and use of landfill gas shall be carried in a manner which minimises risks and hazards for the environment and public health. Further details on gas control are provided in Section 7.4.

5.8 Nuisances and Hazards

Measures shall be taken to minimise nuisances and hazards arising from construction and operation of a landfill such as:

- Emission of odours and dust;
- Wind-blown material particles;
- Noise and traffic;
- Birds, vermin, and insects;
- Aerosol formation; and
- Fires, explosions, and landslides.

During construction and operation, control measures must also be taken so that litter/waste originating from the site is not dispersed onto public roads and the surrounding land.

5.9 Stability

Design and construction of a landfill waste cell and embankments for facilitating infrastructure and roads must be thoroughly analysed in terms of stability with relevant calculations included in a geotechnical report that should accompany the design study. In addition, the stability of the waste body and lining systems should be suitably analysed. Details of such analysis are provided in Section 7.6.

5.10 Risk Assessment

For all landfill Classes, risk assessment studies may be carried out in all stages: design, construction, and operation as well as in closure and aftercare stages, considering site engineering, lining system, leachate, and gas management systems (if present), capping system, stability, and monitoring systems and ensure that both short (construction and operation) and long term (closure and aftercare) criteria are met. A risk assessment study must identify and evaluate all risks by measuring impacts and the likelihood of them occurring. Mitigation measures and strategies should be implemented to reduce and address these risks.

The outcome of the risk assessment studies, after implementing suitable mitigation measures, should identify the following:

- Emissions to groundwater, surface water and the surrounding environment are minimised to an acceptable level;
- The environmental protection systems such as liners, leachate management, gas management, capping and monitoring system and treatment at the site are suitable and sufficient for their purpose;
- Stability of the landfill and all structures within the site is verified; and
- There is no risk to environment and public health.

The Competent Authorities can request risk assessment studies at any stage and in case of any potential concern or unknowns relative to certain or all components mentioned above.

6 Site Infrastructure Requirements for all Landfill Classes

6.1 Access and Internal Roads

6.1.1 Access Roads Network

Local road infrastructure must be able to sustain the operation of a landfill or upgraded accordingly to meet all safety regulations for users. Landfilling requires the transportation of waste via various types of waste vehicles causing an increase on traffic load.

The road network capacity of both main and secondary access roads must be thoroughly examined to be in line with road safety regulations and minimize the disturbance during landfill operational hours to the local community.

The proposed transportation route to the landfill from different sources of waste or other treatment facilities must consider the minimization of transporting waste through residential and other sensitive areas.

The main access road must be a two-lane, asphalt paved road complying with local regulatory requirements considering the class of vehicle entering the site.

Road signage and markings must be included in design and construction phases to increase safety for on-site personnel and visitors.

6.1.2 Internal Roads Network

An internal road network must be constructed to provide access to all facilities and infrastructure within the site. The internal road network should be designed considering local site conditions such as:

- Traffic volume (high or low);
- Condition of existing road network (paved or unpaved road); and
- Landfill Class (Class III – Inert Waste Landfill may require only unpaved roads).

The internal road network can be either paved or unpaved, one or two lane and may include a main access road, a cell perimeter road, temporary roads inside the waste cell and access ramps to the bottom of the cell. All roads shall be designed in accordance with local regulatory requirements considering the class of vehicle entering the site and the type of road (i.e., temporary, or permanent, main access or maintenance access, etc.).

Temporary roads will be required as the working face within the waste cell changes for operational reasons. All temporary roads should be constructed on the landfill with locally available materials to improve traction, such as compacted soils (such as cover material), gravel, crushed stone or crushed inert wastes from construction and demolition activities if available on site.

Road serviceability may be improved through the addition of cement, or asphalt binders where required.

At start of operations, inside the waste cell basin, an internal route should be designed providing access to the working face where disposal operations will take place. The internal route should be constructed according to waste filling plan and following basin's geometry. The minimum thickness of the temporary internal route should be 0.50 m (after compaction) and the suggested minimum width should be 4.0 m.

Access ramps are included into temporary roads network and will provide access to cell basin and internal routes. The maximum longitudinal slope of access ramps should not be greater than 8.0 %.

Internal roads should also include road signage to increase safety for on-site personnel and visitors.

6.2 Stormwater Drainage

Management of stormwater on landfill sites is a key element, as water from precipitation can be a major risk factor with direct negative effects upon the operations of a landfill through:

- Direct interference with ongoing site operations (flood incidents); and
- Contribution to leachate generation.

Stormwater must be collected and discharged through the construction of a water drainage system. Water within the landfill site is categorized into three main categories:

- Clean Surface Water (no waste contact);
- Contaminated Surface Water (superficial waste contact i.e., wastewater from washing trucks etc); and
- Leachate (water which percolates through the waste body and is collected by the Leachate Collection System).

Stormwater to be collected and discharged into a receptor must not have any direct interference with waste at any stage of the collection process, ensuring that collected stormwater returns to the water cycle uncontaminated.

The design of a stormwater drainage system should be considered during the pre-development stage to assist optimising the utilisation of stormwater and minimise impacts of uncontrolled water ingress.

The location of a waste cell might be determined by the local morphology and waters basins. The main targets for design and construction of a stormwater drainage system are the following:

- Preventing the inflow of water to the landfill body, thereby reducing leachate production;
- Diverting the inflow of water outside the landfill, thereby protecting its structural stability;
- Protecting the infrastructures and internal roads of the site from water erosion;
- Providing safe driving conditions for all users;
- Minimizing impacts on downstream surface water management networks; and
- Reducing pollutants in water runoff aiming to protect water quality.

The stormwater drainage system may consist of (but not be limited to) the following:

- Drainage layer (natural or geocomposite) in the Landfill Capping;
- Ditches or trenches in the perimeter of the Landfill Cell;
- Ditches or trenches on the bunds and berms inside Landfill Cell;
- Ditches or trenches on the bunds and berms outside Landfill Cell in both excavated and backfilled areas;
- Ditches or trenches and road gutters at the internal roads;
- Culverts to connect ditches and divert collected water;
- Concrete wells and manholes;
- Pipes (concrete or preferably HDPE);
- Reinforced concrete headwalls at road crossings;
- Channels either concrete or formulated (trapezoidal);
- Down chutes at the capping layer (temporary or final); and

- Suitable shaping of the ground around the landfill cell.

To protect the waste cell from incoming stormwater from surrounding areas, a ditch or trench is constructed around its perimeter to discharge and prevent stormwater becoming leachate. Another reason for constructing a ditch or a trench around the cell perimeter is to avoid overloading the disposal site during filling operations, with stormwater falling into the basin.

Due to the low anticipated precipitation volumes in many parts of KSA, sufficient stormwater management may be established through the implementation of suitable surface shaping and perimeter bunds/berms of the landfill.

Moreover, it should be noted that a vital element of the stormwater collection and discharge system is that all surfaces should be sloped towards the nearest water drainage structure (ditch, trench, channel, etc.) and prevent water retention in hollows of the ground that could affect the stability of the cell.

To optimize operations and reduce leachate generation, it is recommended to apply suitable shaping to the temporary covering layer of the daily cell, so that the stormwater can be diverted away from the active landfill cell. For this purpose, it is recommended that the upper surface of the temporary filling of the cells has a minimum slope of 2-3%, to assist surface runoff.

Stormwater which comes into direct contact with waste on the site must be collected and then diverted to the leachate or other suitable storage infrastructure of sufficient capacity where further treatment, evaporation or other method may be applied as required.

Leachate storage infrastructure and other stormwater drainage system structures must be designed to contain and control stormwater runoff for a 1-in-50-year storm event for all landfill Classes.

6.3 Infrastructures and Utilities

It is important that all utilities and networks such as electricity, water supply, sanitation, cooling and heating, communications, fire protection, lighting, and lightning protection are installed at all landfill sites increasing safety measures for all on-site personnel and provide everything required for the operations taking place at a landfill site.

The minimum required structures for all landfills are the following:

- Gate and fencing;
- Weighbridge facility;
- Reception building;
- Waiting area for incoming waste vehicles;
- Sampling & unacceptable load quarantine area;
- Administrative building;
- Parking areas;
- Maintenance building;
- Wheel washing facility;
- Water supply and distribution;
- Fuel station;
- Stockpiling areas;
- Energy distribution and outdoor lighting;

- Leachate storage/treatment infrastructure (Class 1 and 2 Landfills only);
- Roads; and
- Fire protection zone and firefighting network.

6.3.1 Main Entrance/Exit Gate

All Landfill sites must be fully fenced, and one main entrance and exit gate must be constructed.

The entrance gate will be of the same height as the fence (not less than 2.0 m), equipped with either automated or manual closure system while the length of the gate will be no less than 7.0 m. The main entrance gate/exits must be located close to the Guard House / Weighbridge building.

At the main gate a sign with the main information of the landfill site should be placed (landfill operator, class of landfill, working hours, emergency contact details, etc.).

6.3.2 Fencing

A fence (or elevated earth berm in case of remote and inaccessible areas) must be constructed around the perimeter of the landfill to:

- Reduce onsite trespassing;
- Hinder the access to the disposal area of various animals;
- Set the boundaries of the site;
- Provide a control to air blown litter; and
- Protect from uncontrolled disposal of waste.

Fence should have a minimum height of 2.0 m constructed in the entire perimeter of the site.

Fences with increased height may be required on downwind boundaries of the site, to limit litter blowing off the site, especially where there are potentially sensitive land uses downwind of the site. Alternatively, portable fences of minimum height of 3.0 m, should be placed near to and downwind of the open landfill working face to control and limit the windblown litter.

6.3.3 Waiting Area for Incoming Waste Vehicles

Inside the landfill site and in proximity to the Guard House / Weighbridge building, a waiting area for all waste trucks and vehicles must be provided to avoid traffic congestion during the weigh process of the vehicles.

The required area and number of parking places depends on the predicted incoming traffic volume and must be designed accordingly.

6.3.4 Weighbridge Facility

A weighbridge facility must be constructed close to the entrance gate and next to the Guard House / Weighbridge building where the weighbridge registration equipment is installed.

The weighbridge should be calibrated in accordance with manufacturer specifications at least annually and confirm the accuracy of records. It must always be maintained according to manufacturer instructions. A logbook of weighbridge inspections and certifications must be maintained by the landfill operator and be available when requested.

Depending on the size of the landfill and the incoming traffic volume of waste one (1) or two (2) weighbridges shall be installed for controlling and monitoring incoming and outgoing waste disposal vehicles.

In case two weighbridges are installed, one should be located at the entrance lane and the other at the exit lane of the landfill site. When only one weighbridge is available at the site then it should be placed in a suitable location with all necessary traffic regulations so that waste vehicles can be weighed when entering and exiting the site.

Weighbridge minimum capacity should be no less than 60 tons and the dimensions should be no less than 15.0 m (length) x 3.0 m (width). The weighbridge can also be mobile or removable if all standards and specifications are complied.

6.3.5 Guard House / Weighbridge Building

The Guard House and Weighbridge building is constructed close to the main entrance/exit gate of the landfill and next to the weighbridge facility.

The building must have large window openings on at least three out of four sides to allow for adequate supervision of the entrance/exit area. For operational reasons it is also suggested that the building be elevated from ground level so that the weighbridge operator and waste truck drivers can exchange all necessary documentation without the need for exiting their vehicle, thereby increasing safety and speed of the weighing process.

The Guard House / Weighbridge building should include the following rooms/spaces:

- A control room where the external weighing terminal for registration of all necessary data and information is installed;
- A toilet for working personnel; and
- A storage room where safety and firefighting equipment is stored.

Moreover, for the inspection of incoming loads it is suggested that the Guard House / Weighbridge building should also include:

- A viewing platform to allow viewing of the contents of incoming waste trucks; and
- Elevated mirrors or CCTV cameras which can be used to scrutinise incoming loads.

6.3.6 Sampling and Unacceptable Load Quarantine Area

On all landfill sites, a sampling and unacceptable load area for examination of incoming waste must be constructed.

The area will be fenced, and the surface must be covered with non-absorbent and resistant to corrosion asphalt concrete layer, to avoid any leakage/contamination during sampling process.

At the perimeter of the sampling and unacceptable load quarantine area, concrete channels must be constructed to collect any leachate drainage during the sampling process and through this collection network to a collection tank or leachate pond/lagoon.

If any unacceptable load is found, then the Landfill Operator is responsible to prevent access to the landfill and direct the load off-site.

6.3.7 Administrative Building

The Administrative Building is foreseen to cover the administration needs of the landfill facility. Indicatively, it may consist of the following spaces:

- Offices;
- Meeting room;
- First aid room;
- Laboratory;
- Utilities Area-Generator (if the site is not connected to public power network);
- Warehouse;
- Dressing rooms and personnel toilets;
- Visitors' toilets; and
- Kitchen/Rest Area for personnel.

The abovementioned building should be located close to the entrance area. It should be mentioned that both the size of the administrative building and the numbers of rooms/facilities included, differs for each site, and depends on the number of personnel.

6.3.8 Parking Areas for On-site Waste Vehicles

The operational waste vehicles of the landfill facility will be parked in either covered parking spaces in close range to landfill cell or next to / within a maintenance building if there is space availability.

To avoid any damages to the asphalt paved roads, it is suggested that any heavy-duty machine should be parked in separate parking space at either a widening on the perimeter of the landfill cell or on a temporary road.

6.3.9 Parking Areas for Personnel and Visitors

The vehicles of both personnel and visitors of the landfill site will be parked in either covered or open parking bays in close proximity to the administrative and maintenance building.

6.3.10 Maintenance Building

The Maintenance building should cover most of the urgent maintenance needs of a landfill facility to prevent any suspension of operations. Indicatively, it may consist of the following areas:

- Maintenance main area;
- Onsite vehicles and machineries washing area;
- Storage area; and
- Toilets for personnel.

The building can be constructed with either a metal frame or a reinforced concrete and must have heavy-duty industrial flooring, non-absorbent and resistant to heavy loads and corrosion by mineral oils and other lubricating chemicals.

In the middle of the building, a stair trench should be constructed for access to inspect, maintain, and repair operational vehicles. Above the trench and with an appropriate height, a lifting mechanism with a capacity of at least 3.0 tons should be placed.

Inside the building there will be storage space for spare parts, other consumable materials deemed essential for the safe operation of the facility and a sanitation area for the personnel.

Moreover, a dedicated space for washing all vehicles and machineries operating at the landfill site should be included. This area must have a separate collection network with channels in the perimeter to collect all generated wastewater and lead then to a separate collection tank or to connect with the leachate collection system.

Entrance to the building is provided through an electronically or manually operated industrial safety roller with indicative dimensions to allow the entrance of all different types of waste vehicles operating in landfill.

To ensure adequate natural lighting of rooms, windows should be installed on all building sides. The size of the maintenance building should be relevant to the vehicles and machinery on site.

6.3.11 Wheel Washing System

All landfills should have constructed or installed a wheel washing system for all waste vehicles exiting the site. The purpose of the wheel washing system is to wash the wheels and tires of the waste collection vehicles from the contaminants of the landfill. It is suggested to be located in a widening of the internal access road of the landfill, near the entrance area in the exit direction lane.

Such an area would require constant water supply and should consist of two subsystems:

- Washing subsystem equipped with:
 - Movement monitoring system which starts the operation of the system;
 - Washing water nozzles;
 - Heavy duty grating for the collection of wastewaters;
 - Feeding pump for the washing water;
 - Filter; and
 - Piping with necessary valves.
- Water recycling and sludge removal subsystem equipped with:
 - separation of solids – clean water tank;
 - weir of clean water overflowing into the clean water tank; and
 - excess sludge removal piping with isolation valve and hydraulic equipment.

The wheel washing system is suggested to be equipped with water nozzles, to create water pressure jets with appropriate pressure for the washing of wheels and tyres.

The wastewater generated from the wheel washing area must be collected in a separate tank or be sent directly to the leachate treatment/storage infrastructure on site and must not be discharged to the surface water drainage system.

6.3.12 Water Tank

Regarding the size, class and water needs of each landfill one or more water tanks should be installed to cover the following needs:

- Firefighting; and
- Water supply.

