THE REPUBLIC OF UGANDA

GUIDELINES FOR THE MANAGEMENT OF LANDFILLS IN UGANDA

NATIONAL ENVIRONMENT MANAGEMENT AUTHORITY (NEMA)
NEMA House Plot 17/19/21 Jinja Road
P.O. Box 22255 Kampala Uganda
Tel: +256 -414-251064/5/8
Fax: +256 -414-257521
Email: info@nema.go.ug
Website: http://www.nema.go.ug

December 2020

THE REPUBLIC OF UGANDA

GUIDELINES FOR THE MANAGEMENT OF LANDFILLS IN UGANDA

December 2020

NATIONAL ENVIRONMENT MANAGEMENT AUTHORITY (NEMA)
NEMA House Plot 17/19/21 Jinja Road
P.O. Box 22255 Kampala Uganda
Tel: +256 -414-251064/5/8
Fax: +256 -414-257521
Email: info@nema.go.ug
Website: http://www.nema.go.ug

Table of Contents

FOREWORD......V
EXECUTIVE SUMMARY......VI
ACKNOWLEDGEMENTS......VII
LIST OF ABBREVIATIONS......IX
LIST OF TABLES......X
LIST OF LEGISLATION......XI

CHAPTER ONE: GENERAL INTRODUCTION AND PRINCIPLES......1
1.0 .Introduction......1
1.1. Overview of the physical characteristics of Uganda......1
1.2. Waste generation and composition......2
1.3 Capacity to manage waste......3
1.4 Rationale for waste management......3
1.5 Objectives and existing legislation......4
1.6 Guiding Principles......5
1.7 Waste management hierarchy......6
1.8 Application of Guidelines to new and existing landfill sites......7
1.9 Target Audience......7
1.10 Revision of Guidelines......7
CHAPTER TWO: LANDFILL CATEGORIES AND APPROVALS......8
2.0 Introduction......8
2.1 Class 1 landfill – landfill for hazardous waste......8
2.2 Class 2 landfill– landfill for non-hazardous waste......8
2.3 Waste acceptance criteria and procedures for the landfill categories......8
2.4 Waste prohibited from being landfilled......9
2.5 Potential impacts from landfills......9
2.6 Environmental and social assessments, licences and other approvals......10
CHAPTER THREE: SITE SELECTION, DESIGN AND DEVELOPMENT......13
3.0 Siting of a landfill......13
3.1 Criteria for siting of landfills......13
3.2 Location, site selection and design......14
3.3 Quality assurance and quality control......17
3.4 Site development......17

CHAPTER FOUR: LANDFILL LINER SYSTEM.....19

4.0 Requirements for a landfill liner system.....19

4.1 Requirements of Liner Systems.....19

4.2 Soils.....20

4.3 Geo-membranes (flexible membrane liners).....20

4.4 Geo-textile protection layers.....21

4.5 Field trials.....21

CHAPTER FIVE: PROTECTION OF SOIL AND WATER.....22

5.0 Protection of soil and water.....22

5.1. Requirements - Barriers for soil and water protection.....22

5.2 Groundwater management.....23

5.3 Surface and stormwater management.....23

5.4 Active area drainage.....24

CHAPTER SIX: LEACHATE MANAGEMENT.....25

6.0 Leachate components.....25

6.1 Design criteria.....25

6.2 Leachate drainage, collection and removal.....26

6.3 Leachate storage.....27

6.4 Recirculation of leachate.....27

CHAPTER SEVEN: LANDFILL GAS MANAGEMENT.....33

7.0 Landfill gas.....33

7.1 Requirements – principles.....33

7.2 Objectives of a landfill gas management system.....34

7.3 Landfill gas quantities and properties.....34

7.4 Landfill gas extraction – design and function.....35

7.5 Movement of landfill gas.....37

7.6 Operational criteria and principles.....37

7.7 Optional/supplementary schemes.....38

7.8 Utilisation.....39

CHAPTER EIGHT: SITE DEVELOPMENT – INFRASTRUCTURE.....41

8.0 Site infrastructure.....41

8.1 Site services.....41

8.2 Access and internal roads.....42

8.3 Operational facilities.....42

8.4 Administration facilities.....44

CHAPER NINE: OPERATING AND MANAGING A LANDFILL.....46

9.0 Introduction......46

9.1 Environmental mitigation measures......46

9.2 Landfill operation......48

9.3 Capping design and purpose......53

9.4 Occupational safety, health and security......56

9.5 Community engagement......56

CHAPTER TEN: ENVIRONMENTAL MONITORING OF A LANDFILL......57

10.0 Environmental monitoring......57

10.1 Baseline situation......57

10.2 Groundwater monitoring from non-hazardous landfills......57

10.3 Surface water monitoring......59

10.4 Leachate and leachate sediment monitoring......61

10.5 Landfill gas monitoring......63

10.6 Monitoring of other environmental impacts and mishaps......65

10.7 Environmental monitoring of landfills of Class 1 for hazardous waste......66

10.8 Environmental monitoring of landfills for inert waste......67

10.9 Operational monitoring of non-hazardous landfills......67

10.10 Maintenance monitoring for equipment and facilities......67

10.11 Reporting – frequency, structure and content......67

CHAPTER ELEVEN: LANDFILL CLOSURE, DECOMMISSIONING AND AFTERCARE......69

11.0Procedural matters......69

11.1Closure and Decommissioning......69

11.2Post-closure aftercare......70

APPENDIX 1: A BRIEF DESCRIPTION OF SOME OF THE PHYSICAL-CHEMICAL TREATMENT PROCESSES APPLIED TO LEACHATE PRE-TREATMENT......72

APPENDIX 2: BIOLOGICAL TREATMENT METHODS FOR LEACHATE......74

APPENDIX 3: PHYSICAL-CHEMICAL AND BIOLOGICAL TREATMENT METHODS FOR LEACHATE......76

APPENDIX 4: EXAMPLES OF GAS WELLS......77

GLOSSARY OF TERMS......78

REFERENCES......79

Foreword

After decades of environmental management and specifically, waste management in Uganda, the focus has shifted to ensuring that waste is no longer just disposed in dumpsites but is well managed in engineered landfills. The need is clear. Uganda's population has increased and urban centres have grown. With this growth comes the challenge of effective waste management.

To assist urban centres to manage waste effectively, it is important to distinguish the different types of waste, both hazardous and non-hazardous. The application of the waste management hierarchy to waste management is crucial, as some materials considered waste can actually be reused or recycled as circulative resources, and not disposed. Proper management of waste also contributes to the achievement of environmental principles.

Where it is determined that waste should be disposed, a careful evaluation of the waste disposal methods is necessary. It is not always advised to rush into landfilling as a disposal method. Rather, attempts must be made to dispose of waste using other viable methods such as incineration and composting of waste.

The waste handler must be well versed with the requirements before choosing landfills as a waste disposal method. The Guidelines for the Management of Landfills in Uganda of 2020, therefore, enable the waste handler to be focused on the salient aspects of landfilling of waste.

The Guidelines cover the entire value chain of a landfill, from design and environmental considerations, to surface and groundwater monitoring, the liner system, leachate collection, landfill gas, landfill infrastructure and operations, landfill closure, decommissioning and aftercare. The Guidelines provide detailed explanations, checklists and additional resources that give depth to the specific chapters.

The details in the respective chapters of the Guidelines give the much-needed guidance to a waste handler intending to set up and operate a landfill. This is also helpful to the regulator as all the crucial information on landfills is now available in one reference document, the Guidelines.

It is expected that the Guidelines will be read and applied in tandem with the National Environment Act of 2019, the Petroleum (Waste Management) Regulations of 2019, the National Environment (Waste Management) Regulations of 2020 and other applicable law. In this way, compliance will be entrenched.

Executive Summary

Proper management of waste is crucial to the achievement of a clean and healthy environment and, as such, obliges respect for the waste management hierarchy. The waste management hierarchy enjoins a person who generates waste, a waste handler or a product steward to apply good waste management practices in the following order; prevent, reduce and recover at source, reuse, recycle, recover material by other means, treat waste and then undertake responsible disposal of the waste. Viewed in this way, proper waste management is a key component of the circular economy, requiring the use of circulative resources in the production chain as well as minimising waste generation and disposal.

When it is determined that waste must be disposed, it is important to carefully consider the method of its disposal. The choice of the method depends on the type of waste and availability of other waste disposal options. When it comes to landfills as the option of choice for waste disposal, the Petroleum (Waste Management) Regulations S.I No. 3 of 2019 and the National Environment (Waste Management) Regulations S.I. No. 49 of 2020 apply.

In essence, some types of waste cannot be landfilled, because of the content and hazardous properties in the waste. Additionally, the location of a landfill must be well thought out. The law provides clear guidance in this regard.

The planning and design of the landfill should, therefore, follow specific guidance, including on location, type and placement of liners, placement of leachate management systems, design of the gas collection system, operational requirements and landfill closure, capping and post-closure requirements.

The person designing a landfill is required to put in place measures for the minimisation of greenhouse gases generated from waste deposited in the landfill. Migration of greenhouse gases should be strictly controlled, to enable capture of those gases, to be used to generate energy. For environmental reasons, flaring and venting of gases is prohibited except for normal operational purposes when no energy is produced and in emergency situations. In other words, the venting should be designed in such a manner that the methane gas is burned to curb its greenhouse effects.

The protection of human health and the environment from contaminants emanating from the landfill is a key consideration to be taken into account during design, operation and all other stages of a landfill. If not well designed and managed, surface and groundwater as well as soils can be polluted from leachate ingression. Air pollution may also be of such a magnitude as to impact health. The visual effects and aesthetics of the landfill have also been documented.

It is also important to consider whether a portion of the landfill facility area should be dedicated to composting of suitable organic waste. This is particularly important for sanitary landfills, to avoid unnecessary landfilling of waste and misuse of space. Composting of organic waste also provides opportunity for the waste handler to earn carbon credits under the Clean Development Mechanism of the Kyoto Protocol.

Alongside landfill design, location, and operation, the waste handler should be mindful about landfill closure, decommissioning and aftercare. Environmental monitoring is certainly a key element at this stage as well.

Prof. Sandy Stevens Tickodri-Togboa
Chairman, NEMA Board

Acknowledgements

On behalf of the Government, I would like to thank H.E the President of the Republic of Uganda for his strategic guidance to the development of the environment sector in Uganda. I particularly thank him for spearheading the partnership between Uganda and the Royal Government of Norway as the key Development Partner of choice in strengthening Uganda's institutional capacity for the management of petroleum resources through the environmental pillar of the Oil for Development Programme.

With the financial support provided under the Oil for Development Programme, the National Environment Management Authority (NEMA) was able to prepare the Guidelines for the Management of Landfills in Uganda, 2020. Special gratitude goes to the Norwegian Environment Agency for contracting Bridge Consults of Norway to guide the nature, scope and content of the Guidelines. Bridge Consults, we appreciate you.

The preparation of these Guidelines was a concerted effort involving a number of stakeholders including, Ministries Departments and Agencies (MDAs) and private sector, without whom it would not have been possible to make such comprehensive and streamlined Guidelines.

NEMA in particular appreciates the technical/core working group that developed the initial content for the Guidelines and worked tirelessly to refine the document until its completion. The Guidelines benefited tremendously from the contributions of the individuals who participated in piecing together the different aspects of the Guidelines but also in the painstaking review of the respective chapters. The group's invaluable contribution is much appreciated.

Of special mention is the staff from NEMA, the First Parliamentary Counsel of the Ministry of Justice and Constitutional Affairs, the Ministry of Water and Environment, the Petroleum Authority of Uganda, the Ministry of Works and Transport and Kampala Capital City Authority. Valuable contribution to the content of the Guidelines was also received from Enviroserve, to whom we say thank you.

Special gratitude is extended to Ms. Christine Akello Echookit the Deputy Executive Director of NEMA, for her commitment and dedication to leading the technical team in accomplishing these Guidelines. We thank Dr. Callist Tindimugaya the Commissioner, Water Resources, Planning and Regulation of the Directorate of Water Resources Management in the Ministry of Water and Environment and his staff, especially Ms Mary Nancy Nahabbo the Senior Water Officer and Mr. Joseph Odong the Water Officer, for interventions on water resources aspects of the Guidelines. We also thank Dr. Joseph Kobusheshe the Director Environment, Health, Safety and Security and the environment team from the Petroleum Authority of Uganda for the much-needed input into the Guidelines. Our appreciation also goes to Ms Clare Namanda the Environment Officer and Mr. Joel Kagina Mwesigye Officer Landfill Management, both of the Directorate of Public Health and Environment in Kampala Capital City Authority, for lending their experience to the development of these Guidelines. The input of the technical officers from NEMA in the review of the Guidelines is greatly appreciated. The NEMA staff include: Dr. Jerome S. Lugumira the Natural Resources Manager (Soils and Landuse); Mr. Fred Onyai the Internal Monitoring and Evaluation Manager; Ms Margaret Aanyu the Environment Assessment Manager; Mr. Isaac I.G. Ntujju the Principal Environment Inspector (Oil and Gas); Ms Patience Nsereko the Principal Environment Inspector (Audits and Monitoring); Ms Jennifer Kutesakwe the Senior Environment Inspector; Ms Monica Angom the Senior Environment Inspector (Chemicals); Mr. Dan K. Kiguli the Environment Inspector and Ms Eunice Asinguza the Senior Legal Officer.

Ms Stella Muheki, Mr. Tom Geme and Mr. Kevin Bakulu Mpagi, we thank you for your contribution. To Mr. Isaac Tindyebwa the Senior Environment Education Materials Production Officer of NEMA, we say thank you for the editorials and formatting of the Guidelines.

Special recognition goes to Ms Nancy Awori the Senior State Attorney in the First Parliamentary Counsel of the Ministry of Justice and Constitutional Affairs and Ms. Anette Fischer the Senior Advisor of Miljodirektoratet (NEA), for providing the legal oversight.

We also thank Mr. Frank Eklo the Senior Advisor of Miljodirektoratet (NEA) for providing the overall Programme oversight, and enabling the work on these Guidelines to be done in this challenging year, amidst the Covid-19 pandemic social distancing and virtual interaction interface.

It is my hope that the private sector waste handlers and the local authorities will use these Guidelines to plan, design and operate landfills in Uganda. I also trust that regulatory institutions including NEMA and relevant lead agencies will find these Guidelines very useful in monitoring and regulating landfills in a technical and professional manner.

…………………………………………………

Dr. Tom O. Okurut
EXECUTIVE DIRECTOR - NEMA

List of Abbreviations

AOX	Adsorbable organic halogens
BOD	Biological oxygen demand
CDM	Clean Development Mechanism
CEC	Cation exchange capacity
COD	Chemical oxygen demand
dB	Decibel
ESIA	Environmental and social impact assessment
GCL	Geosynthetic clay liner
GHS	Greenhouse gas emissions
HDPE	High-density polyethylene
LAeq	Equivalent continuous sound level. This is the most commonly used value used to describe sound levels that vary over time. An Leq is the level that would produce the same sound energy over a stated period of time when using a 3 dB exchange rate. It is defined as the sound pressure level of a noise fluctuating over a period of time T, expressed as the amount of average energy. Commonly written as Leq, LAeq, LAeq,t or LAT
LA10	The noise level exceeded for 10% of the measurement period with 'A' frequency weighting, calculated by statistical analysis
LA90	The noise level exceeded for 90% of the measurement period with 'A' frequency weighting, calculated by statistical analysis
LFG	Landfill gas
LLDPE	Linear low-density polyethylene
MDAs	Ministries Departments and Agencies
MDPE	Medium density polyethylene
NEMA	National Environment Management Authority
PPE	Personal protective equipment

List of Tables

Table 6.1: Leachate treatment methods and objectives
Table 6.2: General principles for constructed wetland design
Text box 7.1: Methods to estimate likely landfill gas production rates
Text box 7.2: Extraction pressure and other equipment
Text box 7.3: Flare equipment
Table 10.1: Groundwater monitoring
Table 10.2: Indicator parameters for surface water monitoring
Table 10.3: Parameters for leachate monitoring
Table 10.4: Monitoring combustion products from flare units

List of Legislation

1995 Constitution
Atomic Energy Act, Act 24 of 2008
National Environment Act, Act 5 of 2019
National Environment (Waste Management) Regulations S.I. 49 of 2020
National Environment (Standards for Discharge of Effluent into Water or Land) Regulations, 2020
Petroleum (Exploration, Development and Production) Act, Act 3 of 2013
Petroleum (Refining, Conversion, Transmission and Midstream Storage) Act, Act 4 of 2013
Petroleum (Waste Management) Regulations, S.I. 3 of 2019

Chapter One

General Introduction and Principles

1.0 Introduction

1.1 Overview of the physical characteristics of Uganda

1.1.1 Relief and Physiographic Regions of Uganda

Topologically, most of Uganda lies between 900 – 1500 mean sea level (msl). The lowest point, Lake Albert drops to about 620 msl while the highest point, Magherita Peak on Mt. Rwenzori, is 5,029 msl. Uganda is physiographically divided into four regions, namely; lowlands, plateaus, highlands and mountains. The elevated and steep areas traverse vast areas of Uganda, including the eastern volcanic areas (stretching from Elgon to Morugole), the western volcanic-faulted landscape (running from Kisoro to West Nile), and the hilly western, midwest, and central Uganda, with residual hills dissected by wetland-filled valleys.

Opportunities for constructing landfills in most of these areas are limited because of the elevated and steep topography and associated factors, such as climate and the geomorphological makeup of rocks and soils. The fairly flat terrain in some places in central, eastern, northern and West Nile parts of Uganda are potential areas to locate a landfill; however, some of these areas also make good arable areas, and hence, the choice of landuse must be carefully considered. Topological considerations should also be used in the criteria for chosing sites for landfill. Valleys should be avoided, whether or not there are wetlands, saddles and convergence areas between hills. This is because water is present in such areas. Places that are prone to flooding should also be avoided because of proximity to rivers and lakes.

1.1.2 Climate and weather conditions

Climate in Uganda, just like other areas in the tropics, is highly influenced by elevation. Precipitation, temperature, wind speed and direction, atmospheric pressure, humidity, cloud cover and sunshine duration, among others, are important considerations for location of landfills. Different climatic factors may influence the variability of soil properties. For instance, precipitation influences many soil processes including weathering, leaching, erosion, and acidification. Areas receiving high amounts of rainfall experience increased leaching of soluble nutrients, especially nitrates, compared to those receiving low rainfall. Higher temperatures increase the rate of microbial decomposition of organic matter. Climate is, invariably, a key consideration for landfill site selection due to its influence on soils, leachate management and settlement of waste referred to in section 9.2.6.

1.1.3 Geology and geomorphology

The geology/geomorphology of Uganda shows that the rock structure is generally fairly old (at least 2,700 million years) and weathered, but some areas have younger volcanic ashfalls, and materials that have been re-worked by processes of erosion and deposition. Acidic parent material like the Karagwe-Ankolean System will usually weather to an acidic soil. Granitic parent material from the basement complex will result in soils of relatively high sand contents after weathering. The fairly young geologic material of the mesozoic to tertiary volcanics will often weather to fertile andisols that are richer in nutrients as compared to soils from old, highly weathered rocks of the basement complex.

The geological/geomorphological factors of Uganda, coupled with the topographic and climate functions, would require a lot of thought to be given into decisions regarding location and siting of landfills.

1.1.4 Soils

It is important to understand the nature of soils when locating a landfill. The soils in Uganda are heterogeneous, as a result of soil forming factors operating and interacting with each other over time and space. Soil weathering and climate have an impact on soil when they in turn interact with other intervening processes such as erosion or deposition of parent material. Some soil properties may vary over a short distance depending on the geology of the area. Topography is generally the most dominant factor influencing soil heterogeneity along a hillslope. On a larger scale, other factors, such as geomorphology and climate may have a stronger influence. In addition, the same soil type may be heterogenous and not homogenous as some people may assume. Hence, in siting a landfill, soil type and structure are important considerations.

Soil with low permeability, clay-like soils are best. Sandy and loam-like soils should be avoided. The quantity of the clay in soil and the thickness of the clay layer, are among the many factors that must be considered; hence, it is not advised to locate landfills indiscriminately without due recognition of the need to reserve soils suited for the agricultural needs of the country.

1.2. Waste generation and composition

The composition and quantity of waste in Uganda is changing rapidly. This is due to a number of factors, including; rapid urbanisation, increase in industrialisation, rapid technological advancement, infrastructural development, increase in volumes of trade, increase in Gross Domestic Product (GDP) and per capita income, as well as corresponding changing production and consumption patterns and lifestyles. Hence, Uganda's per capital waste generation is likely to increase, from an average of about 0.55 kg per person per day forecast for the period 2030 to 2040.

Furthermore, the composition of waste in Uganda has also changed. There are increasing quantities of electronic and electrical waste, chemical waste, plastic waste, paper waste, industrial waste, metallic waste, textile waste, construction debris and healthcare waste, among others. These changes in waste composition are expected to continue as the country moves towards middle income status. Also, the practice of repairing damaged equipment/items is giving way to replacements/fittings of new and most often substandard or used components. The increasing use of imported new but substandard items, used, secondhand or reconditioned items whose durability is low, is adding another dimension to the waste management challenge.

Furthermore, the culture of sorting waste has not taken root in Uganda as yet. Hence, domestic waste is mixed with inorganic substances from polythenes, tin and glass, among others. Waste from industries and from construction is not treated any differently. Taking the example of Kampala Capital City, according to Ramboll (August 2018) waste at the Kitezi landfill is 43% biodegradable waste and 42% mixed fines. This is a representation of the waste composition on arrival at the landfill (i.e. after initial extraction of recyclables during collection and transportation).