The capacity of the water tank(s) must be adequate to cover both firefighting and water supply needs and is suggested to either use different water tanks for firefighting and water supply needs or use different chambers within the same water tank so that there is always water availability for firefighting events. There must also be available space next to the water tank for all required installations and equipment.

In case there is an existing water supply network in the vicinity of the Landfill, then the availability to connect directly to it should be examined.

It is recommended that landfill sites located close to environmental, cultural protected areas or in general sensitive areas, the water tank should be connected to a firefighting network (i.e., fire hydrants) which should be extended across the whole site.

6.3.13 Fuel Station

A fuel station may be provided to supply fuel to all operating waste vehicles and on-site machinery.

The fuel station must be in an area where there is no immediate threat in an event of leakage and should be a safe distance from landfill operations. Access to the fuel station should be easy and if possible, in proximity to the entrance area.

The fuel station tank must have enough capacity to fuel all operating machineries and vehicles so that the site will operate without interruption. The fuel tank along with an electric fuel pump may have the following (indicative) main characteristics:

- Volume ~5.000 liters (min. volume);
- Double wall tank;
- Electric fuel pump;
- Fuel supply pistol with safety flap; and
- Ground stand.

6.3.14 Stockpiling Areas

One or more stockpiling areas must be available at the landfill site for the provision of daily temporary cover material and to be used as a firefighting measure in case of emergency.

The stockpiling areas must be easily accessible and in close proximity to the operations taking place at landfill waste cell. It must also be ensured that there is always availability of cover material for both operational and safety reasons.

6.3.15 Lighting Network

A lighting network should only be constructed in large landfill sites (serving major population centers of >500,000 people) where a high traffic volume of waste vehicles is anticipated and working hours extend until after sunset. The internal access road to the landfill cell and infrastructure should have suitable lighting installed to provide visibility and safety to all drivers using it.

The lighting network at all other landfills should only include lighting of facilities and entrance area for operational and security reasons. Other lighting may be provided subject to site / operational requirements.

6.3.16 Fire Protection Zone and Firefighting Network

All landfill sites located close to environmental or cultural protected areas, industrial zones, or any other sensitive areas should include a fire protection buffer zone around the perimeter of the landfill with a minimum width of 8.0 m if local site topography allows it.

Within this zone no vegetation or infrastructure should be constructed to avoid the spreading of a possible fire incident inside the site and provide access area and routes for the fire trucks.

Only in the case of large landfills sites (serving major population centers of >500,000 people) in sensitive areas, a firefighting network (including fire hydrants i.e.) should be developed to cover the whole site and facilities. The firefighting network will be connected to the water tank, which must be monitored to always be full of water in case of emergency.

7 Landfill Design Guidelines

7.1 Cell Design

All landfills are developed as a series of waste cells. A waste cell is the basic structural unit of a landfill and is a clearly defined area that can facilitate incoming waste by eliminating the negative impacts on the environment and human health.

Waste cells are formed by spreading and compacting incoming wastes in layers within a daily defined area. Individual daily waste cells must be compacted and placed as a landfill develops and always following the filling plan to maximize the capacity.

Designing a landfill waste cell, must include:

- The formation of appropriate slopes which will ensure on the one hand the required stability of the structure and placement/retention of the liners and capping systems that will be used, and on the other hand the capacity of the landfill;
- The configuration of excavations so that the resulting formulation of the cell's basin will serve the operation of the leachate collection network; and
- Finally, an important role prior to the construction of the landfill's lining works is the configuration of the final surface which will emerge after all required excavations and will be the basis of the liners (sealing and drainage) layers.

The maximum recommended value for a landfill cell's internal slopes is 1(V):3(H) (vertical: horizontal), although slopes of lesser gradient are preferred as maximum compaction is achieved when the angle of the working face is close to horizontal level. The external slopes of the landfill cell that extend to existing ground, should also have maximum recommended slopes of 1(V):3(H).

Depending on factors such as local morphology, available area, site shape, required volume capacity and proximity to sensitive areas (i.e., water bodies) the above-mentioned suggested slopes are subject to change when a geotechnical report (including a stability analysis) justifies both the need for selecting steeper slopes and the stability (for structure, waste mass, liners, and capping).

In seismically active areas the maximum final slopes should also be 1(V):3(H) and the final design of the landfill cell must be accompanied by a geotechnical report (stability analysis calculation of both the embankments and the interfaces of lining and capping materials) taking into consideration seismic impacts.

Other important factors that must be taken into consideration when designing a landfill cell are:

- Earthworks balance;
- Groundwater level on site;
- Cell basin that promotes easy leachate collection;
- Provision of access to the basin; and
- Presence of public networks (i.e., electricity, pipelines) and buffer zones.

The daily waste cell dimensions differ and are selected respectively every time to fit the daily incoming waste quantity and to suit site operations. The operating working face must have an inclination not exceeding 1(V):3(H) while the upper surface should be inclined directing the rainwater in the opposite direction with a minimum gradient of 1.50 %.

A series of adjoining waste cells developed over the landfill at the same height constitutes a 'lift' and their depth typically ranges between 2 m to 4 m. At the end of every working day the disposed waste must be compacted

and covered with a soil layer of locally sourced cover material of approximately 0.15 m thickness (the operating working face boundary should be included within this layer).

Dimensions of a daily cell are affected by the following criteria:

- The quantity of daily waste accepted;
- Daily cover requirements;
- Slope stability;
- Compaction ratio; and
- Shape of landfill cell.

The cell design is the most vital part of the landfill and all above mentioned considerations should be implemented into the earliest stages of the overall design to avoid problems that may occur in the future.

Special provision must be given in the design of Class I Landfills (Hazardous Waste Landfills) regarding the compatibility of wastes disposed into the same cell. The type of waste to be disposed must be thoroughly examined prior to any landfilling process, since in the event of non-compatible wastes the effects on the environment, human health and even the integrity of the cell structure might be severe.

Class I Landfills should include design and construction/operation of different cells according to the disposed wastes compatibility.

7.2 Landfill Basal Lining System

7.2.1 Introduction

A landfill lining system should be designed and constructed in such a way:

- a. To minimize and as far as possible eliminate leachate leakage as well as gas seepage and/or “migration” from cell basin and side slopes; and
- b. To ensure the effective management of generated leachate and gas through each respective management system.

The landfill lining system must protect both the environment and public health by preventing any possible seepage of the produced contaminants (leachate and gas) inside the landfill cell with the construction of an impermeable layer consisting of both natural (i.e., clay layer) and artificial (i.e., geosynthetics) components.

Landfill designers must ensure that the proposed liner system for a landfill cell is complying with all environmental regulations and the stability of both the lining components and overall structure is ensured by a geotechnical report that includes stability analysis and all relevant calculations and designs.

An effective protection of the soil, groundwater and surface water is achieved combining the following factors:

- a. Naturally existing (in certain cases) impermeable geological layer;
- b. A natural or artificial geological clay barrier layer;
- c. A geomembrane layer; and
- d. A drainage layer combined with a leachate collection system.

The abovementioned factors are taken into consideration along with the geological, hydrogeological, and geotechnical characteristics of the underlying ground and the landfill Class.

The landfill base and side slopes lining system shall consist of a mineral layer which can either be natural or artificial and must satisfy both permeability (K) and thickness (in terms of equivalency) requirements with a

combined effect in terms of protection of soil, groundwater, and surface water at least equivalent in performance to the one resulting from the following requirements:

- **Class 1 Landfills** - landfills for hazardous waste: $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 5.0 m;
- **Class 2 Landfills** - landfill for non-hazardous waste: $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 1.0 m;
- **Class 3 Landfills** - landfill for inert waste: $K \leq 1.0 \times 10^{-7}$ m/s; thickness ≥ 1.0 m.

m/s: meter/second.

It must be noted that the above-mentioned thicknesses are related to laboratory performance equivalents for K factor. This means that the thickness of a barrier layer may vary when performance equivalents are achieved by the combination of a Geosynthetic Clay Liner (GCL) and a layer of compacted soil with minimum thickness of 0.50 m.

Minimum thickness of 0.50 m for the geological barrier, refers to an equivalent permeability.

In all cases, any natural or artificially established geological barrier layer must not be less than 0,50 m thick, which may include the natural ground, subject to it having suitable properties.

Where the geological clay barrier does not naturally meet the requirements set above, it can be completed artificially and enhanced by other means providing equivalent protection (i.e., bentonite).

As a minimum, the base of the landfill lining system shall be a minimum of 2 m above the maximum groundwater level at the site, as determined by a hydrogeological investigation.

7.2.2 Landfill Liner System Risk Assessment Study

In certain circumstances, and subject to request from the Competent Authority, a risk assessment may be required to demonstrate the performance of any proposed landfill lining system to suitably prevent negative impacts on the environment and human health. The risk assessment considerations may involve the following:

- a. Construction methodologies and level of Construction Quality Assurance (CQA) implemented and associated expected leakage rates;
- b. Operational phases and post-closure performance;
- c. Failure and degradation of components, such as liners, leachate collection system and operational/management controls;
- d. Variation of leachate concentration through time;
- e. Stability analysis of components along with interface stability;
- f. Differential and total settlements;
- g. The role of proposed liner system to control leachate and landfill gas; and
- h. Availability of proposed materials.

The results of the risk assessment should feed into the final design parameters of the landfill lining system on a site-specific basis as this will be dependent and vary depending on:

- a. Nature of the waste types disposed;
- b. Geological, hydrogeological, and geotechnical properties of the site;
- c. Climatic conditions;
- d. Sensitive receptors.

All proposed landfill lining systems should be designed in accordance with the relevant risk assessment to confirm suitable performance and protection. It is important to note that landfill sites may have different lining systems applied since several factors can impact the selection of both the materials and layers.

7.2.3 Landfill Basal Liner Layers

Landfill basal liners selection may differ considering the following reasons:

- The requirements set for each class of landfill;
- Subsequently the type of wastes to be disposed;
- The availability of materials in the vicinity of the site; and
- The landfill cell design (i.e., use of geosynthetics instead of natural materials on steeper slopes, etc).

The landfill liner structure (bottom to top) should be designed according to Table 7-1.

Table 7-1: Landfill basal liners structure according to Landfill Classes

CLASS-1 (HAZARDOUS LANDFILL)	CLASS-2 (NON-HAZARDOUS LANDFILL)	CLASS-3 (INERT LANDFILL)
1. SUBGRADE LAYER Thickness: no less than 0.30 m.	1. SUBGRADE LAYER Thickness: no less than 0.30 m.	1. SUBGRADE LAYER Thickness: no less than 0.30 m.
2. CLAY BARRIER LAYER NATURAL or ARTIFICIAL and must fulfil both criteria: 1. $K \leq 1.0 \times 10^{-9}$ m/s; thickness ⁽¹⁾ ≥ 5.0 m (or GCL of equivalent performance); and 2. Thickness ⁽²⁾ : no less than 0.50 m.	2. CLAY BARRIER LAYER NATURAL or ARTIFICIAL and must fulfil both criteria: 1. $K \leq 1.0 \times 10^{-9}$ m/s; thickness ⁽¹⁾ ≥ 1.0 m (or GCL of equivalent performance); and 2. Thickness ⁽²⁾ : no less than 0.50 m.	2. CLAY BARRIER LAYER NATURAL or ARTIFICIAL and must fulfil both criteria: 1. $K \leq 1.0 \times 10^{-7}$ m/s; thickness ⁽¹⁾ ≥ 1.0 m 2. Thickness ⁽²⁾ : no less than 0.50 m.
⁽¹⁾ For K value and associated thickness, refer to commentary in Section 7.2.1 ⁽²⁾ Minimum thickness may be considered in combination with the Subgrade Layer* Note: The geological barrier is determined by geological and hydrogeological conditions below and in the vicinity of a landfill site providing sufficient attenuation capacity to prevent a potential risk to soil and groundwater.		
3. GEOMEMBRANE LAYER Components: 1. Geomembrane of minimum thickness: 2.5 mm. OR (leakage detection system alternative**): 1. Geomembrane of 2.0 mm thickness 2. Geocomposite Drainage Layer 3. Geomembrane of 2.0 mm thickness	3. GEOMEMBRANE LAYER Components: 1. Minimum thickness: 1.5 mm.	3. GEOMEMBRANE AND DRAINAGE LAYER Not required (depending on lining system used)
4. PROTECTION LAYER Components: 1. Geotextile; and/or 2. Fine Sand Layer. (Class of geotextile and/or thickness of sand layer to be determined by suitable analysis/testing)	4. PROTECTION LAYER Components: 1. Geotextile; and/or 2. Fine Sand Layer. (Class of geotextile and/or thickness of sand layer to be determined by suitable analysis/testing)	
5. DRAINAGE LAYER & LEACHATE COLLECTION SYSTEM	5. DRAINAGE LAYER & LEACHATE COLLECTION SYSTEM	

CLASS-1 (HAZARDOUS LANDFILL)	CLASS-2 (NON-HAZARDOUS LANDFILL)	CLASS-3 (INERT LANDFILL)
Components: 1. Coarse Aggregate material with Hydraulic Conductivity $\geq 10^{-3}$ m/s and min. thickness 0.30 m or Geosynthetic Drainage Material with equivalent performance and providing suitable protection to the lining system. 2. Collection pipework: • min. diameter of 200 mm • max. spacing of 25 m • min. gradient of 2-3%.	Components: 1. Coarse Aggregate material with Hydraulic Conductivity $\geq 10^{-3}$ m/s and min. thickness 0.30 m or Geosynthetic Drainage Material with equivalent performance and providing suitable protection to the lining system. 2. Collection pipework: • min. diameter of 200 mm • max. spacing of 25 m • min. gradient of 2-3%.	
6. GEOTEXTILE SEPARATION LAYER 1. Separation Geotextile (Class of geotextile is to be determined by suitable analysis/testing)	6. GEOTEXTILE SEPARATION LAYER 1. Separation Geotextile (Class of geotextile is to be determined by suitable analysis/testing)	6. GEOTEXTILE SEPARATION LAYER Not required.

**If the underlying layer is suitable or can be formulated and compacted according to the requirements, standards, and specifications then the Subgrade Layer may be considered as part of the Clay Barrier Layer to achieve the K factor and minimum thickness criteria equivalency.*

***The construction of a Leakage Detection System is strongly advised for landfills classified as Class 1, however, this is subject to site and/or project specific considerations and may be further analysed through a Risk Assessment Study.*

All proposed landfill liner systems should be in line with the above proposed structure and requirements. Additionally, any slopes to which liner systems are applied and consist of cover material layers (such as leachate collection aggregate or cover soil) should be subject to a veneer stability analysis to ensure suitable design against sliding failure. In some cases, geogrid reinforcement may be required to ensure stability in steep slope scenarios.