1.2.1 Petroleum waste

Petroleum waste is also anticipated to grow with the production phase of the Oil and Gas Industry. Key petroleum waste from exploration and production petroleum activities includes; drill cuttings and drilling fluids (mud), surplus mud additives and produced water. Petroleum waste arising from midstream refinery operations includes; oil contaminated process water, oil sludge, spent catalyst and surplus chemicals. Storage, transportation, treatment and disposal of petroleum waste must be undertaken in accordance with the Petroleum (Waste Management) Regulations, 2019. Petroleum waste should not be taken to broad-purpose landfills since it is considered hazardous and must be managed under special conditions. The waste should be taken to engineered landfills intended to handle only petroleum waste.

1.3 Capacity to manage waste

Uganda still has several open dumpsites and un-engineered landfills. The local governments and private sector waste handlers are involved in collection, transportation and disposal of waste, but waste management is generally not in conformity to the legal requirements in the National Environment (Waste Management) Regulations, 2020 and the Petroleum (Waste Management) Regulations, 2019. Other limitations include: inadequate transporting vehicles; poor road infrastructure which affects transportation efficiency; inadequate or no wastewater/leachate infrastructure; minimum, inadequate and costly operations and maintenance practices; financial constraints and inadequate human resource.

Moreover, inadequate sorting and selection at source, insufficient recycling facilities and industries, and lack of waste characterisation have adversely affected waste management in Uganda. Better waste management practices like recycling and re-use require proper waste sorting and characterisation at source and subsequently reduce the amount of waste to be disposed-off at the landfill. There is, therefore, need to invest in transport infrastructure and facilities to handle waste. The road conditions, especially leading to and at the waste management facility, must be good; and the vehicles and containers to handle waste should conform to specification.

There is need for appropriate waste treatment and disposal mechanisms; as well as skilling, equipping and tooling of the workforce. Skilled labour is built over time and training is important. It is also imperative to develop laboratory and testing capacity for sampling and analysis of waste, in order to inform how the waste should be treated and disposed. It is imperative, therefore, that a person seeking to manage waste must have adequate financial resources and the finances must be sustainable. This is applicable to the establishment of landfills, as well.

Furthermore, there is need for more comprehensive and target-oriented education and awareness programmes and mechanisms for waste sorting and collection at source to facilitate wealth creation and protection of environmental quality or for public health puprpose. Proper waste management mechanisms yield income, improve on public health and serve as climate action in regard to mitigation or reduction of greenhouse gas (GHG) emissions.

1.4 Rationale for waste management

No matter the technique of waste treatment and resource recovery implemented, some amount of waste and waste residue will always have to be disposed of. Some of this waste will be disposed of in a landfill, which is one of the responsible hierarchical waste management practices. Overall, the level of investment in the solid waste sector as a fraction of total project cost is low when compared with other sectors. Few urban authorities have taken steps towards constructing, maintaining, or operating landfills, with the majority of towns using open dumps to dispose off solid waste. Nevertheless, as urbanisation takes its course, urban authorities are taking important steps to improve waste disposal practices; and, so the need to follow specific regulations and guidelines on landfills.

A landfill is an engineered site for disposal of waste into land, lined with impervious plastic sheeting and/or adequate clay liner to prevent leakage or leaching of dangerous substances into soil or water. Under the National Environment Act, 2019, the National Environment (Waste Management) Regulations 2020 and the Petroleum (Waste Management) Regulations 2019, the National Environment Management Authority (NEMA) is required to specify the criteria for the design, construction, operation, decommissioning and aftercare of landfills.

As long as use of landfills remains part of the waste management strategy, best-practice measures must be adopted to ensure that landfills are acceptable to the public. In this context, waste management policies in conjunction with environment policies and laws establish a framework to ensure that landfills are designed to prevent or minimise risks to human health and the environment. It is, therefore, imperative that issues outlined in these Guidelines are considered fully in the design and the development of a landfill.

1.5 Objectives and existing legislation

1.5.1. Existing legislation

Waste handlers operating landfills must meet all the requirements under the applicable law and these Guidelines.

These Guidelines are designed to provide a basis for protecting human health and the environment from the adverse effects of landfilling of waste. This is by implementing the principles of environmental management embedded in the National Environment Act, 2019, the National Environment (Waste Management) Regulations, 2020 and the Petroleum (Waste Management) Regulations, 2019, including use of best available techniques and best environmental practices.

The policy underlying these Guidelines is to reduce the current reliance on dumpsites, which accounts for most of the municipal waste. Where landfills are required, prudent and efficient management is necessary.

The focus is to oblige the waste handler to:

(i) ensure that land acquired for the purpose is adequate for operations for a period of at least 25 years;
(ii) be responsible and liable for monitoring the effects arising from the development and operation of the landfill during the project life, its decommissioning and at least 30 years after closure of the landfill;
(iii) put in place required measures related to financial security;
(iv) prevent misuse of waste intended for landfilling;
(v) put in place mechanisms to ensure recovery of materials from the waste mass that could be put to other uses; and
(vi) prevent contamination of the environment and impacts on human health.

In developing these Guidelines, different criteria for the disposal of waste by landfilling were considered, including those below;

(i) Landfill siting, design and operating criteria, which specify equipment, design features and procedures for the operation of the facility.
(ii) Performance criteria, which specify minimal levels of performance of the facility.
(iii) Risk assessment criteria, which specify acceptable levels of risk to the environment or human health.
(iv) Decommissioning and aftercare criteria.

1.5.2. Design objectives

The Guidelines aim to provide for proper design of landfills, including siting, construction, operation, decommissioning and aftercare design requirements. This includes specific requirements for Class 1 landfills for hazardous waste in accordance with Part VI of the National Environment (Waste Management) Regulations, 2020 other than hazardous waste specified in regulation 70 of those Regulations; or Class 2 landfill for non-hazardous waste which includes biodegrable waste and landfills for inert waste other than similar waste specified in regulation 70 of the National Environment (Waste Management) Regulations, 2020. Care must, however, be taken when deciding to landfill biodegradable waste, since some of it could best be converted to compost manure when the right conditions are applied.

The Guidelines will guide the upgrading of open dumps to sanitary landfills. Some flexibility may be permitted in site-specific cases that have been properly investigated, documented and verified.

1.5.3. Design standards

Landfill design must conform to national law and internationally applicable industry standards. A person who wishes to construct a landfill is expected to be abreast with these requirements during planning for design and siting of a landfill. Design of a landfill should also take into consideration other factors such as social inclusiveness, the acceptability of the landfill to the local community in the vicinity of the landfill, environmental sustainability and governance concerns, as well as equipment and physical infrastructure requirements for the landfill.

1.5.4. Operational objectives

The Guidelines provide:

(i) information on potential impacts of landfill operations on human health, safety and the environment and how these are to be prevented, minimised or mitigated;
(ii) requirements for environmental and social assessment and monitoring of landfill operations to prevent, minimise or mitigate environmental and social impacts;
(iii) opportunity to improve the standard of landfill operations in Uganda; and
(iv) opportunity to consider other options for waste minimisation, which options should be environmentally friendly, socially acceptable and economically feasible.

1.6 Guiding Principles

The principles that will guide the management of landfills are set out in the National Environment Act 2019, the National Environment (Waste Management) Regulations, 2020 and the Petroleum (Waste Management) Regulations, 2019. These include the principles highlighted below.

1.6.1 The right to a clean and healthy environment.

The 1995 Constitution in Article 39 provides for the right to a clean and healthy environment. The Constitution protects both human health and the environment, and addresses environmental quality. The right comes with a duty in Article 17 of the Constitution, to create, maintain and enhance the environment, including the duty to prevent pollution. This is also reflected in section 3 of the National Environment Act, 2019.

1.6.2 The precautionary principle

The precautionary principle has the core components below;

(i) Taking preventive action in the event of uncertainty.
(ii) Noting that there may be threats of serious or irreversible damage.
(iii) Being mindful that lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent harm to human health and the environment.

The precautionary principle is fundamental to the establishment and management of landfills. The waste handler shall prove that the risk inherent in the waste is minimised and contained, and explore a wide range of alternatives to the management of waste.

1.6.3 The polluter pays principle

The polluter pays principle requires the polluter to bear the costs of pollution prevention and control measures. Applied to waste management, the principle obliges the person who generates waste to bear the costs of waste management or clean-up of the environment contaminated by the waste.

1.6.4 The prevention principle

This is known as the prevention before cure principle that emphasizes care and caution to be taken before an activity results into negative impacts on environment and human health. The design and planning of a landfill should forecast the environmental hazards and likely adverse human impacts that may be caused by improper management of waste. Accordingly, the design and planning of a landfill should focus and make use of the waste management hierarchy for disposal of waste in the landfill.

1.6.5 The efficiency and effectiveness principle

This principle emphasises minimising costs to obtain maximum results. An efficient and effective design of a landfill should consider the costs of operation and maintenance, as well as sustainability issues, in order to realize the objectives of use of landfills.

1.6.6 The responsibility principle

Development and management of landfills for proper waste management is a legal obligation for urban authorities in Uganda. On their part, the people have the responsibility to ensure proper and safe waste management for the purpose of maintaining environmental quality and safeguarding public health.

1.6.7 The participation principle

This principle which could also serve as the principle of participatory inclusiveness, focuses on the participation of and commitments by key stakeholders, especially the local community, private sector and local authorities in the area where a landfill is established. The principle enhances popular and effective stakeholder participation, commitment and ownership of the landfill facility. The interests and influences of key stakeholders including the local community should be considered during the planning, design, construction, operation, decommissioning, post decommissioning and aftercare of a landfill.

1.6.8 The integration principle

This principle emphasises the need for all sectors to integrate waste management in their plans and budgets, by applying the waste management hierarchy and, where possible, investing in waste management.

1.6.9 Use of best available techniques and best environmental practices

During the construction and operation of a landfill, it is important that the best environmental practices and best available techniques are applied so as to ensure compliance with applicable laws.

In the management of landfills, the waste handler shall apply the most appropriate combination of environmental control measures and strategies, and utilize the most effective and advanced technologies in the development of activities and the methods of operation.

1.7 Waste management hierarchy

When making decisions regarding the management of hazardous and non-hazardous waste, the waste handler shall manage waste in accordance with the National Environment Act, 2019, the National Environment (Waste Management) Regulations, 2020 and the Petroleum (Waste Management) Regulations, 2019.

Waste should be managed in the preferred order below.

(i) Prevention – prevent generation of waste at source
(ii) Reduction – lower the amount of waste produced, including by use of alternatives
(iii) Re-use – use materials repeatedly
(iv) Recycling – use materials to make new products
(v) Other recovery – recover energy and metals from the waste
(vi) Treatment – use best available technologies and techniques to render the waste benign
(vii) Responsible disposal – safe disposal of waste to landfill (least favoured option)

1.7.1 Application of reduce, reuse and recycle hierarchy approach

Reduce reuse and recycle hierarchy

Use of landfills must be a subsidiary element of an integrated waste management infrastructure, catering only for residual waste that cannot be reused, recycled or disposed off in any other manner. It is, therefore, expected that the waste management hierarchy is used to reduce the amount of waste that may be landfilled.

Priority – pre-treatment

The priority of a waste handler should be pre-treatment of hazardous waste when required before the waste is landfilled. This applies for Class 1 landfill.

Disposal to landfills should only be considered as a last resort when there are no practicable higher-level waste management options. Treatment of hazardous waste before landfilling should be guided by the properties of the hazardous waste. Where properties of certain hazardous waste are such that they cannot safely be deposited directly into a landfill then pre-treatment must be done.

1.8 Application of Guidelines to new and existing landfill sites

These Guidelines should be taken into consideration by NEMA or relevant lead agency in granting approvals for landfills for hazardous waste and non-hazardous waste. Radioactive waste is omitted from this category since such waste is regulated under the Atomic Energy Act, 2008.

1.8.1. Application – new sites

Each new proposal for a landfill must be supported by a comprehensive environmental and social impact assessment. This must demonstrate how the proposal will meet the minimum standards of these Guidelines. In addition, other studies like geotechnical surveys, hydrogeological, hydrology, seismology, landscape and visual studies may need to be undertaken.

1.8.2. Application – existing sites

Operators of existing landfill sites will be required to improve on current measures, facilities and operations and to undertake some structural adjustments on the sites. Consideration of existing sites may be subject to re-assessment.

1.9 Target Audience

The target audience for the Guidelines is:

(i) waste handlers who intend to construct or operate, or are constructing landfills; and

(ii) relevant lead agencies, including local governments close to the existing or proposed landfill sites and other stakeholders.

1.10 Revision of Guidelines

NEMA may, in consultation with a relevant lead agency, revise these Guidelines when deemed necessary.

Chapter Two

Landfill Categories and Approvals

2.0 Introduction

The disposal of hazardous waste to landfills is the least preferred management option. This is because landfills may cause a range of adverse social, health and environmental impacts (which are often long-term) if not properly sited, designed, managed and decommissioned. For this reason, the National Environment (Waste Management) Regulations, 2020 categorise landfills in accordance with the type of waste they should handle.

2.1 Class 1 landfill – landfill for hazardous waste

A Class 1 landfill is a landfill intended to receive only hazardous waste. This category of landfills must be properly designed and managed, bearing in mind the type of waste. In addition, a waste handler is required to employ the waste management hierarchy and to treat hazardous waste when required before it is landfilled.

2.2 Class 2 landfill– landfill for non-hazardous waste

There are 2 types of Class 2 landfills, namely:

(i) landfills to handle biodegradable waste; and
(ii) landfills to handle inert waste other than similar waste that a person is prohibited by the National Environment (Waste Management) Regulations, 2020, from landfilling.

A waste handler shall ensure that waste delivered to a landfill is suitable for the landfill and is accompanied with documentation required under the National Environment (Waste Management) Regulations, 2020. Hence, there should be waste acceptance criteria for each type of landfill.

Co-disposal of waste should only be done when waste falls in the same category, that is, hazardous waste or non-hazardous waste, and when that co-disposal meets specific design and registration criteria. Co-disposal may be done for purposes of sustaining operational costs of the landfill. Care must be taken, however, to ensure that co-disposal is not misused and should not result in hazardous waste being disposed in Class 2 landfills or municipal waste being disposed in Class 1 landfills. Nevertheless, co-disposal of hazardous industrial waste with municipal waste should not be allowed as it is contrary to the law.

Where co-disposal of waste is done in accordance with these Guidelines, the minimum requirements must be established, depending on the type of waste. For instance, a maximum loading ratio must be established. As an operational practice, hazardous industrial waste with acceptable properties may be disposed off in trenches 1-2m deep in the municipal waste layer. The layering of waste may be followed by the stabilisation process.

Stabilisation requires meeting a certain pH (preferably alkaline) to avoid mobility of the toxic elements in the waste. This is achieved by using a variety of ingredients including lime, cement and ash. Stabilization with lime may be added on top of the hazardous waste before the trenches are covered with other waste. The ingredients for stabilization should, however, be determined based on the profile of the hazardous waste. The method of stabilization should be adequate for the kind of waste being disposed of.

2.3 Waste acceptance criteria and procedures for the landfill categories

Waste acceptance will depend on the design and operating criteria for the landfill. The waste handler must have control of access and entry points to track waste received at the landfill.

The transporter delivering the waste to the landfill must present a licence authorising the transportation of hazardous or non-hazardous waste to the landfill and the inspection procedure should include what is presented under paragraph 2.3.1.

The waste handler should have control over operations right from receipt of the waste, that is, at the tipping area using a spotter, as well as control over placement and compaction of waste.

2.3 1 Inspection routines and frequency

Waste inspection routines and frequency should be established for each class of landfill. Hence, the waste handler needs to know the type of waste to be received, and should develop the necessary documentation and prepare the equipment and routines needed to facilitate inspection of the waste. The waste handler should undertake spot testing of waste at certain intervals as per the details provided in the waste manifest accompanying the delivered waste. If needed, each incoming load must be inspected and verified.

2.3.2 Testing procedures and methods

For in-coming waste at the landfill, there should be established testing procedures and methods. This enables a determination of the hazardous characteristics of the waste, and informs how that waste should be handled. Hence, the waste handler shall make use of the testing methods in Schedule 9 of the National Environment (Waste Management) Regulations, 2020.

2.4 Waste prohibited from being landfilled

It is important for a waste handler to appreciate that not all waste can be received in a landfill. This understanding will enable good management of the landfill and avoid catastrophic consequences. The waste handler should, accordingly, be mindful that the waste below is prohibited from being landfilled, with reference to section 70 of the National Environment (Waste Management) Regulations, 2020;

(a) Liquid waste.
(b) Flammable waste.
(c) Explosive or reactive waste.
(d) Electrical and electronic waste.
(e) Infectious healthcare waste.
(f) Radioactive or corrosive waste.
(g) Polymers, including non biodegradable plastics, carrier bags and tyres, although these materials are usually unavoidable in a landfill.
(h) Glass.
(i) Waste from research institutions and education facilities that contains chemical substances whose effects on human health and the environment are not known.
(j) Any other type of waste as may be determined by NEMA.

In any event, the waste management hierarchy should be applied. Liquid waste, for example, can be used as a mixing agent during re-treatment of waste, provided that the liquid waste is compatible with the waste being treated.

2.5 Potential impacts from landfills

There are many potential environmental and social issues associated with the landfilling of waste. Some of these impacts are felt immediately, others in the short-term and others in the long-term.

2.5.1. Leachate to water and soil

Leachate is liquid that drains from a landfill, and, therefore, has the potential to contaminate the soil, surface and groundwater with materials migrating with it. It is, therefore, important to pay close attention to the design of a landfill in order to avoid this problem. Lining should be one of the major component of the design, as required under regulation 75 of the National Environment (Waste Mnagement) Regulation, 2020. Adequate leachate treatment is also an important measure.

2.5.2. Landfill gas emissions

Landfill gas is a natural byproduct of the anaerobic decomposition of organic material in landfills. Landfill gas is composed of roughly 40-60% methane (the primary component of natural gas), 35-45% carbon dioxide and a small amount of non-methane organic compounds, including oxygen, nitrogen, hydrogen and water vapour. While the major constituents of landfill gas, methane and carbon dioxide, are odourless, other minor constituents of landfill gas including organosulfur compounds can be very odourous. On its part, methane if not controlled, will pose a high risk of explosions and fires that will cause deaths, injuries and damage to property, since it is explosive by nature.

A good landfill design should, therefore, provide for the collection and control of accumulation and migration of landfill gas into the atmosphere. It should also allow the capture and convertion of the gas as a renewable energy resource in line with the relevant written law and environmental standards.

2.5.3. Other environmental impacts

Other environmental impacts may include offensive odour, litter as well as presence of rodents and birds, noise and air pollution. Landfilling may also affect threatened and endangered species of plants and animals, native vegetation and features of cultural and natural heritage. To prevent or minimise the impacts of landfills, measures should be put in place to abate the related pollution, in accordance with the National Environment Act, 2019 and the National Environment (Waste Management) Regulations, 2020 and any other written law.

2.5.4. Impacts on human health and workplace environment

Impacts on human health arising from pollution of the environment are associated with air pollution, bad odour and noise, among others.

Workplace impacts relate to adequacy of space for operation and seating, ventilation, noise management and lighting for people working indoor. If personal protective equipment (PPE), adequate signage, welfare and off-site breaks are not provided, workers will also be exposed to poor air quality and injuries.

Persons outside the landfill, especially communities living near the landfill may experience noise pollution, bad odour, heavy traffic, litter, waste slides, among others. Other impacts may be contamination of water resources, and emission of pollutants into air. Vulnerable persons, especially children, expectant mothers and the elderly are most at risk.

2.4.5. Socio-economic impacts

Improper landfill management may result in visual and scenic nuisance such as flies, rodents and other pests, litter, odour, smoke and noise, which explains why people do not want to reside close to landfills. Proximity to a landfill may also have an adverse negative impact on the value of housing and other property, depending on the actual distance from the landfill.

2.6 Environmental and social assessments, licences and other approvals

Due to the impacts associated with waste management practices, the National Environment Act, 2019 requires a waste handler to undertake an environmental and social assessment. This is to ensure that environmental and social impacts, risks or other concerns regarding the waste management activity are taken into account during project approval. A certificate of approval of environmental and social assessment is, therefore, a prerequisite to waste management. The said certificate usually also provides that other approvals are obtained before undertaking the waste management activity.

Other studies like geotechnical surveys, hydrogeological, hydrological, seismological, landscape and visual intrusion studies should be undertaken as well. These studies should be taken into account in site selection and design of a landfill, in addition to being part of the environmental and social assessment process.

2.6.1 Environmental risk assessment

An environmental risk assessment may be required under the National Environment Act, 2019 to identify and estimate the likelihood or probability of an adverse or hazardous outcome or event and its consequence on human health or the environment, resulting from the operations of a landfill. NEMA may require a risk assessment to be undertaken as part of an environmental and social impact assessment or separately from the latter.

2.6.2 Financial security

NEMA will require a waste handler to provide financial security before development of a landfill, considering that the activity is likely to have a deleterious impact on human health or the environment. Since availability of capital and finances to run operations is usually a major constraint to the development and operation of landfills, a financial security must be considered. A financial security is required under the National Environment Act, 2019, the National Environment (Waste Management) Regulations, 2020 and the Petroleum (Waste Management) Regulations, 2019.

The financial security will be used in the event that:

(i) environmental liability is not covered in general liability policies;
(ii) there is need for environmental response action to an emergency occasion by the project or activity;
(iii) the cost of environmental remediation is likely to be substantial;
(iv) the waste handler fails to comply with an order of compliance issued by the NEMA; or
(v) there is a risk of the waste handler becoming insolvent. Financial security may also focus on the costs of site remediation, site closure and post-closure liabilities, all of which are the responsibility of the waste handler.