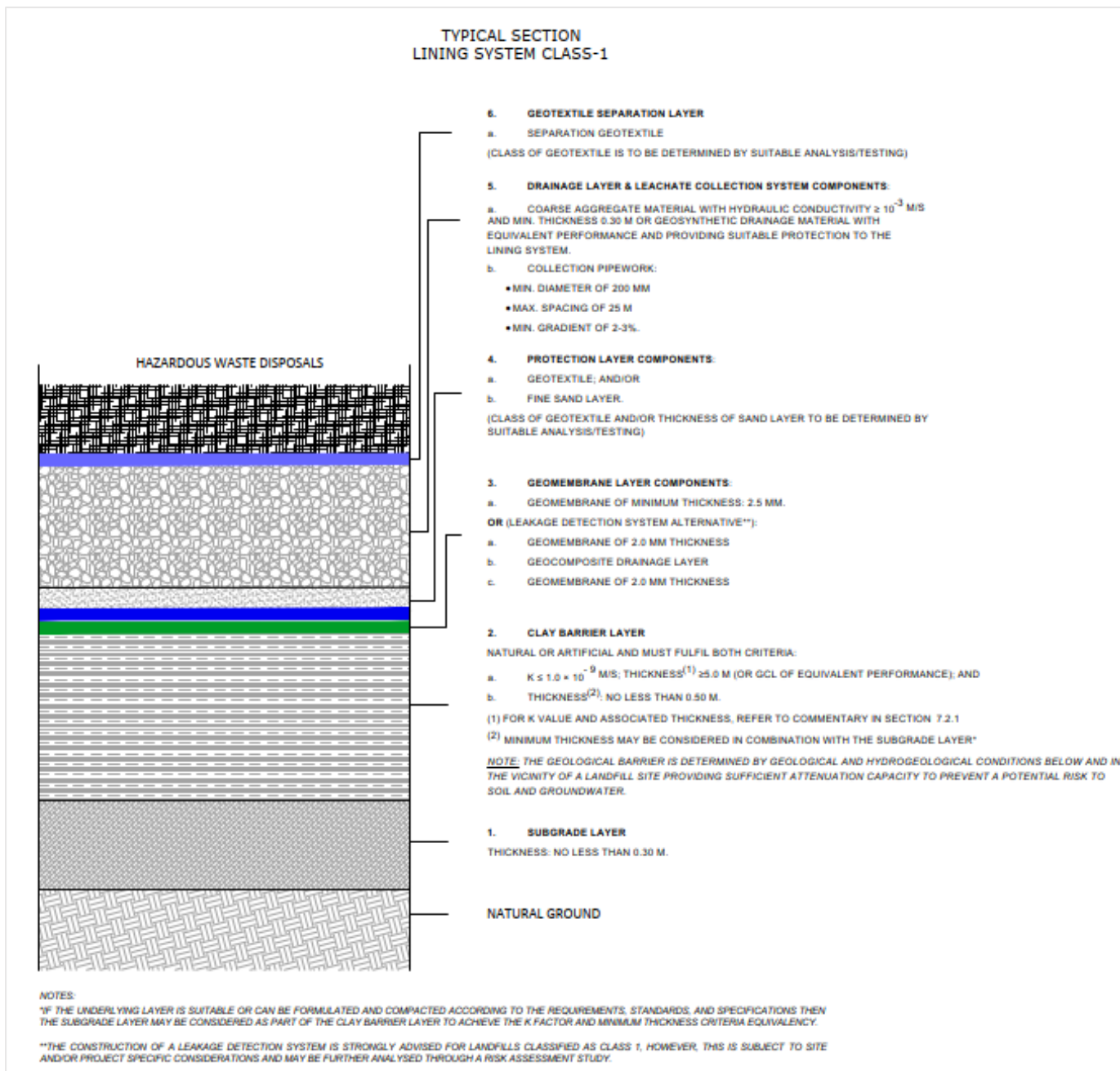


Figure 7-1: Typical Section Lining System Class-1

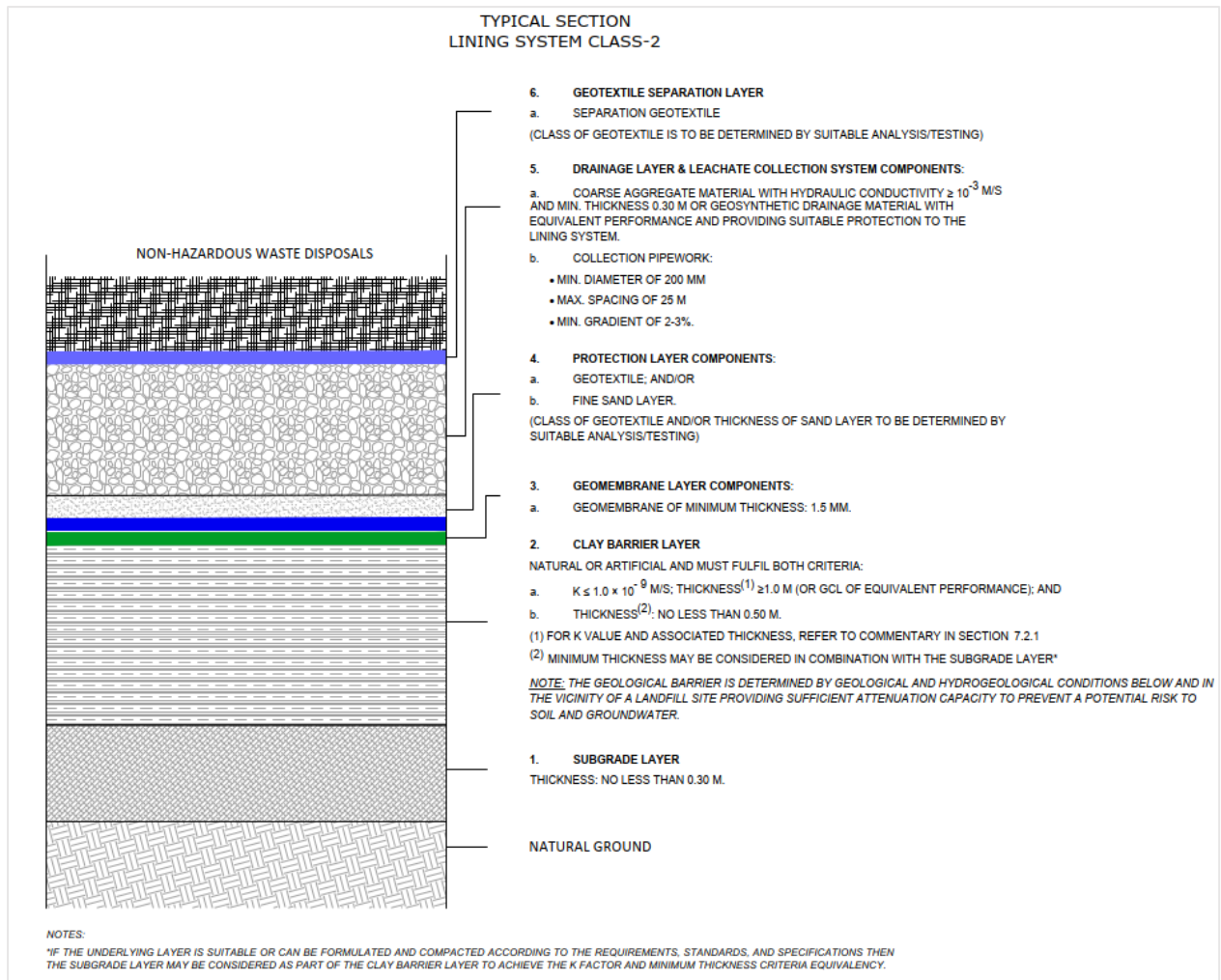


Figure 7-2: Typical Section Lining System Class-2

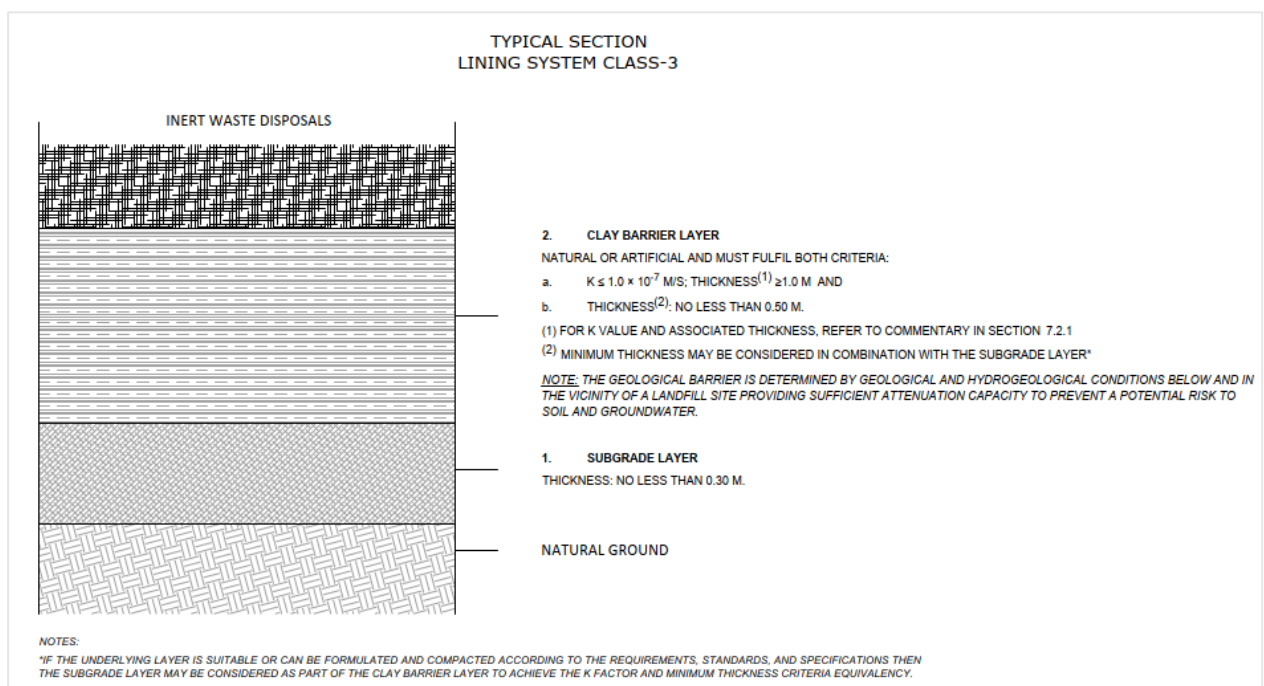


Figure 7-3: Typical Section Lining System Class-3

7.2.3.1 Prerequisites

Prior to the installation of the landfill lining system, it is important to ensure that the prepared surface after completing the earthworks is clear and smooth to facilitate the placement of the selected lining system without causing damage. It must be ensured that the surface is flat, free of vegetation, stones or construction materials of any kind and the layer should be levelled and compacted with suitable equipment.

The configuration of the surface aims:

- a. To prevent damage to the overlying lining system;
- b. To achieve a satisfactory contact between the surface and the lining system;
- c. To avoid the occurrence of differential and total settlements; and
- d. To create an additional "barrier" against vertical movement of contaminants (leachate).

Once the initial surface is configured according to the above-mentioned principals, the landfill liners may be installed.

7.2.3.2 Subgrade Layer

The subgrade or sub-base layer will normally consist of the underlying local natural geology and must be applied in **all Landfill Classes (1, 2 & 3)**. The role of the subgrade layer is to provide a suitable base for the liner system by limiting differential settlements that could cause stability issues and providing a smooth well compacted surface to facilitate the geological clay barrier layer.

This layer will consist of a compacted soil material with a minimum thickness of 0.30 m. In case of rocky outcrops, these should be levelled and covered by at least 0.30 m of compacted soil material. Where underlying materials are categorized as soils, the existing soil material should be properly compacted.

All relevant drawings and documents for the construction or formulation of the subgrade layer must be verified and approved by a qualified Geotechnical Engineer.

To ensure the quality of the prepared subgrade layer, it is compulsory to be included in the Construction Quality Assurance (CQA) Plan which accompanies the landfill design documentation, thereby verifying its suitability for the intended purpose.

7.2.3.3 Clay Barrier Layer

Clay is a suitable material for the construction and development of a low permeability barrier layer for all classes of landfill sites, minimizing leakage risks to either groundwater or surface water receptors.

The Clay Barrier Layer must be applied in **all Landfill Classes (1, 2 & 3)** and can be either a natural or artificial layer (or combination) in accordance with the requirements of this document.

The permeability requirements of the clay barrier layer for both basin and side slopes of the waste cell must be in accordance with the following limits:

- **Class 1 Landfills** - landfills for hazardous waste: $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 5.0 m;
- **Class 2 Landfills** - landfill for non-hazardous waste: $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 1.0 m;
- **Class 3 Landfills** - landfill for inert waste: $K \leq 1.0 \times 10^{-7}$ m/s; thickness ≥ 1.0 m.

m/s: meter/second.

Prior to the construction of the **geological clay barrier layer**, samples of the clay to be used must be submitted to a certified laboratory to determine the geological and geotechnical properties of the material. The results

will lead to the development of compaction and hydraulic conductivity curves that must be used to determine the clay's suitability as a low permeability barrier.

The shaping and placement of the geological clay barrier layer will be done with successive compacted layers of approximately 0.15 – 0.20 m, on the shaped foundation layer and must have a minimum thickness of 0.50 m.

The final surface of the clay barrier layer should be smooth maintaining the slopes and shape of the design. After compaction the final thickness of the layer should not be less than 0.50 m. The layer should be completely smooth without the presence of cracks or irregularities in the final surface, so that the geomembrane will be placed on it safely and with no risk of damage.

If the required quantity of the materials for the construction of the geological clay barrier layer cannot be retrieved in the wider project area or the cost of importing clay materials to the construction site is not cost-effective, other solutions should be examined such as addition of bentonite or other low permeability additives into the soil. In all alternatives, the required percentage of either bentonite into soil or other mixture must be determined by laboratory testing at certified laboratories to confirm equivalency.

An **artificial clay barrier layer** should be a combination of a GCL and a compacted soil layer. Installation of an artificial clay barrier layer should be selected when:

- Required quantities of suitable specification of clay materials are not available within suitable proximity to the site; and/or
- The required bentonite or other additives to achieve the hydraulic conductivity properties would be excessive and have major cost, time, and potential quality control implications in comparison to the use of a GCL.

Based on the above, a Geosynthetic Clay Layer (GCL) may be proposed as an artificial clay barrier layer, which ensures equivalent results with a barrier layer as specified in Table 7-1, Item 2.

The GCL shall consist of a layer of bentonite encapsulated between two geotextiles (one nonwoven and one woven polypropylene geotextile or both nonwoven polypropylene geotextile) needle punched. The physical properties of the GCL, along with testing and installation requirements shall comply with the approved CQA Plan, which shall include the following topics as a minimum:

- Manufacture details, including details of all components of the finished material as well as all physical and mechanical property requirements;
- Supply, delivery, storage, and handling requirements;
- Conformance testing requirements (with methods complying to international standards such as ASTM or ISO); and
- Installation and repair procedures.

Prior to installation of the GCL, the earthworks / subgrade surface preparation shall comply with the requirements of Section 7.2.3.1.

All relevant drawings and documents for the construction of the clay barrier layer must be verified and approved by a qualified Engineer. To ensure the quality of the constructed clay barrier layer, it is compulsory to be included in the Construction Quality Assurance (CQA) plan which accompanies the landfill design documentation, thereby verifying its suitability for the intended purpose.

7.2.3.4 Geomembrane Layer

The geomembrane layer consists of a high-density polyethylene (HDPE) material which may be textured or smooth, depending on project-specific requirements and is applied only in **Landfill Classes 1 and 2**. The geomembrane should have a low permeability, a physical strength capable of withstanding mechanical stresses and strains, and be chemically compatible with the waste contained by the liner. The thickness of the geomembrane shall comply as a minimum with the requirements of Table 7-1, or be subject to change based on a Risk Assessment Study.

Landfill designers must make every reasonable endeavour to ensure that the geomembrane to be used is the most appropriate under the circumstances and that it meets both physical and mechanical requirements. The physical properties of the geomembrane shall comply with an approved CQA Plan, which shall include the following topics as a minimum:

- Manufacture details, including details of all components of the finished material as well as all physical and mechanical property requirements;
- Supply, delivery, storage, and handling requirements;
- Conformance testing requirements (with methods complying to international standards such as ASTM or ISO);
- Geomembrane deployment;
- Geomembrane seaming/jointing (welding), covering both trial seams and field seams;
- Sampling and testing requirements (both non-destructive and destructive testing);
- Repair and patching procedures; and
- Protection and backfilling.

A geomembrane **Leak Location Survey (LLS)** may be conducted upon completion of the geomembrane installation and filling of the subsequent cover layers (refer to Section 7.2.5).

All relevant drawings and documents for the installation of the geomembrane layer must be verified and approved by a qualified Engineer. To ensure the quality of the installed geomembrane layer, it is compulsory to be included in the Construction Quality Assurance (CQA) plan which accompanies the landfill design documentation, thereby verifying its suitability for the intended purpose.

7.2.3.5 Protection Layer

The protection layer is applied only in **Landfill Classes 1 and 2** aiming to protect the underlying geomembrane layer and may consist of two sub-layers:

- a geotextile; **and/or**
- a fine sand layer of 0.10 m thickness.