To ensure that the appropriate level of financial assurance is maintained, it is recommended that the waste handler reviews the status of financial assurances. This is aimed at mitigating financial risks and ensuring the viability of financial resources.

Where resources are highly constrained, a landfill may be established in a phased manner to meet the minimum criteria to handle a specific category of waste. The landfill should be developed progressively, depending on availability of finances and related resources.

2.6.3 Management of petroleum waste

A certificate of approval of environmental and social assessment will be required by a licensee under the Petroleum (Exploration, Development and Production) Act, 2013 or the Petroleum (Refining, Conversion, Transmission and Midstream Storage) Act, 2013. The certificate must be obtained before the licensee can enter into a contract with a third party for the management of petroleum waste. This condition must be adhered to by a waste handler for petroleum waste, to ensure that the necessary competences and potential impacts are identified and resources are planned.

2.6.4 Licence to manage waste

NEMA may issue a licence to manage waste under the National Environment (Waste Management) Regulations, 2020. In respect to an application to manage petroleum waste, this licence may only be issued after the applicant has entered into a contract with a licensee as required by the Petroleum (Exploration, Development and Production) Act, 2013 or the Petroleum (Refining, Conversion, Transmission and Midstream Storage) Act, 2013. In addition, the licensee must possess technical capacity, competence and financial capability.

2.6.5 Other approvals

These may include; a wastewaster/effluent discharge permit, a site/building plan, among others, provided for under applicable law.

Chapter Three

Site Selection, Design and Development

3.0 Siting of a landfill

Site selection, design and development are prerequisite for a landfill. It is, therefore, important that the requisite preparation is done right, and that adequate resources are set aside for the purpose. Various parameters should be considered in selecting a suitable site for a landfill.

These parameters include:

(i) geo-factors (geological, hydrological, hydrogeological, topographical, geomorphological, tectonical, seismotectonical conditions);
(ii) engineering factors (engineering geological, geotechnical, soil and rock properties);
(iii) environmental factors (pollution, geo-material quality, protected sites, basins and aquatic ecosystems, forests and rangelands, water supply and treatment plants); and
(iv) socio-economic and socio-cultural factors (the needs of local communities, gender and youth considerations, land use, facilities, cultural and religious aspects, psychological, economical, special conditions including growth and managing the demands of cities and towns which are expanding and rebuilding).

These parameters should be viewed within the wider physical environment that should inform site selection.

3.1 Criteria for siting of landfills

The person applying to become a waste handler shall prepare an environmental and social assessment to inform site selection, design and development. Geotechnical and/or geohydrological site investigations or studies should normally precede environmental and social assessment. Environmental and social assessment should be undertaken in accordance with the National Environment (Environmental and Social Assessment) Regulations, 2020.

The environmental and social assessment may include an environmental risk assessment and should consider proposed landfill design and operation. This should include:

(i) an evaluation of possible alternative landfill sites to identify those sites with the best potential to be developed in a manner that poses the minimum risk to human health and the environment;
(ii) detailed and illustrative features of the proposed landfill worksite layout, including the leachate barrier; leachate storage, treatment and disposal system; stormwater management works; water quality monitoring installations; landfill gas management and monitoring infrastructure; and final capping;
(iii) a scaled plan diagram of the site, including site infrastructure and facilities;
(iv) projections of the types and quantities of waste to be received, the classification of the waste, the design capacity of the landfill or cell, and the expected life of the landfill/cell;
(v) a filling plan that is consistent with a planning approval, showing the proposed layout of the cells, the type and amount of waste to be deposited in each cell, the projected rate of filling, and the location of any special waste expected to be landfilled;

(vi) if applicable, details of waste reprocessing to take place at the landfill, the nature of resources to be recovered from waste received at the landfill, and the locations and sizes of proposed stockpiles, if any;

(vii) information to demonstrate that the proposal will meet the required outcomes in these Guidelines, with justification for any proposed alternatives to the acceptable measures described in these Guidelines; and

(viii) confirmation that the application has been prepared by a suitably qualified and experienced person(s).

The information in paragraph (vii) above should be supported by a hydrogeological risk assessment, landfill gas risk assessment, air quality impact assessment, odour impact assessment, noise impact assessment, water balance calculations for leachate management, recipient/discharge assessment and proposed environmental monitoring programmes. These assessments may be undertaken singly or in combination, as may be recommended by NEMA or relevant lead agency.

3.2 Location, site selection and design

3.2.1. Location

Location is an important factor in determining the environmental risks posed by a landfill. Some of the minimum standards in these Guidelines will be easier to achieve, by selecting a site where natural barriers (such as hydrogeological barriers) protect environmental quality and where the buffer around sensitive receptors ensure that there will not be adverse impacts on environmental quality.

The risk of leachate contamination increases where the site is in poor hydrogeological conditions, near sensitive water bodies such as streams and wetlands, or near water sources used for drinking, irrigation, industrial use or stock watering.

Geological, geo-physical and geo-technical studies should be undertaken to determine site suitability, including the type and nature of materials required for the landfill. Such an assessment should include; trial pits, boreholes, in-situ tests, sampling, laboratory testing and compaction trials.

This would assist the developer in:

(i) determining the suitability of in-situ materials (type, permeability and volumes) for use in the construction, operation, decommissioning and restoration of the landfill facility; and

(ii) carrying out a materials balance on a phase by phase basis.

Location should also be determined by:

(i). hydrogeological assessment, groundwater quality and water management information, including—
  - ❑ water balance for the site and estimated volume of leachate to be generated.
  - ❑ leachate collection, storage facilities, treatment and disposal.
  - ❑ stormwater diversion banks and/or cut-off drains and storage dams.
  - ❑ water supply and effluent management.

(ii). meteorological data, including monthly rainfall, monthly evaporation, seasonal wind strength and direction;

(iii). the potential environmental impacts of the landfill operations, including landfill gas, odour, litter and noise;

(iv). the location of the landfill, including the topography of the area; and

(v). measures for emergency preparedness and response. The design concept for a landfill depends on the geology, geophysical and geotechnical information of the site.

The person applying to be a waste handler should ensure that the studies mentioned above are undertaken to guide the formulation of a site-specific design and to inform the environmental and social assessment report.

3.2.2. Site selection and design

The aspects below should be considered in site selection and design;

(i) Physical conditions of a site and distance from settlements.
(ii) Proximity to existing and planned land uses.
(iii) Size of the landfill site.
(iv) Type and quantities of waste – hazardous and non-hazardous waste should be handled differently.
(v) Stormwater management – an appropriate stormwater drainage system of an appropriate capacity.
(vi) Leachate management – an efficient leachate collection and treatment system.
(vii) Landfill gas control – for collection, treatment and utilisation or safe disposal of landfill gas.
(viii) Stability of the subgrade, the basal liner system, the waste mass and the capping system - to prevent excessive settlement or slippages and unacceptable leakage of leachate.
(ix) Minimisation of environmental nuisances – litter, odour, dust, noise and vermin.
(x) Visual appearance and landscape - visual impact of landform. A vegetative screen serves to reduce the visual intrusion impact of the landfill on adjacent properties.
(xi) Operational and restoration infrastructure – during site development, operation and restoration.
(xii) Monitoring requirements – for leachate, ground and surfacewater, and landfill gas and air quality.
(xiii) Estimated total cost of the facility – from design, construction, operation, closure and aftercare.
(xiv) Intended after-use of the facility – to be compatible with the material components and physical layout of the capping system, the surrounding landscape and current and future landuse zoning as specified in the relevant development plan.
(xv) Waste composting facilities, especially for sanitary landfills that receive a lot of biodegradable waste.
(xvi) Security infrastructure.

Siting and design should also consider the aspects below;

(i) Environmental sensitivities – sensitivity of the receiving environment, including a flood- plain, a wetland, river and lake. The landfill should be sited at least 500m from the boundary of an existing or planned sensitive landuse. In any event, a locally adequate buffer must be maintained to ensure that sensitive ecosystems are protected.

(ii) Protection of soil and water – use of suitable liners. The type of liner to be used will depend on the hydrogeological conditions of the site. Concrete liners should be atleast 0.5m thick and at a minimum 1.5m above groundwater at all times, considering the hydrogeologic conditions at the site, including the hydraulic capacity of the underlying soils. If the liner is made of other materials such as plastic sheeting or clay, however, it should be atleast 1m thick and at a minimum of 3m above groundwater. Any pollution of groundwater should be avoided outright.

(iii) Planning for buffer zones - The landfill facility, including the buffer zone, should on the whole be at least 500m from the nearest human settlement or commercial area as prescribed under the National Environment (Waste Management) Regulations, 2020. The identified site for the landfill must not only cover the area required for the landfill but also the buffer zone of at least 200m around it. 100m closest to the landfill site boundary shall be reserved for natural and landscaped screening. Only the 50m buffer closest to the landfill footprint shall be used for access roads, surface water management works, leachate management, landfill gas management and monitoring works, firebreaks, and other ancillary works as required.

(iv) Landscaping the landfill site – avoid water convergence areas and drainage lines, and flood plains. This will ensure exclusion from seasonal wetlands and streams. Watershed characterisation with the potential leachate migration routes around the landfill should be modelled to inform response in case there is need during emergencies.

3.2.3 Suveys to be undertaken for site section

A number of surveys should be undertaken to establish the information required under 3.2.2. A desk study usually kick-starts the process. A desk survey should include a compilation of all available information from archives, including geological and soil maps, topographical maps, archaeological maps and records, land cover, area designations and meteorological data, aerial or remote photographs, surface and groundwater data, including data on local abstractions and water quality.

Desk surveys should be followed by walkover surveys that involve a visual inspection of the site and surrounding area. During walkover surveys, the topography and geomorphology of the site should be inspected, and the geological, hydrological and hydrogeological aspects, including groundwater and surface water usage should be noted.

Thereafter, it may be necessary to carry out some preliminary ground investigation using techniques such as trial pitting, geophysics or shallow probing. It may also be necessary to establish monitoring to provide a baseline with which potential future activities can be compared. The information obtained in the preliminary assessment should be used to reduce the number of sites being considered and to select the sites at which detailed investigations should be contemplated.

3.2.4 Design of landfill

The site selected should be designed to; minimise potential environmental impacts, minimise health and safety risks for landfill operators and the public, encourage on-site recycling, and to make the most efficient use of resources on site.

Landfills for hazardous waste, in particular, should be designed and sited, taking into account the scale and complexity of operations expected, equipment to be employed, type and volume of hazardous waste to be handled and potential environmental impacts.

Landfill practice is dynamic in that it will change with both advances in technology and changes in legislation. To incorporate such advances and changes, a periodic review of the design should be carried out, as the lifespan of a landfill site from commencement to completion is longer compared to other construction projects. Generally, landfills are constructed in a phased manner.