The geotextile is typically a non-woven, needle punched and manufactured from fibres of polypropylene with the addition of UV stabilisers. The geotextile layer is to be installed over the entire area of the waste cell (basin and side-slopes) to protect the geomembrane from sharp objects during construction and operations that could cause damage.

The geotextile does not only serve the purpose of protecting the geomembrane from damage but also provides additional enhancement of stability through improved shear strength while also contributing to the drainage capacity.

The properties of the geotextile shall be dictated by the nature of the overlying layers and the total potential pressure to be applied (determined by the height of the waste body as well as vehicle loads and capping). Confirmation of the suitability of the geotextile properties may be determined through the execution of a

Cylinder Test using samples of the materials to be used with an allowable strain of 0.25%, or through alternative approved testing.

The physical properties of the protection geotextile shall comply with an approved CQA Plan, which shall include the following topics as a minimum:

- Manufacture details, including details of all components of the finished material as well as all physical and mechanical property requirements;
- Supply, delivery, storage, and handling requirements;
- Conformance testing requirements (with methods complying to international standards such as ASTM or ISO); and
- Geotextile installation.

The protection of the geomembrane can be enhanced with the addition of a fine sand layer. This layer will be a minimum of 0.10 m thick and will consist of fine sand. The material should be placed in a single layer and must be nominally compacted with low ground pressure machinery.

All relevant drawings and documents for the construction and installation of the geomembrane protection layer must be verified and approved by a qualified Engineer. To ensure the quality of the constructed geomembrane protection layer, it is compulsory to be included in the Construction Quality Assurance (CQA) plan which accompanies the landfill design documentation, thereby verifying its suitability for the intended purpose.

7.2.3.6 Leachate Drainage Layer

The drainage layer will be constructed over the protection layer of the geomembrane. The leachate collection system will be installed in this layer which is an integral component of the overall landfill liner system. A drainage layer must be applied in **Landfill Classes 1 and 2**.

The drainage layer will extend to the entire area of the landfill and should have a minimum thickness of 0.30 m. In certain circumstances, and subject to suitable justification and special approval, the drainage layer may be replaced with a permeable sand layer, with drainage aggregate placed only around the pipe network. This scenario will only be considered in low leachate generating circumstances, subject to design justification.

The drainage layer is a high-porosity medium providing a preferential flow-path to the leachate collection system and must be selected to maximise drainage of generated leachate in the long term. The layer will consist of clean, coarse aggregate with the following recommended properties:

- 85% of the material not less than 40.0 mm;
- 10% of the material not less than 20.0 mm;
- Uniformity coefficient less than 2.0;
- Fines content less than 1.0 % by weight; and
- Low calcareous material (CaCO_3 content < 20%) that would be subject to chemical erosion.

The hydraulic conductivity of the layer should be greater than 1×10^{-3} m/s.

The aggregate drainage layer may be replaced by a Geosynthetic Drainage Layer (GDL) with an equivalent performance in terms of hydraulic conductivity when reasons such as capacity saving or shortage of required material quantities in the wider area may require it. This substitution should be used as an alternative only for the side slopes of landfill waste cell and not the basin, and suitable protection of the lining system in these areas should be applied.

Within the Drainage Layer, a pipe network shall be installed to collect and direct leachate to the leachate collection sump. Further details on this are provided in Section 7.3.

Installation of the drainage layer shall be undertaken with utmost care to prevent damage to the underlying liner layers. All required testing and installation requirements for the drainage layer shall be covered in the CQA Plan.

All relevant drawings and documents for the construction and installation of the drainage layer must be verified and approved by a qualified Engineer. To ensure the quality of the constructed drainage layer, it is compulsory to be included in the Construction Quality Assurance (CQA) plan which accompanies the landfill design documentation, thereby verifying its suitability for the intended purpose.

7.2.3.7 Geotextile Separation/Filtration Layer

A geotextile separation/filtration layer must be applied in all landfills with a constructed drainage layer regardless their Class.

The drainage layer will be separated from the waste body by a separation/filtration geotextile of suitable strength and permeability, to prevent the entry of fine-grained materials produced from waste disposal into drainage layer causing clogging of both the layer and underlying leachate pipes. The properties of the geotextile must be verified with calculations to prevent clogging.

It should be noted that the installation of this layer may need to form part of the operational stage of the landfill in order to avoid long-term exposure and surcharging issues.

7.2.3.8 Geosynthetics Anchorage Trench

All geosynthetic materials (GCL, geomembrane, geotextiles, geosynthetic drainage layer, etc.) are to be suitably anchored at the crest of the perimeter embankment of the cell and in the intermediate berms or benches (if required) in anchor trenches. Anchorage of these material prevents slipping which may be caused by various factors such as the forces of overlying layers and waste deposits, shrinkage and expansion of the materials and wind.

The geosynthetics of the landfill liner system are anchored in a trench with minimum dimensions of 0.70 m x 0.70 m (width x depth) with a minimum runout (distance from the edge of the slope to the anchor trench) of 1.0 m, or subject to anchorage calculations. The slopes of the trench will be smooth/rounded to avoid any geosynthetics damage. After the installation of the geosynthetics, the anchor trench should be backfilled with the products of the excavation, which should be compacted in layers.

7.2.4 Leakage Detection System

The overall performance of the landfill liner system may be monitored to verify initial design assumptions and overall system performance. This process will require installation of a leakage detection system within a double liner system, consisting of a drainage layer (or geo-drain) located between the two lining systems. Leakage through the primary (upper) liner system is captured in the leakage detection layer and rained to a leakage detection sump. The volume of leachate detected in the leakage detection sump provides an indication of the leakage of the primary lining system and may indicate a failure in the system.

The requirement for such a system will be subject to a Risk Assessment Study and is typically only recommended for hazardous waste containment (Class 1) and leachate ponds.

Where present, the leakage detection system should be monitored on a regular basis. Excessive leakage or notable increases in leakage rates will require an investigation into potential reasons and mitigation measures, should there be any impact on groundwater quality.

7.2.5 Leak Location Survey (LLS)

While not a mandatory requirement, the implementation of a Leak Location Survey (LLS) or geophysical leak detection allows for verification of the absence of major damage to the installed geomembrane which may have occurred during the construction process prior to the commencement of operations.

The requirement for an LLS may be enforced by facility owners or approval authorities in the case of high-risk sites, or to provide additional “peace-of-mind” that installations have been carried out in accordance with the design and specifications.

7.3 Landfill Leachate Management System

7.3.1 Leachate Collection

Leachate generation in a landfill depends predominantly on the volume of precipitation that falls directly into the waste body along with the moisture content of the waste.

The quality of generated leachate depends on the chemical and biological components that are acquired during the percolation of stormwater through the waste body. Parameters that determine leachate composition are the type and composition of disposed waste, age of the residues and degree of compaction.

The leachate collection system is designed to collect the generated volumes of leachate via a network of perforated pipes connected to non-perforated main transfer pipes to a sump and then according to the design are extracted from the waste cell either by gravity or a pumping. Therefore, the leachate collection system consists mainly of:

- Perforated collection pipes (secondary pipes);
- Perforated or non-perforated transfer pipes (main pipes);
- Sump constructed at the low point of the cell;
- Clean-out pipes (if required);
- Leachate pumping station along with riser system (when there is no gravity extraction); and
- Inspection manholes (used for gravity extraction).

A leachate gravity collection system is not recommended. When the gravity leachate extraction method is used, the main transfer pipe (or pipes) penetrates the embankment and lining systems and then can either terminate in inspection wells/manholes before connecting to another transfer pipe and finally terminate at the leachate storage infrastructure or can directly terminate at the leachate storage infrastructure.

It must be noted that when applying the extraction via gravity method it is strongly advised that further monitoring of the geosynthetics welding points with the pipe at the embankment penetration area should be provided.

In the recommended method of leachate extraction via a pumping station, the main transfer pipe (or pipes) terminates into a sump constructed at the lowest point of the cell and from there a pump placed inside a riser pipe transfers collected leachate outside the waste cell to the leachate storage infrastructure.

Special care should be given to the riser system as it must be ensured that the pump can be easily retrieved in case of damage and a backup pump must always be available at the site.

All generated leachate is extracted from the waste cell to the leachate storage infrastructure such as a collection tank, pond, or lagoon prior to further treatment process.

Regarding leachate extraction methods (gravity or pump), the following should be considered:

- Height of water table;
- Local topography;
- Available area;
- Capacity needs;
- Environmental restrictions (i.e., maximum height or elevation), and
- Underlying geological layers.

The leachate collection system should be designed to accommodate a 1 in 50-year storm event. In addition, the diameter of pipes must be no less than 200 mm, while the perforated pipes should have perforations covering the upper $\frac{2}{3}$ of the pipe surface. The pipes shall have suitable strength and stiffness properties to ensure stability against crushing or deflection.

The maximum permissible leachate head on the drainage layer (as measured at the lowest point of the layer is 0.30 m). The longitudinal gradient of the collection and transfer leachate pipes should be a minimum of 2 - 3%.

The leachate collection and transfer pipes should not be spaced at more than 25 m apart. Depending on the site condition and with suitable justification, the proposed distance may differ.

All pipes should be HDPE due to their high chemical resistance. The use of other materials should be justified.

To reduce the risk of mechanical failure of the leachate collection and transfer pipes, they must be:

- Preferably flexible rather than rigid;
- Placed inside trenches or formulated areas;
- Placed on evenly prepared bedding material; and
- Protected by a traffic-control program minimising the movement of heavy waste vehicles and machines across and above them to avoid puncturing until sufficient waste has been placed over the drainage layer.

Collection and transfer pipes must be placed over a bedding layer and pipes should then be backfilled with the same material to the one used at drainage layer. The upper limit of the pipe should not have a distance less than pipe's diameter from the disposed waste.

The leachate collection system is designed and dimensioned according to the leachate generation forecast. The amount of leachate should be calculated for all phases of operation, to determine the critical values required for sizing.

7.3.2 Leachate treatment

Depending on the specific local conditions, the characteristics of the leachate and the receiver in which it is discharged, the leachate treatment can be performed in the following types of installations, namely:

- On-site treatment facility, which allows the leachate to be discharged directly into the natural receiver in compliance with the relevant legislation regarding the value of the effluent quality indicators;

- An on-site leachate pre-treatment facility before being discharged to an urban wastewater treatment plant, in compliance with the values of the effluent quality indicators; and
- Given the high evaporation rates and often remote locations of landfill infrastructure in KSA, leachate evaporation ponds are considered as a valid method of leachate containment / treatment.

The leachate storage infrastructure must either be lined properly or constructed with chemical resistant materials such as HDPE.

Leachate recirculation may be applied, but only when it is considered as a part of the overall gas management system (optimization of biological activity processes). Recirculation is not permitted as a disposal option for generated leachate. Recirculation of a limited portion of the leachate generated may only be undertaken on an emergency basis.

Finally, recirculation procedures may only be initiated after the gas extraction system is installed so that additional gas generation may be suitably collected and treated.

7.4 Landfill Gas Management

7.4.1 Landfill Gas Collection

Landfill gas is defined as the mixture of gases produced during the biodegradation of waste inside the landfill waste cell, with the major constituents being methane and carbon dioxide. The decomposition of the waste begins immediately after disposal within the cell. It is important to note that the constituents of landfill gas mean that it may be flammable and can be an asphyxiant.

The gas is produced only in landfills that accept biodegradable wastes (Classes 1 & 2). Class 3 landfills (Inert Landfills) do not produce gas due to the nature of the disposed waste.

Landfill gas must be managed throughout the lifetime of the landfill and during closure and aftercare period. The objectives of a landfill gas management system are as follows:

- To minimise any potential impacts on air quality;
- To minimise the risk of migration of the gases of the site and to nearby infrastructure;
- Avoid unnecessary ingress of air into the landfill to reduce the risk of fires; and
- Allow for effective control of gas emissions for treatment or energy recovery.

Depending on the waste types to be disposed, and the expected gas volumes to be generated, the following elements must be present at landfills classified in Classes 1 (Hazardous Landfill) and 2 (Non-Hazardous Landfill):

- Fully operational cell lining system to prevent gas migration to the underlying geological layers and groundwater;
- Fully operational capping system (at the time of closure of the cell) to minimize gas emissions to the atmosphere;
- Active gas extraction system to maximize collection efficiency or passive venting of gas provided a risk assessment study verifies that expected produced gas emissions are minimal and there is no risk for the environment and human health; and
- A combustion system or other proposed gas treatment method only where required according to expected gas generation.

Gas management design and planning is based on calculations of the maximum anticipated generated quantity which is determined by a landfill gas generation forecast model and may be further enhanced through the implementation of a pumping trial.

The layout of gas collection and extraction systems should be designed in such a way that no negative effect to the landfill liner and capping systems will arise.

The materials of gas collection systems must be resistant to factors caused by:

- High temperature inside the waste body (up to 70° C);
- The weight loads coming from the waste body, the capping system, and traffic or movements of the equipment (compactor, trucks, etc.);
- Microorganisms.

Gas management system pipe materials must be tolerable of expected physical, chemical, and biological strains. In all cases, the pipes shall be suitably specified to ensure long-term stability and to meet the requirements of the gas extraction system.

The landfill gas collection and treatment system shall consist of the following:

- Vertical Collection wells (boreholes) for either passive venting or active extraction with suitable wellheads and associated fittings;
- Horizontal collection pipes network;
- Horizontal transfer pipes network (to collection substations);
- Gas collection substations / manifolds;
- Condensate separators/traps;
- Gas discharge pipes (from collection stations to the flare); and
- Flare unit or controlled gas combustion plant/gas recovery plant.

The appropriate collection and extraction method of gas involves the use of a vertical and/or horizontal network.

Vertical Collection wells (boreholes).

The collection wells should be located as symmetrically as possible and at an equal distance from each other (recommended, about 50,0 m). The wells shall be located as close as possible to the berms and the traffic routes.

Gas wells must be watertight to prevent air from entering; they must withstand the overburden loads and be easily repaired and controlled. The gas well consists of a vertical filter layer constructed from gravel and positioned inside the waste body along with a sufficient filter pipe which is perforated at the bottom part and non-perforated at the upper part.

This arrangement of the collection well elements ensure a uniform extraction of the gas generated inside the waste body.

Horizontal gas collection pipes are perforated pipes, installed in gravel filled trenches of high permeability, and are located under the final capping layers of the landfill and/or at varying depths if installed during operations. Pipe diameters shall be determined through suitable design calculations.

Horizontal gas transfer pipes are non-perforated pipes, installed in a backfilled trench, and are located inside the final capping layers of the landfill and/or at varying depths if installed during operations. Pipe diameters shall be determined through suitable design calculations.

Gas collection station is the facility where generated gas is collected throughout the gas collection system before sent to a flare unit or a combustion system. The gas is initially collected by the gas collection network and is transferred to the gas collection station via a transfer pipe before ending to the main gas transfer pipe that will send generated gas to either a flare unit or a combustion system depending on the proposed solution.

Gas collection stations are only constructed in active extraction system. The number of collection stations is determined according to the expected gas production of the waste disposals.

Condensate separator / condensate trap is a tank made of corrosion-resistant materials installed in low point areas which can be easily accessible for discharge. Since generated gas is saturated with water vapours it leads to the formation of condensates in the pipeline network. Condensate separators/traps are installed only in active extraction system.

In the design of the gas system, a study of possible dynamic gas migration outside the landfill as well as the technical measures for prevention of migration should be included. Migration of landfill gas poses an environmental and hazard risk. The main pathways through which gas can migrate includes:

- High permeability strata along the underlying layers of landfill site;
- Through cavities created inside the waste body;
- Cracks either on final capping or on site's perimeter;
- Through pathways caused by tree roots;
- Through gas or leachate monitoring wells;
- Through highly fissured strata into the atmosphere or adjacent buildings; and
- Along underground routes of utility networks.

Should a passive venting system be proposed, and to confirm that gas migration is not expected to pose any significant risks, a Risk Assessment Study should be undertaken. Parameters such as landfill location, type of disposed waste, capacity and soil strata should be considered.

7.4.1.1 Active Extraction System

An active gas extraction system to maximize collection efficiency is designed and constructed when the expected generated gas is sufficient to either be flared in a flare unit or sent into a gas recovery plant facility. The proposed active extraction system along with the expected gas production should be confirmed with calculations and if required by a Risk Assessment Study.