Whether a landfill is designed by a municipal authority or other landfill owner or with private sector involvement, the design and approval of the selected site should be in accordance with the National Environment (Waste Management) Regulations, 2020 and relevant national and international standards that are in consonance with the Regulations. Landfills for petroleum waste should conform to the requirements under the Petroleum (Waste Management) Regulations, 2019.

Attention should be paid to:

- ☐ investigations to obtain information on the site, including geotechnical investigations;
- ☐ hydrogeological assessments to collect information on the interaction between geological conditions of the site and groundwater;
- ☐ requirements for an engineered geological barrier and bottom liner system;
- ☐ leachate management system (for collection and treatment of leachate);
- ☐ a landfill gas collection and treatment system;
- ☐ stormwater and surface water management;
- ☐ construction and division of cells;
- ☐ a landfill cover system;

- ☐ an environmental monitoring system; and
- ☐ a plan for landfill closure and aftercare.

3.3 Quality assurance and quality control

Quality assurance and quality control are integral parts of a landfill design scheme. The intending owner of the landfill or waste handler should, therefore, put in place quality assurance and control plans, and ensure they guide design specifications. Where geosynthetic materials (factory fabricated polymeric materials, like geomembranes, geotextiles, geonets, geogrids and geosynthetic clay liners) are used in the design, they should be accompanied with manufacturing quality assurance and manufacturing quality control documentation.

Quality assurance and quality control must also be carried out during construction and installation of liners. In-situ and laboratory quality control tests during construction of a landfill should be undertaken for concrete mixed, polyliner welds, pipe welds and compaction tests.

The different design and construction features should be checked for performance effectiveness at every stage of the project (construction, operations, decommissioning and aftercare stages). This should apply also to new landfills, expansion of existing facilities, site remediation projects and final cover systems. Liner installation is a critical operation which should have quality assurance and quality control procedures to prevent leaks when the liner is subjected to waste loads.

The waste handler should produce a validation report as part of the quality assurance and quality control documentation required by the regulatory authority. Accordingly, a detailed and comprehensive checklist for quality assurance and quality control should be developed and operationalised during the development and management of a landfill. The quality assurance and quality control checklist should consider all the criteria set above and other relevant ones.

3.4 Site development

3.4.1 Site Layout

The site layout shall include all the components of the landfill and should minimise the potential for leachate and landfill gas impacts offsite, taking into consideration groundwater flow direction and surface water infiltration and discharge points.

The production of a digital ground model, also referred to as digital terrain model or topographical map, should be undertaken during pedologic and hydrologic assessments.

3.4.2 Site Preparation

The extent of preparatory works is site specific and should be determined during the environmental and social assessment stage. The preparatory works will include the stripping and/or filling of soil to formation level for: a lining system for cell/phase construction; leachate and gas management facilities; groundwater, surface water and leachate systems; landscaping and screening; among other site infrastructure.

3.4.3 Materials Requirement and Material Balance

The landfill should be constructed using the right materials, and the waste handler must ensure that the material is used for the right purpose and in correct proportions.

Materials are required during landfill development for:

(i) basal mineral liner;
(ii) cap barrier layer liners;
(iii) leachate detection, collection and drainage blanket/layer;
(iv) other drainage layers such as capping layer and groundwater/surface water protection layer;

(v) gas collection and venting system;
(vi) roads;
(vii) cover (daily, intermediate);
(viii) embankments;
(ix) internal and external bunds; and
(x) restoration layers (subsoil and topsoil).

Materials required may need to be stored on-site for a period of time, depending on the material. Hence, the material should be stored in a manner that prevents degradation and erosion, and maximises its reuse potential.

Excavated soil, in particular, should be stockpiled appropriately to prevent erosion of the soil into the surrounding environment and to ensure that the soil is available for future use during site decommissioning and restoration.

Prior to construction or lateral expansion of a landfill, the developer should;
(i) determine the suitability, depth and volumes of topsoil and subsoil at the landfill site; and
(ii) determine storage locations for salvaged topsoil, and measures to be taken to prevent the use or loss of salvaged topsoil during storage.

3.4.4 Phasing

The landfill should be developed in a series of phases. Phasing should allow progressive use of the landfill area so that construction, operation (filling), decommissioning and restoration can occur simultaneously in different parts of the site. To avoid frequent (and disruptive) preparatory works, it is recommended that the design lifespan of a phase be a minimum of 12 months.

The manner of phasing will depend on anticipated waste intake, which will determine the size and lifespan of the phase and the sequence of operations.

3.4.5 Cells

Cells are sub-divisions of phases. Cells should be established in each phase, based on the amount of waste to be managed and water balance calculations. The objective of operating a landfill in cells is to place waste in a manner that is mechanically stable, reduces generation of leachate, minimises the area of exposed waste, controls litter, birds and other pests, and maximises the degree of compaction.

The number and alignment of cells should not constrain vehicular maneuvering. For each cell, the developer should indicate; estimated void space volume, active lifespan, and sequence of development of the cell.

3.4.6 Bunding

Bunds should be constructed at the landfill site to:
(i) provide a primary buffer to prevent unauthorised access to the site (these are perimeter bunds);
(ii) control nuisances such as litter and noise (temporal bunds); and
(iii) separate cells or phase (boundary bunds) in order to prevent seepage of leachate into adjoining cells and into the outer environment.

The design of perimeter bunds should be consistent with existing topography, and the bund may be 2m and above. Where perimeter bunds are constructed, embankment slopes should be stable.

Temporary bunds are generally around 2m in height with side slopes of 1:2.5 and are moved along as the site construction progresses. These bunds may also act as a storage area for final/intermediate cover material.

Boundary bunds of approximately 2m in height may be located on the base of the facility and will include a primary liner that will continue under the inter-cell bunding. Consideration needs to be given to the relationship between the bund, base liner and leachate collection system.

Chapter Four

Landfill Liner System

4.0 Requirements for a landfill liner system

The developer should undertake lining of a landfill in a manner that protects the surrounding environment including soil, groundwater and surface water. The lining of a landfill should contain leachate generated within the landfill, control ingress of groundwater, and assist in the control of the migration of landfill gas. The liner may also attenuate contaminants in migrating leachate. A further function of the liner is to control and prevent infiltration of groundwater.

4.1 Requirements of Liner Systems

(a) Class 1 landfill - for hazardous waste

A double composite liner should be used for hazardous waste landfill facilities. This system has two composite liners on top of each other, with a leachate detection system between each layer. It should consist of the liners below;

(i) A minimum 0.5m leachate collection layer with a minimum hydraulic conductivity of 1x103m/s.

(ii) Top composite liner consisting of, at a minimum—
- a minimum 2mm HDPE or equivalent flexible membrane liner; and
- a 1m thick layer of compacted soil with a hydraulic conductivity less than or equal to 1x10-9m/s constructed in a series of compacted lifts no thicker than 250mm when compacted or a 0.5m artificial layer of enhanced soil or similar substance giving equivalent protection, also constructed in a series of compacted lifts no thicker than 250mm when compacted;
- a minimum 0.5m thick leachate detection layer with a minimum hydraulic conductivity of 1x10-3m/s or a geosynthetic material that provides equivalent performance; and

(iii) Bottom composite liner consisting of, at a minimum—
- a minimum 2 mm HDPE or equivalent flexible membrane liner upper component;
- base and side wall mineral layer of minimum thickness 4m with a hydraulic conductivity less than or equal to 1x10-9 m/s; and
- a minimum 1m of the 4m thick mineral layer should form the lower component of the composite liner and should be constructed in a series of compacted lifts no thicker than 0.25m when compacted.

(b) Class 2 landfills - Non-hazardous biodegradable waste

(i) A double composite bottom liner system should, at a minimum, consist of the components below;

- A minimum 0.5m thick leachate collection layer with a minimum hydraulic conductivity of 1x10-3m/s.
- The upper component of the composite liner must consist of a flexible membrane liner. At a minimum, a 2mm HDPE or equivalent flexible membrane liner should be used.
- The lower component of the composite liner must consist of a 1m layer of compacted soil with

a hydraulic conductivity of less than or equal to 1x10-9m/s constructed in a series of compacted lifts no thicker than 250mm when compacted or a 0.5m artificial layer of enhanced soil or similar substance giving equivalent protection, also constructed in a series of compacted lifts no thicker than 250mm when compacted.

(ii) Top layers consisting of, at a minimum—

- ☐ 0.5m thick layer of compacted soil with a hydraulic conductivity less than or equal to 1x10-7m/s, constructed in a series of compacted lifts no thicker than 250mm when compacted or an artificial layer of enhanced soil or similar substance giving equivalent protection, also constructed in a series of compacted lifts no thicker than 250mm when compacted;
- ☐ 0.5m thick leachate detection layer with a minimum hydraulic conductivity of 1x103m/s or a geosynthetic material that provides equivalent performance; and
- ☐ Top vegetation/soil cover - uncontaminated soil of minimum 0.6m, enough to enable the root systems of grass and bush to anchor onto the soil.

(c) Class II landfills – for inert waste which is non-hazardous

The liner system for an inert landfill should, at a minimum, have a base and side wall mineral layer of minimum thickness of 1m, with a hydraulic conductivity less than or equal to 1x10-7m/s or a 0.5m artificial layer of enhanced soil or similar susbstance.

4.2 Soils

There are at least two important properties of a soil that can make a natural liner. These are the properties below.

(i). Soils with a high cation exchange capacity (CEC) – a CEC of at least 10mEq/100g has been reported to be effective (Ojuri, 2015), but even CEC of 12 to 13mEq/100g has been found to be suitable (Akgun et al. 2017). Cation exchange capacity (CEC) is a soil chemical property. It is the ability of the soil to hold or store cations.

(ii). Soil with high clay content, necessary to reduce conductivity.

Soils with a high CEC withhold contaminants from migrating to the water table, have suitable particle size distribution and low hydraulic conductivity, and also contain appropriate clay mineralogy.

Soil with high clay content is usually associated with lower member landscapes (for example, wetlands) and is along rivers and lakes. Of importance is the clay mineralogy; reports suggest clays derived from volcanic ash are better, because they contain a special clay called smectite, with good binding effect and it improves CEC.

The ability of clay to retard water movement and absorb exchangeable cations makes it a suitable natural material for a low-permeability liner. Natural clays of low hydraulic conductivity, such as clays, silty clays and clayey silts, have the potential to make good liners. Clay soils with a low coefficient of permeability and sufficient thinkness significantly retard leachate loss to groundwater. To meet the performance standards of the whole liner, the clay component needs to be tested for effectiveness and low hydraulic conductivity.

The continuity and hydraulic conductivity of in-situ natural liner materials are difficult to predict, and expensive to prove and for this reason engineered liners are recommended.

4.3 Geo-membranes (flexible membrane liners)

There are many types of geo-membranes or flexible membrane liners as they are often called. A geo-membrane for use as a component in a basal landfill liner should be impermeable, have a physical strength capable of withstanding mechanical stresses and strains, and should be chemically compatible with the waste contained by the liner.

Mechanical stresses that the geomembrane may be subjected to, take the form of both short term and long term stresses. Short term stresses can originate from handling during installation, while long term stresses can result from the placement of waste and from subsequent differential settlement in the foundation soils. The geomembrane must have sufficient strength to meet the strain requirements at anchor trenches and on side slopes. The maximum slope gradient must be determined for the particular liner.

4.4 Geo-textile protection layers

Geo-textiles are employed to protect the integrity of the geo-membranes. Proper installation and testing of geo-membranes and their geotextile protection layers is required in order to meet the performance requirements of the system design. Installation procedures for membranes must minimise wrinkling, buckling and tensioning. Wrinkling is undesirable as it increases the potential for failure at the wrinkle point and reduces the close contact between the underlying clay and geo-synthetic clay liner.

The purpose of the protective layer is:
(i). to minimise the risk of geo-membrane damage/puncture during construction and during the subsequent operation of the landfill; and
(ii). to minimise the strains in the geo-membrane and hence the risk for future punctures forming due to environmental stress cracking.

Non-woven needle punched geo-textiles have been widely used as a protection material. Selecting an adequate and appropriate geo-textile protection for geo-membranes is a fundamental aspect of landfill barrier design if the robustness and integrity of these systems is to be ensured in the long term.

Leak detection checks should be undertaken once the geo-membrane is installed and the drainage material is placed to ensure that the geo-membrane has not been damaged during its installation and at the placement of the drainage material.

4.5 Field trials

Geotechnical properties of the materials and construction procedures to be used in the placing of the landfill liner should be tested prior to construction. The tests should be carried out with different waste streams likely to be contained by the liner, thus enabling the determination of any potential reactions between the liner and the waste. A trial constructed under controlled conditions should be used to verify the performance objectives. Field trials should be planned, specified, supervised and interpreted by a registered geotechnical engineer.

The field trial must be designed to provide the information below;
(i) Suitability of the materials under site conditions.
(ii) Ability of the materials to achieve the geotechnical design criteria.
(iii) Suitability of the method of placement and compaction methods to achieve the design criteria.
(iv) Information for the construction method statement for the liner. This should include types of tests, testing frequencies, equipment used, lift thickness, and number of passes of the compacting equipment.

In addition, in-situ hydraulic conductivity tests should be performed on the trial pad. Undisturbed soil samples may be used to simulate field conditions in the laboratory.

The waste handler should liaise with the regulatory institutions responsible for standards on liners to ensure suitability of the liner system adopted for the landfill. These include the materials laboratory of the Ministry of Works and Transport, Uganda National Bureau of Standards, and NEMA.

Chapter Five

Protection of Soil and Water

5.0 Protection of soil and water

Uganda has a wide variety of soil types, but is dominated by feralsols and its associates such as plinthosols, which represent the terminal stages of soils formation, and typical of geologically stable landscapes. These soils are mostly acidic, and are low in cation exchange capacity (CEC). Because of the low CEC, their ability to hold nutrients is low. This in turn affects their fertility and agricultural potential, and impacts their ability to buffer groundwater systems and surface water from pollutants emerging from agricultural fields. Nonetheless, they are able to respond to fertilizers, especially when properly used, and so siting landfills on them must be guided and with the understanding that the country has limited fertile land suitable for agriculture. Uganda also has a fairly large proportion of land with hydric soils (gleysols and histosols) and soils modified by a temporary moisture regime (such as vertisiols), even though they are not wetland soils. These are found in low-lying areas and their use for landfill purposes is limited by either being in water convergence areas or having elevated water tables.

Groundwater and surface water are major natural resources of both ecological and economic value and their protection is of prime importance. It is, therefore, essential that a landfill design includes provisions for the management and protection of both groundwater and surface water. Information arising from the environment and social assessment will assist in detailing the level of groundwater and surface water management required.

5.1. Requirements - Barriers for soil and water protection

5.1.1. Geological barrier

A geological barrier is intended to protect the surroung soil, surface water and groundwater from contamination from a landfill. It is, therefore, required to be around and below the landfill, and should have properties to retard flow of materials across it. The barrier should, accordingly, be at least 1.5 m above the ground water table. The thickness of this layer should depend on (i) type of landfill; (ii) position of the water table; and (iii) the landscape position where the landfill is set.

5.1.2.Artificial Barrier

Requirements for this barrier, including material depend on the category of landfill. These requirements are described in section 4.1.

5.1.3. Local adaptation of requirements

A landfill barrier layer may be compacted clay, geo-membranes (predominantly HDPE) or geo-synthetic clay to reduce infiltration of leachate into the groundwater, water into the waste (for landfill capping) and escape of gas from the waste.

The structure and type of liner used should conform to the topographical and geological conditions of the landfill site, soil conditions, groundwater conditions, as well as the location of the leachate collection facility. For a site with an engineered hydro-geological barrier, (that is, a sub-soil of a thickness of more than 3m with a maximum permeability of 10-7m/s and highest groundwater table minimum 1m below the geological barrier), a low cost mineral liner system that meets the permeability required in section 4.1 is sufficient for bottom sealing of the landfill area for the disposal of municipal waste (that is, general waste of a non-hazardous nature).

5.2 Groundwater management

Since a landfill must not impact on beneficial uses of groundwater, the design of the landfill must consider the local hydrogeological environment.

Where the water table is near, a landfill should not be located in such an area. This is because technologies required to reduce the groundwater flow beneath the landfill are largely non-existent in Uganda as yet. In any event, best available technologies should be encouraged even when the risk is minimal but likely.

In advanced economies, it is possible to construct underdrains beneath the landfill liner and groundwater extraction bores around the landfill to reduce the groundwater beneath the landfill. Even then, if the groundwater is not regulated, its upward or outward force through the base or sides of a landfill can cause a structural failure of the liner. If the liner system is located above the water table so there is an unsaturated zone immediately below the waste, the likelihood is that no groundwater control measures will be required.

Where groundwater control measures are required, the subsequent outlet for the groundwater should be established. This may be directly to a water body or to a retention pond if the groundwater does not meet the water quality standards of the receiving waters. Monitoring wells should be installed appropriately to monitor groundwater contamination and if applicable, landfill gas leakage. Installation of monitoring wells will depend on the directional flow of groundwater (shallow and deep aquafers) and the water table, guided by hydrogeological assessments.

5.3 Surface and stormwater management

Surface and stormwater collection systems should be available at all landfills. This prevents ponding and the infiltration of water into the landfill, which increases the generation of leachate.

5.3.1 Surface water runoff

The surface water drainage system should be provided to collect and transport run-off from the landfill and surrounding area to drains at the periphery of the landfill. Drainage channels should be located so that surface water run-off from the surrounding area is intercepted and diverted before it reaches the waste. Perimeter surface water control systems are usually designed to manage both offsite run-off and onsite run-off.
Surface water run-off from paved areas and site access roads may be directed to stormwater retention ponds or if necessary, to leachate storage facilities. Provision should be made for surface water from parking, fueling, repair, maintenance or paved areas to pass through oil interceptors.

It may be necessary to provide a settlement pond to remove solids from surface water from cells under construction or from surface water running off restored areas. Water from cells under construction may need to be pumped to the drainage channels or retention pond. Surface water from the restored areas should be transported through drainage layers incorporated in the capping system to the perimeter drainage channels. Surface waters in active cells should be directed into the leachate collection and treatment system and should be monitored.

The design of surface water drains is usually based on storm events with specified return period and duration of rainfall. Common return periods for design purposes are 1, 5, 10, 25 and 50 years. The return period may be selected based on site characteristics, the risk of failure and the consequences of failure of the drainage system. The longer the return period of record, the higher the likelihood of capturing the range of possible flood events. Hence, a 1-in-50year interval is best advised in estimating return period flood values to inform the design of surface water drains.

The surface water management systems should be designed to collect and control at least the water volume resulting from a specified duration and return period.

5.3.2 Stormwater management

As part of the surface water management systems in section 5.3.1, storage ponds and other drainage measures should be designed to contain and control rainfall run-off for a 1-in-20-year storm event for a prescribed landfill or a 1-in-10-year storm event for a solid inert landfill, although a 1-in-50year storm event is advised, to cover the design and post closure management period. Storm events up to 1-in-100year recurrence intervals (low frequency extreme rainfall) should also be considered to ensure that they do not result in any catastrophic failures, such as flooding of the landfill or failure of dams or leachate storage ponds.

Generally, the principal design objective of stormwater retention/sedimentation/storage ponds is to directly bypass and discharge (without treatment) clean runoff from any surrounding undisturbed catchment areas, and to provide for containment and treatment of contaminated stormwater.

The volume of sediment-laden stormwater runoff should be minimised by implementing erosion controls measures, including; minimising areas with exposed soils, stabilising exposed areas by re-vegetation and other stabilisation measures, reducing erosive effect of stormwater, protecting stockpiles, managing unsealed roads, controlling site exit, and maintaining structures for erosion control.

Sediment-laden stormwater runoff should pass through appropriate sediment control structures. Sediment controls include vegetative buffers, silt fences, fibre rolls, turbidity or silt curtains, and sediment basins.

The need for sediment control features will depend on; the topography and how this will influence water velocity, the nature of the water environment into which the eventual discharge from the site will flow, the typical intensity of storm events, and the extent of vegetative cover on the catchment area.

5.4 Active area drainage

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

To design an active area drainage:

(i) slope the surfaces inwards to a low point draining into the waste;
(ii) provide ample slope to keep the tipping area from flooding; and
(iii) minimise the active area and hence stormwater ingress into the waste mass.

During operations of the landfill, it is important to apply intermediate cover regularly, and promptly to minimise further contamination of the runoff (albeit that the sediment component needs to be treated for a period of time).

Chapter Six

Leachate Management

6.0 Leachate components

Leachate is a liquid which has percolated through the waste, picking up suspended and soluble materials that originate from or are products of the decomposition of solid waste.

As far as possible, leachate should be avoided. In general, the composition of leachate will be a function of the type and age of waste deposited, the prevailing physico-chemical conditions, the microbiology and the water balance of the landfill. The main components in the leachate from landfill sites may be grouped into four classes below.

(i) Major elements and ions such as calcium, magnesium, iron, manganese sodium, ammonia, carbonate, sulphate and chloride.
(ii) Trace metals such as mercury, chromium, nickel, lead and cadmium.
(iii) A wide variety of organic compounds which are usually measured as Total Organic Carbon (TOC) or Chemical Oxygen Demand (COD); individual organic species such as phenol and chlorinated organic compounds, can also be of concern.
(iv) Micro-organisms.

Landfill site specific leachate discharge requirements will determine the components of leachate that require treatment or removal. Ammonia is probably the most important inorganic contaminant with the greatest potential to adversely impact on surface water and groundwater. Other components such as heavy metals and sulphides may, however, be significant in certain circumstances. Organic compounds that are hazardous at low concentrations may also be present, such as pesticides (atrazine, simazine) and adsorbable organic halogen compounds. Most of these organic compounds are man-made but some may be formed within the landfill.