An active gas extraction, consists of the following components:

- Gas extraction well;
- Gas pipelines;
- Gas collection stations;
- Exhaust pipes and main gas transfer pipe;
- Condensate separator/trap;
- Controlled gas combustion unit (flare unit) / gas recovery plant.

7.4.1.2 Passive Venting System

For Waste disposals where the active phase of gas formation has been completed, and can no longer be recovered or burned controllably, must be passively vented/degassed to prevent the accumulation of gas in waste disposals.

At a methane content concentration of less than 20% or at an amount of captured gas $<100 \text{ m}^3 / \text{h}$, the generated gas can be diverted through the capping layer. The landfill gas must be able to flow inside the gas drainage layer and through a network of perforated pipes and wells should be released in the atmosphere.

The gas venting system must be designed so as not to exceed a value of 2 liters of gas / hour $\times \text{m}^2$. Precipitation from water drainage layer must not enter either the perforated pipes or gas wells network.

Passive venting of landfill gas is only permitted when small quantities of gas are produced which are not considered harmful to either the environment or public health and a Risk Assessment Study should be undertaken for verification.

The sizing of a passive venting system is based on the forecast of the production of the storage gas. For existing waste disposals, it is necessary to perform aspiration tests, and their results are correlated with the theoretical forecast, insofar as this can be achieved.

The passive venting system must be constructed to ensure the safety of all structures and facilities, the operating personnel, and the environment.

The entire gas collection system must be watertight and must be isolated from drainage collection layer or any other external impact i.e., precipitation. Moreover, positioning of the components of the gas collection system must not affect the operation of any other equipment or the lining layers in cell's base.

7.4.2 Landfill Gas Treatment

The landfill gas generated by the decomposition of waste must be collected and treated in a way that reduces the negative effects it may have on the environment and reduces the potential hazard of the main component's methane (danger of explosion) and carbon dioxide (danger of suffocation). The gas treatment is done depending on the capture technique used - active or passive. The gas treatment and recovery techniques are chosen according to the methane concentration and the capacity of the gas treatment system must be sufficient to manage the volume of generated gas inside the landfill.

Treatment of the gas stream pre- or post-combustion will be a site-specific issue based on the precise composition of the gas stream, as proved by relevant measurements and calculations.

The amount of gas that can be captured for a given period, as well as its methane content, is determined according to the gas generation forecast and the experimental results. Based on the results, the type of gas treatment is decided.

A gas extraction system must also contain a safety control system for controlled combustion such as a flare unit, to ensure that gas will burn in the event of a fault in extraction system. In this case, the controlled combustion unit is dimensioned at 60% of the amount of gas captured from generated waste. The gas contains, in addition to the main components (CH_4 and CO_2), traces of halogenated compounds, sulphur, phosphorus, etc. These components can harm gas extraction and treatment systems, they also affect the quality of emissions, the removal of these elements can be done through biological filters or activated carbon, respectively by washing or catalytic oxidation of the gas.

All flaring units or combustion engine equipment utilised on site to manage gas must be designed to meet the following requirements:

- Discharge outlet must be upright and not obstructed by any component;
- Sampling sockets should be fitted to allow easy monitoring;
- Engine crankcase emissions must be controlled to minimise releases to the environment;
- Methane and flow rate of inlet gas should be continuously monitored and evaluated;

- Sampling must be carried out after combustion is completed (i.e., downstream of the flame); and
- Flare unit designs must include adequate cover to always enclose the flame.

7.5 Landfill Capping System

A Landfill Capping System must be designed and constructed to control and restrict the potential negative impacts that the landfill may have on the environment and public health, such as:

- Leachate generation;
- Gas generation;
- Odour emissions;
- Presence of birds, vermin, and insects; and
- Wind-blown materials.

Due to the fact that leachate and gas generation continues for many years after the end of operations at a landfill, a suitable encapsulation system is required to minimize the potential negative effects on the environment and public health. The main objectives when designing a capping system are as follows:

- To define the required capping system that limits environmental risks;
- To ensure stability of the capping system;
- To minimize infiltration of stormwater into the waste body;
- To connect to existing surface water drainage system structures;
- To control gas emissions and migration;
- To provide a suitable separation between the waste body and the environment; and
- To suit the requirements for final closure and aftercare use / monitoring / maintenance.

The landfill capping system should be designed in such a way that any failures during the aftercare period can easily and safely be identified and restored.

The final elevation of the landfill must not deviate from the provisions of the permitting requirements, design and construction and must also be verified with measurements. After settlement, the slope of the landfill capping surface should range between 4-5 %.

The landfill capping structure (bottom to top) should be designed according to Table 7-2.

Table 7-2: Landfill capping structure according to Landfill's Classes

CLASS-1 (HAZARDOUS LANDFILL)	CLASS-2 (NON-HAZARDOUS LANDFILL)	CLASS-3 (INERT LANDFILL)
1. LEVELLING LAYER 1. Thickness: no less than 0.30 m. (Temporary Cover/Capping Layer can be considered as a levelling layer)	1. LEVELLING LAYER 1. Thickness: no less than 0.30 m. (Temporary Cover/Capping Layer can be considered as a levelling layer)	1. LEVELLING LAYER 1. Thickness: no less than 0.30 m. (Temporary Cover/Capping Layer can be considered as a levelling layer)

CLASS-1 (HAZARDOUS LANDFILL)	CLASS-2 (NON-HAZARDOUS LANDFILL)	CLASS-3 (INERT LANDFILL)
2. GAS DRAINAGE LAYER Components: 1. Coarse Aggregate material with Hydraulic Conductivity $\geq 10^{-3}$ m/s and min. thickness 0.30 m or Geosynthetic Gas Drainage Material with equivalent performance. 2. Separation Geotextile (Installed only when Gas Drainage Layer consists of aggregate materials) <i>Layer may be removed if waste type does not produce significant gas volumes (subject to technical justification)</i>	2. GAS DRAINAGE LAYER Components: 1. Coarse Aggregate material with Hydraulic Conductivity $\geq 10^{-3}$ m/s and min. thickness 0.30 m or Geosynthetic Gas Drainage Material with equivalent performance. 2. Separation Geotextile (Installed only when Gas Drainage Layer consists of aggregate materials) <i>Layer may be removed if waste type does not produce significant gas volumes (subject to technical justification)</i>	2. GAS DRAINAGE LAYER Not required
3. CLAY BARRIER LAYER NATURAL or ARTIFICIAL and must fulfil the following: 1. $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 0.6 m (or GCL of equivalent performance) Separation geotextile needed under natural clay if underlying layer is coarse material	3. CLAY BARRIER LAYER NATURAL or ARTIFICIAL and must fulfil the following: 1. $K \leq 1.0 \times 10^{-9}$ m/s; thickness ≥ 0.6 m (or GCL of equivalent performance) Separation geotextile needed under natural clay if underlying layer is coarse material. <i>NB: Clay barrier layer may be removed if Geomembrane Layer is included in Class 2 Capping System, i.e., only a Clay Barrier Layer OR Geomembrane Layer is required.</i>	3. CLAY BARRIER LAYER Not required
4. GEOMEMBRANE LAYER 1. Minimum thickness: 1.5 mm.	4. GEOMEMBRANE LAYER 1. Minimum thickness: 1.5 mm. <i>NB: Geomembrane layer may be removed if Clay Barrier Layer is included in Class 2 Capping System, i.e., only a Clay Barrier Layer OR Geomembrane Layer is required.</i>	4. GEOMEMBRANE LAYER Not required
5. PROTECTION LAYER Components: 1. Geotextile; and/or 2. Fine Sand Layer min. thickness 0.10 m. (Class of geotextile and/or thickness of sand layer to be determined by suitable analysis/testing)	5. PROTECTION LAYER Components: 1. Geotextile; and/or 2. Fine Sand Layer min. thickness 0.10 m. (Class of geotextile and/or thickness of sand layer to be determined by suitable analysis/testing)	5. PROTECTION LAYER Not required

CLASS-1 (HAZARDOUS LANDFILL)	CLASS-2 (NON-HAZARDOUS LANDFILL)	CLASS-3 (INERT LANDFILL)
6. DRAINAGE LAYER Components: 1. Coarse Aggregate material with Hydraulic Conductivity $\geq 10^{-3}$ m/s and min. thickness 0.30 m or Geosynthetic Drainage Material with equivalent performance. 2. Separation Geotextile (Installed only when the Gas Drainage Layer consists of aggregate coarse materials) <i>Layer may be removed subject to design justification</i>	6. DRAINAGE LAYER Components: 1. Coarse Aggregate material with Hydraulic Conductivity $\geq 10^{-3}$ m/s and min. thickness 0.30 m or Geosynthetic Drainage Material with equivalent performance. 2. Separation Geotextile (Installed only when the Gas Drainage Layer consists of aggregate coarse materials) <i>Layer may be removed subject to design justification</i>	6. DRAINAGE LAYER Not required
7. COVER LAYER The Final Cover Layer should include the following: 1. Compacted covering soil with a min. thickness 1.0 m OR 1. Compacted covering soil with a min. thickness 0.30 m 2. Stone erosion protection layer with a min. thickness 0.20 m <i>(Selection of materials and thickness is subject to availability and provision of suitable erosion protection design justification, considering site and climatic conditions)</i> <i>Topsoil and vegetation may be implemented where feasible.</i>	7. COVER LAYER The Final Cover Layer should include the following: 1. Compacted covering soil with a min. thickness 1.0 m OR 1. Compacted covering soil with a min. thickness 0.30 m 2. Stone erosion protection layer with a min. thickness 0.20 m <i>(Selection of materials and thickness is subject to availability and provision of suitable erosion protection design justification, considering site and climatic conditions)</i> <i>Topsoil and vegetation may be implemented where feasible.</i>	7. COVER LAYER The Final Cover Layer should include the following: 1. Compacted covering soil with a min. thickness 1.0 m OR 1. Compacted covering soil with a min. thickness 0.30 m 2. Stone erosion protection layer with a min. thickness 0.20 m <i>(Selection of materials and thickness is subject to availability and provision of suitable erosion protection design justification, considering site and climatic conditions)</i> <i>Topsoil and vegetation may be implemented where feasible.</i>

All proposed landfill capping systems should be in line with the above proposed structure and requirements. Additionally, any slopes to which liner systems are applied and consist of cover material layers (such as drainage aggregate or cover soil) should be subject to a veneer stability analysis to ensure suitable design against sliding failure. In some cases, geogrid reinforcement may be required to ensure stability in steep slope scenarios.

It is important to note that capping of dumpsites / open dumps which do not have a basal lining system compliant with this Guideline may be subject to more stringent capping measures and should be designed using a risk-based approach.

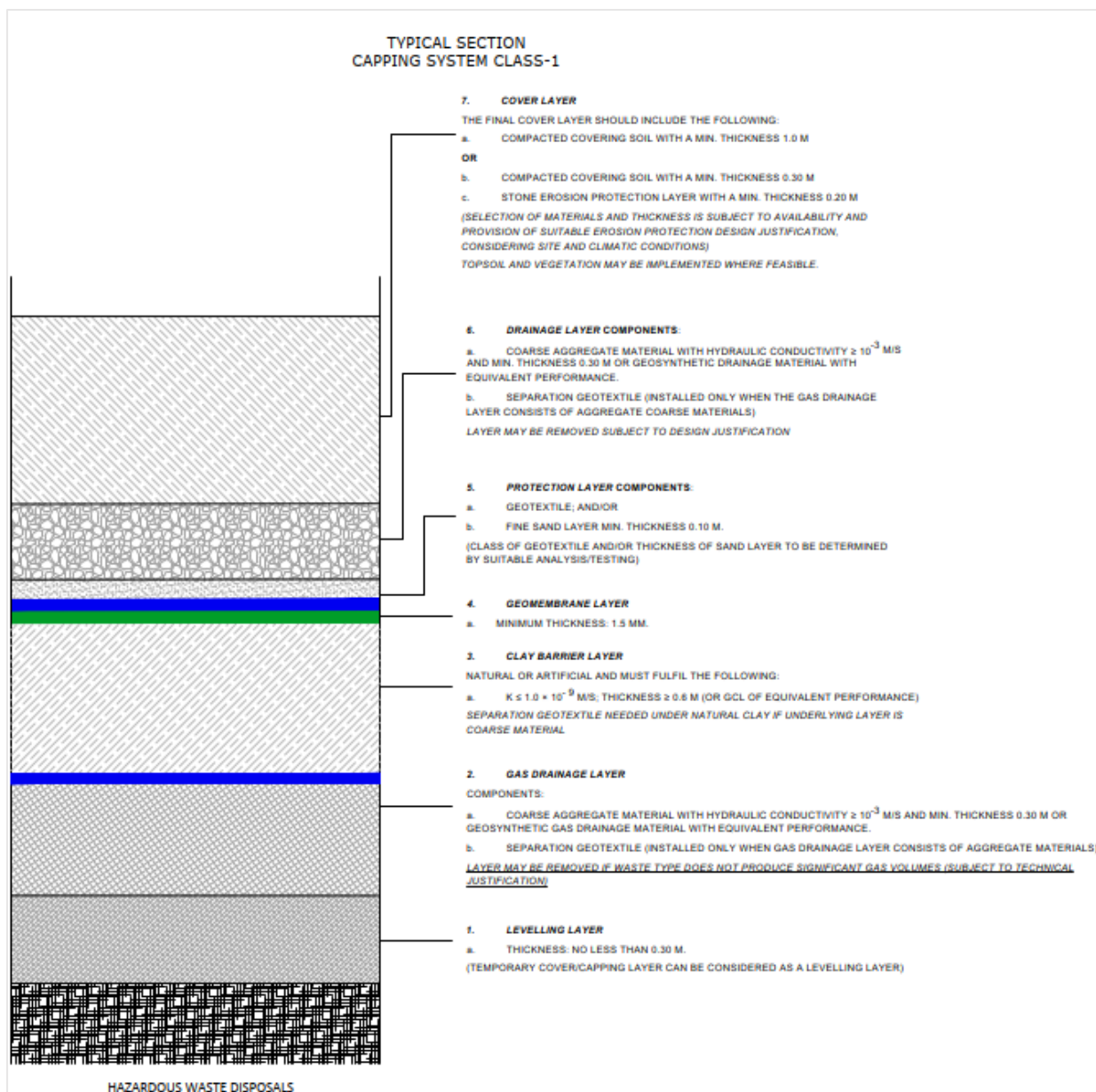


Figure 7-4: Typical Section Capping System Class-1

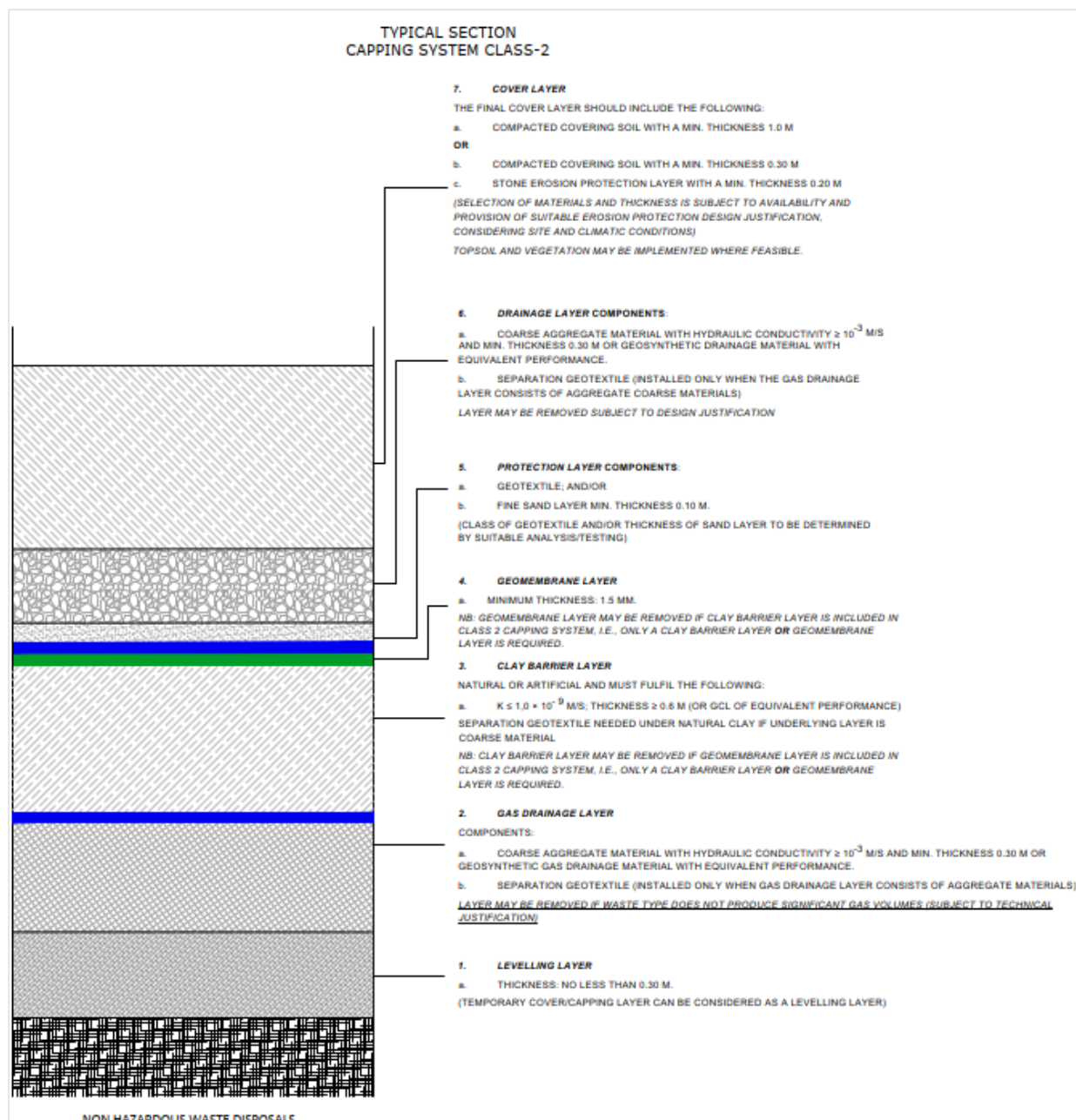


Figure 7-5: Typical Section Capping System Class-2

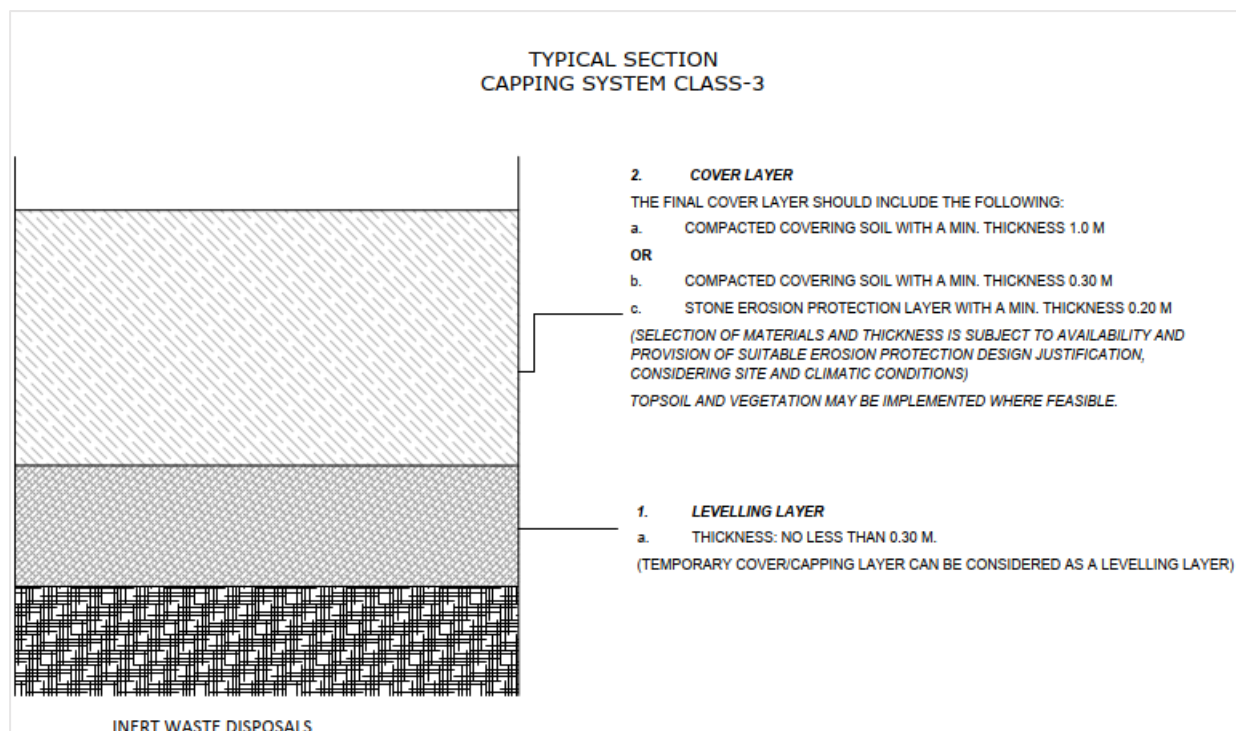


Figure 7-6: Typical Section Capping System Class-3

7.5.1 Landfill Capping Layers

7.5.1.1 Levelling Layer

The levelling layer will constitute of either the temporary capping/cover layer or a compacted soil layer available on site or nearby and should be applied to **all Landfill Classes (1, 2 and 3)**.

The role of the levelling layer is to provide a suitable base for capping layers by limiting differential settlements that could cause stability issues and providing a smooth well compacted surface to facilitate geosynthetic installations. The temporary cover/capping layer may be used as the levelling layer, subject to it meeting these requirements.

This layer will consist of a compacted soil material with minimum thickness of 0.30 m.

In the case of Landfills Classes 1 and 2, the levelling layer must allow the gas to penetrate, and the permeability coefficient must be $\geq 1 \times 10^{-4}$ m/s. The levelling layer may consist of any permeable soil/material (sand, demolition debris etc.) that does not have potential to damage the overlying capping system.

To ensure the quality of the constructed or formulated levelling layer, it is compulsory to be included in the Construction Quality Assurance (CQA) plan which accompanies the landfill design documentation, thereby verifying its suitability for the intended purpose.

7.5.1.2 Clay Barrier Layer

Clay is a suitable material for the construction and development of a low permeability barrier layer as required **only for Landfill Classes 1 & 2**. The capping system for Class 1 Landfills requires a clay barrier system, while the capping system for Class 2 Landfills may be removed, subject to the inclusion of a geomembrane layer.

Should a clay barrier (natural or artificial) be used, the same requirements as stated under Section 7.2.3.3 shall apply, with the exception of the hydraulic conductivity requirements which shall be in accordance with Table 7-2.

7.5.1.3 Gas Drainage Layer

A Gas Drainage Layer should be installed **only for Landfill Class 1 and 2** which are expected to generate gas.

The gas drainage layer will be constructed over the levelling layer and aims to prevent the accumulation of gas under the lining system. In addition, it contributes to the controlled emission, pumping and flow of generated gas to its management utilities.

The gas drainage layer can be either a coarse aggregate material with hydraulic conductivity of $\geq 10^{-3}$ m/s and a minimum thickness 0.30 m or a geosynthetic gas drainage material with equivalent performance.

It must be noted that the gas drainage layer and the drainage layer are similar and the only difference between the two layers is their use. All requirements, specifications and standards remain the same.

When the Gas Drainage Layer consists of aggregate coarse materials, a separation/filtration geotextile should be installed above it, to avoid clogging of the layer. The properties of the geotextile shall be determined based on its ability to prevent fines from clogging the drainage layer.

The layer will consist of coarse aggregate with the following recommended properties:

- 85% of the material not less than 40 mm;
- 10% of the material not less than 20 mm;
- Uniformity coefficient less than 2.0;
- Fines content less than 1.0 % by weight; and
- Low calcareous material (CaCO₃ content < 20%) that would be subject to chemical erosion.

The hydraulic conductivity of the layer should be greater than 1×10^{-3} m/s.

The aggregate drainage layer may be replaced by a Geosynthetic Drainage Layer (GDL) with an equivalent performance in terms of hydraulic conductivity when reasons such as capacity saving or shortage of required material quantities in the wider area may require it.

7.5.1.4 Geomembrane Layer

The geomembrane layer consists of a high-density polyethylene (HDPE) material which may be textured or smooth, depending on project-specific requirements and is applied only in **Landfill Classes 1 and 2**. Should a clay barrier layer be included in a Class 2 landfill capping system, the requirement for a geomembrane layer may be removed.

The geomembrane should have a low permeability, a physical strength capable of withstanding mechanical stresses and strains and be chemically compatible with the waste contained by the liner. The thickness of the geomembrane shall comply as a minimum with the requirements of Table 7-2, or be subject to change based on a Risk Assessment Study. Should a geomembrane be used in the capping design, the same requirements as stated under Section 7.2.3.4 shall apply.

Consideration may be given to the use of Linear Low-Density Polyethylene (LLDPE) geomembrane in capping applications due to its increased flexibility which may be useful in countering differential settlement concerns.

7.5.1.5 Protection Layer

The geomembrane protection layer is installed above the geomembrane, if applicable. The protection layer shall comply with the requirements of Section 7.2.3.5.

7.5.1.6 Drainage Layer

The drainage layer will be constructed for **Landfill Classes 1 and 2** over the geomembrane protection layer. The drainage layer shall comply with the requirements of Section 7.5.1.3 (Gas Drainage Layer).

7.5.1.7 Geotextile Separation/Filtration Layer

A geotextile for separation between the cover layer and underlying drainage layer must be installed for **Landfill Classes 1 and 2**. The geotextile separation layer shall comply with the requirements of Section 7.2.3.7.

7.5.1.8 Cover Layer

The Cover Layer will be constructed for all **Landfill Classes (1, 2 and 3)** and should comply with the requirements of Table 7-2, consisting of suitable covering and erosion protection layers.

If only cover soil is placed, then the minimum compacted thickness applied shall be 1.0 m and suitable design justification for erosion protection shall be provided. Alternatively, a covering soil of minimum thickness of 0.3 m shall be applied with the addition of a 0.2 – 0.3 m stone/gravel erosion protection layer.

The selection of materials and their thicknesses for the cover layer is subject to their availability on or near to the site, while also considering site and climatic conditions. Importantly, erosion protection of the cap shall be considered, noting that vegetation might not be feasible considering climatic conditions.

The main purposes of the cover layers are to:

- Facilitate evaporation;
- Minimize water penetration to the waste mass;
- Provide a suitable layer to support vegetation (if feasible);
- Reduce erosion; and
- Improve visual impact of the landfill.

The cover layer should be able to provide a suitable growing medium for the establishment of a vegetative cover if feasible. Local plantation such as bush species with short rooting systems may be used. It must be noted that the establishment of a vegetative cover is subject to local climate conditions and should be evaluated separately for each landfill site.

Shaping of the cover layer should prevent ponding of surface water and promote drainage away from the landfill. Minimum slopes of 5% are typically recommended.

The main characteristics of the applied topsoil cover layer are presented below:

- Cover layer shall be of sufficient quality to contribute to the biological functions of the plants (when a vegetative layer is established);
- Cover layer must originate from the surface layer of existing topsoil of the area and shall be excavated, stored, and arranged in windrows prior to construction. The Competent Authority must approve the locations of the proposed excavated areas for the required soil materials; and
- Excavated products which will be used must be free of impurities such as construction waste materials or demolition products (rubble), stones, NaCl, or even remnants of plants.

The covering material must not include pieces of rock larger than 0.15 m in diameter. The material of the cover layer must have a permeability coefficient k of 1×10^{-5} m/s to 1×10^{-7} m/s.

The erosion protection layer should be of a coarse material and should not have a thickness less than 0.30 m. The layer can be any material capable to resisting erosion.

7.6 Landfill and Lining System Stability

Waste is not characterized as a geotechnically homogeneous material and as such, considerations and precautionary measures must be taken regarding stability of waste bodies and development of potential settlements over time as it is subject to decomposition, consolidation, and significant variation, both spatially and over time.

Stability and settlements of waste bodies, formulation of earthworks and foundation of a landfill waste cell, environmental management infrastructure along with their foundations and the interactions between them and ground must be assessed by a suitably qualified engineer to verify that there are no risks for instability. A geotechnical stability report should accompany the verification including all relevant analysis and calculations proving that all precautions have been taken. The geotechnical report should be conducted in the design stage prior to any construction works and in accordance with the Competent Authorities requirements.

The geotechnical stability report should take account of:

- Settlement or slippage within the foundation (sub-grade) beneath landfill's waste cell base or sides;
- Slippage within the landfill liner system;
- Slippage at the waste or cover material and liner interface (veneer stability);
- Rotational failure within the waste, or through the whole cross-section;
- Slippage failure of the capping system or of its components;
- Effects of settlements on the landfill capping systems;
- Effects of settlements on utilities and infrastructures;
- Presence of leachate inside the waste body; and
- The maximum height as mentioned in the environmental permit.

A geotechnical report should in any case verify the final selection of slopes and make any recommendations for reinforcement or enhancement to basal or capping lining systems. Interface friction must be assessed between each layer under all conditions of use; static and dynamic, temporary, or permanent.

Furthermore, it must be verified that the strengths of the geosynthetics are sufficient and give satisfactory safety factors above the permissible limits for the proposed configuration of the bottom, slopes, and the final overlap of waste cell.

Another important issue regarding the stability of a landfill is possible slipping of the body of the waste on the successive artificial layers.

To reduce the degree of settlements, apart from achieving a high compaction ratio of disposed waste, the following should be followed:

- Maximum slope of 1(V):3(H); and
- Slopes of temporary covers between phases of a landfill 1(V):2(H) to 1(V):3(H).

To anticipate the effects of settlements, landfill designers must add a surcharge to the post-settlement levels and distinguish clearly on design drawings the ultimate post-settlement levels and the surcharged levels to which each phase of the site is to be filled, capped, and restored.

Landfill Operators are responsible for monitoring the degree of settlements and to achieve the required compaction ratios and slopes included in the design studies.

Values between 15-25 % are acceptable when considering the void capacity and final pre-settlement contours of a waste landfill.

Where differential settlements may occur, provision should be made to accommodate the settlement and the associated stresses, most commonly by:

- Additional thicknesses of capping materials to accommodate differential movement or to allow removal of material if settlement does not occur as predicted.

A stability assessment must take account for site-specific conditions and should use geotechnical parameters appropriate to the disposed waste type.

Cohesive materials should have a bearing capacity of not less than 50 kPa while non-cohesive waste should have an in situ bearing ratio of at least 5.0%.

Settlements in a landfill are divided into primary and secondary. Initially, primary settlements occur at a short period after waste disposal operations and mainly within the first one or two months. The degree of primary settlements is significant and result from the abrupt movement of the waste deposits due to overlying disposals. It is important to note that when a higher compaction ratio is achieved the degree of primary settlements is expected to be smaller.

The magnitude of the settlement decreases with time and depth and most settlement takes place in the first three years.

The main mechanisms that cause waste settlements are:

- Corrosion, oxidation, and combustion thereof;
- Biochemical decomposition (fermentation) and decomposition under aerobic & anaerobic conditions;
- Compression and repositioning or reorientation of waste components;
- Movements of fine-grained materials in large gaps.

The factors that affect the size and evolution of settlements are the initial density and the management (compaction - layer thickness) etc. of the disposed waste, height of the embankment, filtration levels, the climatic factors etc.

Complete construction and installation of capping layers prior to expected settlements could lead to irreversible failures of the layers and a geotechnical report based on data from settlements monitoring program should determine the exact time of final closure.

It is recommended that the maximum height of a landfill's final capping should be determined by the geotechnical report and the environmental permit.

7.7 Small Landfills

For Class-2 Landfills characterized as small, infrastructures and facilities that are not considered vital for the daily operations of the Landfill or due to the limited presence of personnel and machineries are not considered necessary, may be foreseen.

A Landfill is regarded as “small” when twenty (20) tons of municipal solid waste per day or less are disposed, based on an annual average.

Infrastructures and facilities that may be excluded from small Landfills are: Waiting area, Maintenance building, Fuel Station or any other that does not have any direct impact on daily operations. All other technical requirements, standards and procedures remain the same.

8 Monitoring and Operation

8.1 Landfill Monitoring

The proposed monitoring system for landfills classified in Classes 1 and 2, consists of:

- Leachate monitoring system;
- Groundwater monitoring system;
- Surface water monitoring system;
- Gas monitoring system; and
- Settlement monitoring system.

Part of the overall monitoring system is also a series of parameters, which have a significant role in organizing and monitoring the various processes in the landfill. These parameters are the following:

- Meteorological data;
- Volume and composition of the incoming waste; and
- Monitoring of all the supportive works and registering of all problems that affect the proper operation of the facility.

All data collected from the monitoring systems should be kept on-site in appropriately organized records. The parameters to be measured and the methodology are presented in Annex 1.

8.1.1 Leachate Monitoring

The volume of the produced leachate should be measured with the installation of a suitable flow meter at the exit of the transfer pipe prior to discharge of generated leachate to the leachate storage infrastructure.

Leachate samples will be taken from leachate storage infrastructure, while treated leachate samples should be taken from the treatment facility if applicable.

8.1.2 Groundwater Monitoring

The groundwater monitoring system serves two main purposes:

- To demonstrate that the landfill is not causing significant degradation of groundwater; and
- To evaluate characteristics, magnitude, and extent of contamination of the groundwater resource if groundwater composition has been degraded.

There will be two types of groundwater monitoring wells:

- Down-gradient wells; and
- Up-gradient wells.

The up gradient well will present the pre-existing condition of the groundwater prior to any effect of landfill operation and should be installed in a location that will not be affected by the construction or operations during the lifetime of landfill. It will be used as a reference point and a minimum of one (1) well is required.

The down-gradient wells will be located downstream to detect any sign of leachate leaking out of landfill waste cell and should consist of a minimum of two (2) wells.

Samples should be collected at the same period from both up-gradient and down-gradient wells to provide data on seasonal or long-term trends in groundwater.

Even though the condition of the groundwater may change over time because of natural or other (not related to the landfill) effects, monitoring both the up-gradient and down-gradient wells, landfill related changes will be identified to prevent further pollution.

The results of all sample analysis taken from the wells must be reviewed and interpreted by a Certified Laboratory that can identify if there are potential negative impacts upon the underlying groundwater which could indicate a failure in the existing lining systems.

The parameters to be measured and frequency of sampling are presented in Annex 1.

8.1.3 Surface Water Monitoring

The surface water monitoring system involves frequent visual inspections. Evidence of degradation may include obvious signs, such as dead or unhealthy flora and fauna, visible leachate pools or streams, unnatural water clarity or colour and unusual odours.

Apart from visual inspections, surface water should be checked quarterly during operating phase and every six months during aftercare phase. During those sampling rounds, field measurements at representative surface water locations should be taken (if available), measuring parameters, and using the methodology indicated in Annex 1.

Two (2) sampling points are required as a minimum (if available). The first sampling point should be in the higher point of the perimetric stormwater drainage ditch while the second one should be at the lower - discharge point. In this way possible leachate leakage/contamination will be monitored.

8.1.4 Gas Monitoring

Monitoring of gas is a procedure that involves two key elements:

- Knowledge of the produced gas volume and composition; and
- Monitoring of possible gas migration.

The first goal of gas monitoring can be achieved via a portable landfill gas measurement device (landfill gas analyser). This device should be equipped with gas probes and a data logger (for data storage and uploading to a server or a computer). Measurements will take place at landfill gas wells and should at least include pressure, methane content, carbon dioxide content and oxygen content.

The quantity of produced gas can be recorded via the flare.

Landfill gas migration requires specific procedures to be established for its assessment. The need for gas migration monitoring comes from its flammability and explosive potential.

The purpose of gas migration monitoring is to ensure that the gas does not migrate and accumulates in on-site structures or offsite locations, in concentration level that could be potentially hazardous for humans and environment.

For inspection of possible migration, monitoring boreholes of small depth (not exceeding 6.0 m) should be drilled in outside the perimeter of landfill waste cell basin. The distance between boreholes should not exceed 50 m.

8.1.4.1 Explosive gasses control

Landfill Operators of all Landfill Classes units must ensure that:

- The concentration of methane gas generated by the facility does not exceed 25 percent of the Lower Explosive Limit (LEL) for methane in facility structures (excluding gas control or extraction system components); and
- The concentration of methane gas does not exceed 100 percent of the Lower Explosive Limit (LEL) for methane at the facility property boundary.

The LEL for methane is 5% (methane/air).

8.1.5 Settlements Monitoring

The number and location of occurring settlements is an important parameter to be monitored and can directly affect all aspects of the waste cell. Thus, it is essential that a record of this phenomenon is kept, including all collected data.

The measurement of the settlements could be done by two methods:

- Comparison between surveys that are conducted every three (3) months during the first year from closure, every six (6) months for the next two (2) years and once a year for the following years until the end of aftercare period which is defined by the Competent Authority;
- Installation of settlement plates and monitoring every three (3) months during the first year from closure and every six (6) months until the end of aftercare period.

A record should be kept with all implemented surveys so that those can be compared according to the schedule of implementation and locate the exact location or areas where settlements have occurred.

The settlement plates are installed on the waste surface (in the areas where final waste height has been reached). These plates include a steel plate (4.0 mm thickness) where a steel pipe (2" diameter) is welded. The base of the settlement plates is installed on the levelling layer of the capping system secured in its position by a concrete layer (thickness 0.20 m). The iron pipe is used to measure height reduction in the event of occurring settlements.

For better monitoring of the settlements, settlement plates should be placed on the waste relief of the landfill in a grid of approximately 50 m or with a density of 1 per 3,000m².

The initial elevation of pipes is measured, recorded, and compared with the elevation retrieved from next measurement. The measurements should be done every month at the beginning of the rehabilitation works and till their completion, every 3 months the next year and every 6 months till the expiration of the aftercare period of the landfill.

8.2 Construction Quality Assurance (CQA)

Development and implementation of a Construction Quality Assurance (CQA) Plan provides the means of demonstrating to the public and regulating authorities that the landfill is constructed to meet the design requirements. While it is the responsibility of the Construction Contractor to implement the requirements of the CQA Plan, a suitably qualified 3rd Party CQA Engineer should be appointed to supervise this implementation during the full construction period.

The CQA plan must be able to verify:

- That all materials used comply with landfill design specifications;

- That all methods of construction/installations are according to requirements; and
- That design requirements of all structures, equipment and operations have been met.

Moreover, CQA plan must contain at least the:

- Material/construction specifications and standards;
- Testing methods, frequency, and standards;
- Corrective action to be taken where necessary;
- Appropriate documentation of all executed procedures;
- Emergency plan;
- All elements of the landfill basal liner system;
- All elements of the landfill capping system;
- All elements surface water drainage system;
- All elements of leachate management system;
- All elements of gas management system;
- All elements of environmental monitoring system; and
- All infrastructure and equipment.

The production of the CQA Plan, and all testing and reporting must be completed under the management of a suitably qualified Engineer or Company, independent to the landfill's Contractor/Operator.

On completion, a validation report should be implemented and submitted to the Competent Authority and should include:

- Demonstration of CQA compliance throughout the construction period;
- Justifications for any deviations from the initially agreed plan;
- The results of all testing, this should include the records of any failed tests accompanied with a written explanation, and details of the remedial action taken, referenced to the relative secondary testing;
- Plans to present the location of all tests;
- "As-built" drawings and sections of the works;
- Copies of site's Engineer daily records;
- Records of any problems or non-compliances and applied solution; and
- Any other site-specific information considered relevant to prove the integrity of the construction.

Laboratory testing with respect to CQA must be undertaken to the national or relevant international standard (such as ASTM or ISO). Generally, it is recommended that as a minimum, the manufacture, test methods and installation of geosynthetic products should comply with the latest version of the relevant Geosynthetics Research Institute (GRI) Specifications as well as manufacturer guidelines for each specific product used. The use of these standards and any required project-specific adjustments shall be covered in the design, specifications and CQA Plan as developed by a suitably qualified Engineer.

8.3 Working Plan

A Site-Specific Working Plan in accordance with landfill site waste management licence application is required be developed and forwarded to the Centre for review and approval prior to commencement of the site operations.

The Working Plan will include all documentary procedures which will be applied to control all aspects of works and operations on site.

Issues to be considered and should be included within the Working Plan are outlined in the following sections.

8.4 General Filling Plan Requirements

The knowledge of quantity, type, and properties of accepted incoming waste is vital for the design, construction, and operation of a landfill site.

A key element, required for the construction and operation of a landfill, is the filling sequence plan. The filling sequence plan is designed according to the prediction of the evolution of waste cell filling over time, which subsequently is related to the selected filling operation methods. The filling plan is the way in which the landfill will be gradually filled with waste.

In relation to the filling plan requirements, the following definitions should be considered:

- **Daily cell:** the basic structural unit of the landfill. The dimensions of the cell may differ from day to day. The main objective is to construct a cell which can handle the day's volume of solid waste, and which will require the minimum amount of daily cover soil;
- **Lift:** a set of cells with the same altitude consists of a lift. Lift is the ground level where the movement of the trucks takes place;
- **Cell:** is a specific area where the lifts are built according to the fill sequence plan of the landfill.

The main principles of the filling plan are presented below:

- Creation of well compacted and covered lifts with slopes not exceeding 1(V):3(H) and upper surface gradient of minimum 5.0 %;
- Creation of small active working front which should not exceed 1(V):3(H) slope aiming to avoid failures or corrosion;
- Minimization of the stormwater inflow into the active cell resulting in lower leachate production;
- Provision of easy and safe accessibility to the waste trucks in all phases of the cell's development;
- Creation of backup working fronts for use in case of emergencies; and
- Stormwater should not pass over the working face but should travel peripherally outside the storage area.

8.4.1 Initial Deposition

The deposition of the first layer of waste is one of the most sensitive procedures in the operation of the waste cell, because it is a critical point where failures often may occur. When depositing the first layer there is a risk of:

- Damage to the basal lining system; and/or
- Damage to the leachate collection network.

To avoid the above risks, it is necessary to lay the first layer of waste in the following way:

- The entrance ramp of the vehicles in the basin is constructed from top to bottom, so that the machines that shape it are always based on the compacted soil material of the ramp and not on the bottom of the cell;
- At the end of the entrance ramp, a temporary manoeuvring platform should be constructed for the waste trucks;
- The initial layer of waste should be carefully placed and spread from the constructed platform. This initial layer of waste should consist of fine waste material, and should specifically exclude any bulky or sharp materials which could damage the lining system;
- This first layer of waste is to be laid in bulk and should not be compacted;
- The purpose of this is to create a layer on which the disposal operations can follow, without damaging the drainage layer and the underlying liner systems. The area that will be laid each time in this way, will be covered with a covering material. The thickness of the layer to create a single surface will be of the order of 0.80 m – 1.0 m; and
- This process continues until the entire surface of the cell basin is covered with fine waste.

8.4.2 General Deposition

The Landfill Operator must consider the prevailing wind direction and strength when planning the filling direction and sequence as this will assist in the general reduction of nuisance caused by odour, dust, litter, and noise. Careful phasing is critical in minimising airborne emissions.

During landfilling operations in the waste cell, a temporary road should be constructed from the cell's access ramp to the operational working face. The underlying layers of the cell's temporary road can be made of well compacted waste, without containing any sharp edges and covering of at least 0.40m compacted soil.

Inside the landfill cell, the disposal and burial of the waste should start from downstream to upstream direction. Filling plan development will begin in daily cells of 2.5 – 3.0 m thick each, starting from the lowest points of the available space. The waste trucks, via the temporary route, will approach the working front, where they will deposit the waste. Temporary roads within the cell will be constructed on a 0.50 m height embankment and will be regularly maintained, so that the passage of vehicles through this route will be safe.

The waste disposal should be unloaded as close as possible to the working face. Upon unloading, the machine (dozer) will push forward the disposed waste towards the slope, in a downstream direction. The created surface will be the new level on which the incoming wastes will be unloaded, in order to follow the same procedure again.

8.4.3 Daily and Final Cover

Daily cover assists in preventing materials becoming windblown, deterring scavengers, birds, and vermin, and improving site's visual appearance. The coverage of the waste must be done daily except for the working face slope, which is covered at the end of each week. The required soil quantity for the temporary cover will be transferred from stockpile area, with sufficient material available to create a covering layer of 0.15 – 0.20 m thick.

The Landfill Operator should identify any wastes which have characteristics requiring a particular method of handling at the site and which is not part of day-to-day procedures. Typical examples are:

- Fine particulate material;
- Empty containers;
- Oversize objects;

- Sludges;
- Very light materials, for example expanded polystyrene; and
- Foul smelling wastes.

Consideration should be given to pre-treatment of these types of wastes to reduce handling difficulties.

When cell reaches the final height as per the design, the final levelling layer will be constructed (refer to Section 7.5.1.1). For the upper flat surfaces of the final waste level, the gradient should be a minimum of 5.0 % to allow for suitable stormwater drainage.

The top and side surfaces of a completed cell, which are not to be covered by another cell, should be covered with a layer of at least 0.50 m of compacted soil. This intermediate cover should be thick enough to prevent erosion of the cover by wind, water, and traffic.

A final compaction ratio of between 0.80 – 1.20 tonnes/m³ is optimal to initiate the biodegrading process and ensure suitable stability and capacity within the landfill cell.

8.5 Waste Acceptance

The Waste Acceptance Criteria (WAC) that the incoming Waste must meet to be accepted for disposal in each classified landfill shall be established in accordance with the requirements and technical controls on waste landfilling issued by the MWAN and in accordance with conditions and provisions of the License or Permit.

8.6 Unacceptable Loads

All loads which fail to meet the Waste Acceptance Criteria must be managed in accordance with the requirements set in the Technical Guideline.

Analytical details of all materials held within the unacceptable load quarantine area must be kept. As a minimum requirement the following records should be held for every load:

- Date of arrival;
- Details of the source of the waste and the company/waste truck bringing the load to the site;
- The type of waste; and
- Quantity transported.

All labelling must be resilient enough to stay attached and legible throughout the entire of storage time at the quarantine area.

Daily inspection of the condition of containers and pallets must be undertaken, and written records should be kept of these inspections. If a container is found to be damaged, leaking or in a state of deterioration, it must be immediately contained, or otherwise the contents transferred to another container or processed.

All spillages of hazardous wastes must be logged. Where spillages are greater than 200 litres the MWAN must be informed as soon as possible.

Containers must be stored in such a manner that leaks and spillages cannot drain outside the quarantine area.

8.7 Operations and Maintenance

As a minimum, effective operational and maintenance systems should be employed on all aspects in the site where failure could impact the environment or human health.

Operational and Maintenance systems should include:

- Documented procedures to control operations that may have an adverse impact on the environment and human health;
- A defined procedure for identifying, reviewing, and prioritising items of plant for which a preventative maintenance regime is appropriate;
- Documented procedures for monitoring emissions; and
- A preventative maintenance programme covering all site infrastructure and facilities, the failure of those could lead to hazard impacts on the environment. The maintenance system should include auditing of performance against requirements arising from the above and reporting the result of audits to senior management.

Auditing and inspection records must be maintained for a minimum of 5 years and be provided to the Competent Authority or their designated representative, when requested.

8.8 Competence and Training

Training must be provided to all personnel of the landfill site with respect to:

- Health and Safety and individual responsibilities that all personnel should maintain; and
- Understanding of the environmental impacts that personnel's tasks could have and provision of instructions to assist in mitigating any negative impacts.

8.9 Accident Plans

An Accident Plan must be compiled by the Landfill Operator and reviewed at least once every three (3) years, or in the event of an accident and should include and identify:

- The chances and consequences of accidents; and
- Actions to prevent accidents.

The Accident Plan must:

- Identify potential for on-site accidents or hazards;
- Provide an assessment of the risks;
- Identify necessary risk management/mitigation measures;
- Specify any risk management measures that are used at the landfill;
- Include contingency actions to be taken in the event of an accident to mitigate consequences; and
- Make provision for the hazards displayed by any hazardous wastes accepted at the landfill.

Specific elements of accidents to be considered at landfills may include, but should not be limited to, the following:

- Uncontrolled migration of landfill gas;
- Fire;
- Explosion;
- Waste slippage;

- Failure of a basal or side wall liners;
- Incompatible wastes coming into contact to each other;
- Discharge of leachate to an uncontained area;
- Overfilling of leachate storage infrastructure;
- Emission of a treated leachate before adequate checking of its composition;
- Failure of leachate pumps;
- Traffic accident; and
- Failure of surface water drainage causing flooding.

9 Record Keeping and Reporting

The Landfill Operator shall report to the MWAN as follows:

- a. Monthly, the data recorded following the monitoring, to demonstrate compliance with the provisions of the Licence;
- b. Within maximum 12 hours from the finding, any significant negative ecological effects revealed by the control and monitoring program and follow the decision of the MWAN on the nature and timing of the corrective measures to be taken.

The Landfill Operator shall promptly notify the competent authority for environmental protection of significant adverse effects on the environment and comply with the decision of the competent authority for environmental protection on remedial measures imposed in the post-closure period.

9.1 Volume and Composition of Incoming Waste and Soil Material for Coverage

The Landfill Operator must keep records for a series of information collected during the inspection and weighing of the incoming waste trucks at the entrance of the site. The record must include type and quantity (in tonnes) of waste received along and must be provided to the Competent Authority at an agreed frequency and in an agreed format. Also, it must be always available for random inspection.

This information should include:

- Source of waste;
- Type of waste;
- Weight of waste;
- Title and address of the owner of the vehicle, full name, and telephone number of the responsible; and
- Title and address of the waste producer, full name, and telephone number of the responsible.

In every inspection the following information will be registered:

- Date and time of inspection;
- Source of incoming waste;
- Vehicle and driver's data; and
- Observations and remarks of the inspector.

The above-mentioned inspections will provide information for the composition of the incoming waste and its variation through the year and according to their source.

Finally, during the entry of the waste vehicles, the volume and source of incoming daily cover material should be registered as well.

9.2 Records of Significant Events

The following significant events must be recorded, on site:

- The start and end of any construction and engineering works undertaken on site;
- Start and end of any waste management processes carried out on site;
- Maintenance of machinery and equipment;

- Breakdown events;
- Emergencies;
- Problems with accepted waste and actions taken;
- Site inspections;
- Despatched records to the Competent Authority;
- Events of severe climatic conditions or disasters;
- Complaints; and
- Pest or vermin incidents.

The Site Manager or nominated person must maintain a record of the above information in the site diary on a daily basis. The site diary must be always kept at the site and be available for inspection at all reasonable times by any officer of the Competent Authority.

9.3 Archiving of Records

Copies of all records related to wastes movements must be kept on site by the Site Manager for at least three (3) years, before archiving. Moreover, archived records should be kept by for a period of twelve (12) years following site closure.

10 Site Closure and Aftercare

10.1 Site Closure Plan

The Landfill Operator is required to develop and maintain a Site Closure Plan which will include the following as a minimum:

- Confirmation of the capping system including performance characteristics;
- Detailed information on the leachate and gas collection system and its performance throughout the filling operations. Issues to be included are related to the proposed completion date of leachate and gas control;
- Monitoring plan for the site with respect to leachate (and underlying groundwater) quality and gas production to determine when site closure is achieved (that is, when significant leachate production has ceased, and landfill gas monitoring levels indicate low concentrations of Methane and Carbon Dioxide over a two-year period);
- Removal of pipelines and structures where applicable and the complete emptying of any potentially harmful contents;
- Plans of all underground pipes and structures;
- The method and resource necessary for the clearing of leachate storage infrastructures (if applicable);
- Methods of dismantling buildings and other structures; and
- Testing of the soil to determine the degree of any pollution caused by the operations performed and the need for any remediation measures to return the site to a satisfactory state as defined by the initial site report.

Moreover, Article (171) and Article (172) of the Implementing Regulations of the Waste Management Law must be considered in the development of the Site Closure Plan.

The Site Closure Plan must be reviewed at least once every three (3) years. Other reasons for the review of the Site Closure Plan would include any proposed changes to the phasing of the landfill. The Plan should be kept updated and must include all changes occurring.

10.2 Aftercare Monitoring

Monitoring plays a vital part in determining the overall performance of the landfill against any initial assumptions made and annual reviews should consider the progress made.

The landfill operator should carry out the post-closure monitoring, for a period established by the competent authority (minimum 30 years). This period may be extended if during the monitoring program the landfill is found to be unstable and may present any risks to the environment and human health.

The values measured/observed for each environmental factor are compared with those provided by the legislative norms in force. The Landfill Operator should monitor the following:

- Quality and volume (quantity) of leachate production (both throughout closure and post-closure of the landfill);
- Impact of generated leachate on the underlying groundwater quality, considering the parameters outlined in Appendix 1;
- Generation, flow, and concentration of gas;

- Composition of the gas;
- Potential for leachate or gas to be generated in future;
- Stability of the waste body, capping system, and infrastructure; and
- Presence of specific problematic issues and concerns which could present a risk in the future.

The operator of the landfill is obliged to report the results of the aftercare monitoring activity to the competent authority, at its request.

Annexes

1. Environmental Monitoring Parameters

At the time of writing, the Competent Authority related to Environmental Monitoring is the National Center of Environmental Compliance (NCEC). All Requirements and Standards set by NCEC relevant to the landfill shall be adopted for the purposes of monitoring, including any provisions outlined in the environmental permitting process.

The purpose of this Annex is only to provide a guidance in the event that the aspects mentioned below are not sufficiently covered in the NCEC standards or permitting requirements.

The minimum procedures to be considered during environmental monitoring must check:

- That waste has been accepted and disposed in accordance with the criteria set for the Class of landfill;
- That the processes within the landfill proceed as desired;
- That the environmental protection systems are functioning fully as intended; and
- That the permit conditions for the landfill are fulfilled.

Meteorological Monitoring Parameters

Within the framework of the environmental monitoring system, it becomes necessary to record the main meteorological parameters, such as rainfall, temperature, winds, evaporation, and humidity, both during the operation phase and after its closure.

Meteorological Data Parameters

	OPERATION PHASE	AFTER-CARE PHASE
Volume of precipitation	daily	daily, added to monthly values
Temperature (min., max.)	daily	monthly average
Direction and force of prevailing wind	daily	not required
Evaporation (lysimeter) (*)	daily	daily, added to monthly values
Atmospheric humidity	daily	monthly average

(*) Or through other suitable methods.

Leachate, Surface Water & Gas Monitoring Parameters

Sampling of leachate and surface water if present must be collected at representative points. Sampling and measuring (volume and composition) of leachate must be performed separately at each point at which leachate is discharged from the site.

Monitoring of surface water if present shall be carried out at no less than two points, one upstream from the landfill and one downstream.

Gas monitoring must be representative for each section of the landfill. The frequency of sampling and analysis is listed in the following table. For leachate and water, a sample, representative of the average composition, shall be taken for monitoring.

	OPERATION PHASE	AFTER-CARE PHASE ⁽²⁾
Leachate volume	monthly ⁽¹⁾ ⁽³⁾	every six months
Leachate composition ⁽²⁾	quarterly ⁽³⁾	every six months
Volume and composition of surface water ⁽⁷⁾	quarterly ⁽³⁾	every six months
Potential gas emissions and atmospheric pressure ⁽⁴⁾ (CH ₄ , CO ₂ , O ₂ , H ₂ S, H ₂ etc.)	monthly ⁽¹⁾ ⁽⁵⁾	every six months ⁽⁶⁾
⁽¹⁾ The frequency of sampling could be adapted based on the morphology of the landfill waste (in tumulus, buried, etc.). This must be specified in the permit. ⁽²⁾ The parameters to be measured and the substances to be analysed vary according to the composition of the waste deposited; they must be laid down in the permit document and reflect the leaching characteristics of the wastes. ⁽³⁾ If the evaluation of data indicates that longer intervals are equally effective, they may be adapted. For leachates, conductivity must always be measured at least once a year. ⁽⁴⁾ These measurements are related mainly to the content of organic material in the waste. ⁽⁵⁾ CH₄, CO₂, O₂, regularly, other gases as required, according to the composition of the waste deposited, with a view to reflecting its leaching properties. ⁽⁶⁾ Efficiency of the gas extraction system must be checked regularly. ⁽⁷⁾ On the basis of the characteristics of the landfill site, the competent authority may determine that these measurements are not required and will report accordingly Leachate volume and Leachate composition apply only where leachate collection takes place.		

Groundwater Monitoring Parameters

A. Sampling

The measurements must be such as to provide information on groundwater likely to be affected by the discharging of waste, with at least one measuring point in the groundwater inflow region and two in the outflow region. This number can be increased based on a specific hydrogeological survey and the need for an early identification of accidental leachate release in the groundwater.

Sampling must be carried out in at least three locations before the filling operations to establish reference values for future sampling.

B. Monitoring

The parameters to be analysed in the samples taken must be derived from the expected composition of the leachate and the groundwater quality in the area. In selecting the parameters for analysis account should be taken of mobility in the groundwater zone.

Parameters could include indicator parameters to ensure an early recognition of change in water quality. Recommended parameters: pH, TOC, phenols, heavy metals, fluoride, AS, oil/hydro-carbons.

	OPERATION PHASE	AFTER-CARE PHASE
Level of groundwater	every six months ⁽¹⁾	every six months ⁽¹⁾
Groundwater composition	site-specific frequency ⁽²⁾ ⁽³⁾	site-specific frequency ⁽²⁾ ⁽³⁾
⁽¹⁾ If there are fluctuating groundwater levels, the frequency must be increased. ⁽²⁾ The frequency must be based on possibility for remedial actions between two samplings if a trigger level is reached, i.e., the frequency must be determined based on knowledge and the evaluation of the velocity of groundwater flow. ⁽³⁾ When a trigger level is reached (see C), verification is necessary by repeating the sampling. When the level has been confirmed, a contingency plan (laid down in the permit) must be followed.		

C. Trigger levels

Significant adverse environmental effects should be considered to have occurred in the case of groundwater, when an analysis of a groundwater sample shows a significant change in water quality. A trigger level must be determined taking account of the specific hydrogeological formations in the location of the landfill and groundwater quality. The trigger level must be laid down in the permit whenever possible.

The observations must be evaluated by means of control charts with established control rules and levels for each downgradient well. The control levels must be determined from local variations in groundwater quality.

LIST I OF FAMILIES AND GROUPS OF SUBSTANCES

List I contain the individual substances which belong to the families and groups of substances enumerated below, except for those which are considered inappropriate to List I based on a low risk of toxicity, persistence, and bioaccumulation. Such substances which regarding toxicity, persistence and bioaccumulation are appropriate to List II are to be classed in List II.

1. Organohalogen compounds and substances that may form such compounds in the aquatic environment
2. Organophosphorus compounds
3. Organotin compounds
4. Substances which possess carcinogenic, mutagenic, or teratogenic properties in or via the aquatic environment. Where certain substances in List II below are carcinogenic, mutagenic, or teratogenic, they are included in category 4 of this List.
5. Mercury and its compounds
6. Cadmium and its compounds

7. Mineral oils and hydrocarbons

8. Cyanides

LIST II OF FAMILIES AND GROUPS OF SUBSTANCES

List II contains the individual substances and the categories of substances belonging to the families and groups of substances listed below which could have a harmful effect on groundwater.

1. The following metalloids and metals and their compounds:

Zinc	Selenium	Tin	Vanadium
Copper	Arsenic	Barium	Cobalt
Nickel	Antimony	Beryllium	Thallium
Chromium	Molybdenum	Boron	Tellurium
Lead	Titanium	Uranium	

2. Biocides and their derivatives not appearing in List I.

3. Substances which have a deleterious effect on the taste and/or odour of groundwater, and compounds liable to cause the formation of such substances in such water and to render it unfit for human consumption.

4. Toxic or persistent organic compounds of silicon, and substances which may cause the formation of such compounds in water, excluding those which are biologically harmless or are rapidly converted in water into harmless substances.

5. Inorganic compounds of phosphorus and elemental phosphorus.

6. Fluorides.

7. Ammonia and nitrites.

Settlements Monitoring Parameters

	OPERATION PHASE	AFTER-CARE PHASE
Structure and composition of landfill body (¹)	yearly	-
Settling behaviour of the level of the landfill body	yearly	yearly reading
(¹) Data for the status plan of the concerned landfill: surface occupied by waste, volume and composition of waste, methods of depositing, time and duration of depositing, calculation of the remaining capacity still available at the landfill.		

Summary

1. Leachate Monitoring Parameters and Sampling:

The parameters to be measured as well as the frequency of sampling are shown in the following table:

PARAMETERS	FREQUENCY	
	OPERATIONAL PERIOD	AFTERCARE PERIOD
Leachate Volume	Monthly	Every 6 months
Leachate composition	Every 3 months	Every 6 months
Treated Leachate Composition	Monthly	Monthly

The parameters to be analysed from the samples taken are the following:

- pH	- Ammonium (NH ₄ -N)	- Phenols
- Conductivity	- Organic N	- Phosphate
- Odours	- Cl	- Total Solids (TS)
- Temperature	- Zn	- Volatile Solids (VS)
- BOD ₅	- As	- Suspended solids (SS)
- COD	- Cd	- Dissolved Solids (DS)
- TOC	- Cu	
- SO ₄	- Ni	

2. Groundwater Monitoring Parameters and Sampling:

The parameters to be measured as well as the frequency of sampling are shown in the following table:

PARAMETERS	FREQUENCY	
	OPERATIONAL PERIOD	AFTERCARE PERIOD
Level of Groundwater	Every 3 months	Every 6 months
Groundwater composition	Every 3 months	Every 6 months

The parameters to be analysed from the samples taken are the following:

- pH	- Ammonium (NH ₄ -N)	- Phenols
- Conductivity	- Organic N	- Phosphate
- Odours	- Cl	- Total Solids (TS)
- Temperature	- Zn	- Volatile Solids (VS)
- BOD ₅	- As	- Suspended solids (SS)
- COD	- Cd	- Dissolved Solids (DS)
- TOC	- Cu	
- SO ₄	- Ni	

3. Surface water Monitoring Parameters and Sampling:

The parameters to be measured as well as the frequency of sampling are shown in the following table:

PARAMETERS	FREQUENCY	
	OPERATIONAL PERIOD	AFTERCARE PERIOD
Volume of surface water	Every 3 months	Every 6 months
Composition of surface water	Every 3 months	Every 6 months

The parameters to be analysed from the samples taken are the following:

- pH	- Ammonium (NH ₄ -N)	- Phenols
- Conductivity	- Organic N	- Phosphate
- Odours	- Cl	- Total Solids (TS)
- Temperature	- Zn	- Volatile Solids (VS)
- BOD ₅	- As	- Suspended solids (SS)
- COD	- Cd	- Dissolved Solids (DS)
- TOC	- Cu	

- SO ₄	- Ni	
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4. Gas Monitoring Parameters and Sampling:

The parameters to be measured as well as the frequency of sampling are shown in the following table:

PARAMETERS	FREQUENCY	
	OPERATIONAL PERIOD	AFTERCARE PERIOD
Produced gas volume	monthly	Every 6 months
Pressure, methane content, carbon dioxide content and oxygen content	monthly	Every 6 months

The parameters to be analysed from the samples taken are the following:

CH₄, CO₂, O₂, regularly, other gases as required, according to the composition of the waste deposited, with a view to reflecting its leaching properties.

5. Settlements Monitoring Parameters and Sampling:

The parameters to be measured as well as the frequency of sampling are shown in the following table:

	OPERATION PHASE	AFTER-CARE PHASE
Structure and composition of landfill body	yearly	
Settling behaviour of the level of the landfill body	yearly	yearly reading



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