The composition of the leachate is an indication of the state of the biological and chemical processes occurring within the waste mass and the solubility of the ions. If leachate is to be removed and treated to meet the National Environment (Standards for Discharge of Effluent into Land or Water) Regulations, 2020, certain parameters will have particular environmental and economic significance. It is important, therefore, that a good leachate drainage, collection and removal system is designed to address the risks associated with leachate.

6.1 Design criteria

An understanding of how much leachate will potentially be generated and its quality is essential at the conceptual design stage of a leachate management strategy. Water balances are used to assess likely leachate generation volumes. Factors to consider in assessing the water balance in a landfill include; waste volumes, waste input rates and absorptive capacity, effective and total rainfall, infiltration, among others.

Water balance calculations are important in order to design the leachate collection and treatment systems and to design sizes of cells.

As the landfill design progresses, the water balance calculations should be refined. At a minimum, a simple water balance calculation should be undertaken twice yearly, to check whether there has been any increase in leachate production.

The calculation should be of the form:

$$Lo = [ER(A) + LW + IRCA + ER(l)] - [aW]$$

where:
Lo = leachate produced (m3)
ER = effective rainfall (use actual rainfall (R) for active cells) (m)
A = area of cell (m2)
LW = liquid waste (also includes excess water from sludges) (m3)
$IRCA$ = infiltration through restored and capped areas (m)
l = surface area of lagoons (m2)
a = absorptive capacity of waste (m3/t)
W = weight of waste deposited (t/a)

The accuracy of water balance calculations will depend on the methodology used and on the sources of data. Each is subject to errors in estimation. On-site measurements of leachate quantities will, however, guide calculations.

Water balance calculations should be carried out for a number of scenarios such as average monthly leachate volumes to be generated, the maximum quantity of leachate generated during development using 2 and 5-day rainfall events with 10 and 25 year return periods. These calculations will assist in predicting the likely rate of leachate generation. Site conditions will, however, influence the actual rate of generation and a peak flow factor of 3 to 5 times the predicted average flow rate should be used when sizing plant/pipework.

The design of a landfill should also cater for gravity flow of the leachate. This has the advantage of reducing the maintenance and costs incurred in pumping of leachate.

6.2 Leachate drainage, collection and removal

It is accepted best practice to operate landfill sites on the basis of containment to prevent leachate polluting groundwater and also to avoid landfill gas migration. Creating a site with a high degree of containment, however, may result in the accumulation of leachate at the base of the site. As the head of leachate builds, there is an increased risk of leakage. In addition, gas extraction becomes more difficult as the depth of the unsaturated waste layer decreases. Hence, there is need to remove the leachate from the base of the site and to treat it in an environmentally acceptable manner, in accordance with applicable law and environmental standards.

A leachate collection and removal system should be established in a landfill as an integral component of the landfill liner system, except, perhaps where inert waste is being managed. The leachate collection and removal system must be able to deal with the high potential for system clogging from the growth of biofilms. The system is required to manage greater potential flow rates and greater densities and loads of waste. Geo-textile filter selection, in particular, must consider the clogging issue.

The leachate collection and removal system should include the components below.

(i) A drainage layer (blanket) constructed of either natural granular material (sand, gravel) or synthetic drainage material (such as geo-net or geo-composite). Synthetic drainage material may be used on sidewalls of the landfill cells, where the construction and operation of granular material may be difficult.
(ii) Perforated leachate collection pipes within the drainage blanket to collect leachate and carry it to a sump or collection header pipe.
(iii) A protective filter layer over the drainage blanket, if necessary, to prevent physical clogging of the material by fine grained material.

(iv) Leachate monitoring point(s).
(v) Leachate collection sumps or header pipe system where leachate can be removed.

The leachate collection and removal system should be maintainable. This can be achieved by the inclusion of external rodding ports in the design of the system. The main access will be through the leachate sump access pipe. This allows for the installation of a central rodding point at the surface so that the pipework can be cleared of blockages and facilitates access for CCTV inspection. Maintenance access points to sump access pipes should, however, be installed from outside the landfill. Additional airtight access points should be added at the end of the main pipelines.

Methane levels in pumping chambers and collection pipes must be monitored and venting may be allowed in the event of emergencies or normal operational safety, but in a manner that harnesses the energy and does not allow migration of this greenhouse gas. All pump inlets and outlets in manholes should be submerged so that their integrity is not compromised, whilst any monitoring equipment should not cause sparks within any closed spaces.

The adjusted landfill operational approach may imply accepting partial collection and treatment of leachate and partial controlled release for recirculation, attenuation, dilution and dispersion.

6.3 Leachate storage

Storage facilities for leachate may take the same form as those for stormwater retention. Such facilities should be sized to accommodate the leachate volume calculated and should be designed to prevent overtopping.

All components of the leachate storage system should be adequately designed to prevent leakage. When using concrete tanks or pre-fabricated components, storage bunds should be provided for. In situations where it is necessary to line the leachate storage facility with a geo-synthetic material, the design/construction and associated quality control and quality assurance should follow the general guidance given under Chapter 4 on the lining systems.

A storage lagoon for leachate from a Class 2 landfill – for non-hazardous waste may consist of the composite liner below.

(i) The upper component of the composite liner may consist of a flexible membrane liner. At a minimum, a 2mm HDPE or equivalent flexible membrane liner should be used.
(ii) The lower component of the composite liner may consist of a 1m layer of compacted soil with a hydraulic conductivity of less than or equal to 1x10-9m/s, constructed in a series of compacted lifts no thicker than 0.25m when compacted or a 0.5m artificial layer of enhanced soil giving equivalent protection, also constructed in a series of compacted lifts no thicker than 0.25m when compacted.

A storage lagoon for leachate from Class 1 landfill may consist of a similar lining system to that of a Class 2 landfill (the flexible membrane, however, needs to be compatible with the leachate) but leakage detection should be provided for in the design.

The integrity of the liner system for a storage lagoon should be checked prior to placement of leachate through the use of leak detection checks and liquid retention tests. These surveys may need to be repeated during the operational life of the lagoon. The time interval of such surveys will be site specific.

6.4 Recirculation of leachate

Leachate recirculation may be done to promote more uniform degradation rates and as a short term leachate storage measure.

The potential benefits of leachate recirculation include:

- (i) increased quantity and quality of landfill gas for use in energy recovery projects;
- (ii) reduction in the cost of leachate collection and disposal;
- (iii) enhancement of landfill settlement and possible opportunity to recover air space; and
- (iv) early stabilisation of the landfill, leading to reduced post-closure time and cost.

Recirculation should only be carried out if an appropriate lining system and leachate collection and removal system is in place.

For proper execution of leachate recirculation, the aspects below are necessary.

- (i) A leachate reintroduction system contained within the landfill enclosure.
- (ii) A composite lining system with a leachate handling system that demonstrates a minimum of 6 months' acceptable liner performance (where for existing lined sites groundwater monitoring indicates no landfill induced contamination).
- (iii) An adequate monitoring system for determining the level of leachate in the waste.
- (iv) Provision for run-off collection and containmentin areas where soil cover has been applied.
- (v) Trained landfill operators that understand the operational requirements of leachate recirculation.

Leachate recirculation systems should, if possible, allow for leachate collected from the base of the landfill to be reintroduced to the waste mass without any exposure of the anaerobic leachate to the atmosphere.

When acetogenic leachate is being generated, it may be preferable to pre-treating extracted leachate through an aerobic treatment process before recirculation. This limits the build-up of inhibitory contaminants such as ammonia, and especially very acidic leachates which prevent the rapid establishment of neutral pH conditions conducive to methanogenic conditions. If "fresh" leachate is to be directly reinjected and low pH values measured, it may be advantageous to incorporate a pH buffer to maintain methanogenic (near neutral) conditions. These options are considered practicable even though they are associated with high landfill costs. Nonetheless, there are potential savings in reduced operation of leachate systems where waste stabilisation periods are substantially reduced.

6.4.1 Leachate treatment – requirements and options

The main constituents of leachate requiring treatment are the potential pollutants in Table 6.1.

A choice should be made from the leachate treatment categories below;

- (i) Physical/chemical pre-treatment.
- (ii) Biological treatment.
- (iii) Combination of (i) and (ii) in one system.
- (iv) Advanced Treatment.

Table 6.1: Leachate treatment methods and objectives

Treatment Objective	**Main Treatment Options**	**Class of Landfill**
Removal of degradable organics (reduce BOD levels)	Aerobic Biological Treatment ❍ Aerated lagoon/extended aeration –subsequent settling ponds ❍ Activated sludge ❍ Sequencing batch reactor (SBR) ❍ Anaerobic biological ❍ Upflow anaerobic sludge bed (UASB)	2
Removal of ammonia	Aerobic Biological ❍ Aerated lagoon /extended aeration ❍ Activated sludge ❍ Sequencing batch reactor (SBR) ❍ Rotating biological contactor Physico-Chemical Treatment ❍ Air stripping of ammonia ❍ pH adjustment ❍ chemical precipitation ❍ Oxidation and Reduction	2
Denitrification	❍ Anoxic biological ❍ Sequencing batch reactor (SBR)	2
Removal of non-degradable organics and colour	❍ Coagulation using lime, alum, ferric chloride, and land treatment (decontaimination) ❍ Activated carbon adsorption ❍ Reverse osmosis ❍ Chemical oxidation	1, 2
Removal of hazardous trace organics	❍ Activated carbon adsorption ❍ Reverse osmosis ❍ Chemical oxidation	1, 2
Removal of methane	Air stripping	2
	Aerobic biological (limited)	1, 2
Removal of dissolved iron and heavy metals and suspended solids	❍ Coagulation using lime, alum, ferric chloride, and land treatment (decontaimination) ❍ Aeration and settling ❍ Activated carbon adsorption	1, 2
Final polishing	❍ Reed beds or wetland system ❍ Sand filtration	2
Volume reduction	❍ Reverse osmosis ❍ Evaporation –initial evaporation ponds	1, 2

Note:
1= Hazardous waste, 2 = Non-hazardous Biodegradable waste
Table modified from Hjelmar et al., 1995

6.4.2 Physical - chemical pre-treatment

Physical-chemical pre-treatment methods are particularly useful in treating leachate from older/closed landfills that have lower biodegradable organic carbon, or as a polishing step for biologically treated leachate. Some of the physical-chemical treatment processes applicable include: physical processes to reduce suspended solids, or remove oil or sand in the influent; coagulation/flocculation/precipitation to eliminate some percentage of organic compounds; air stripping to remove dissolved methane, ammonia and other undesirable volatile substances; and chemical oxidation and adsorption to remove and separate suspended solids, colloidal particles, and heavy metals in chemical sludge with contaminants which should be treated with subsequent steps. Appendix 1 is a summary of some of the physical-chemical pre-treatment processes.

Some of these processes are quite complex and expensive as well. In addition, the resultant sludge will still need to be treated. Hence, biological pre-treatment with nitrification of biodegradable components could reduce the cost of treatment.

6.4.3 Biological treatment of leachate

Leachate usually contains high concentrations of degradable carbon compounds or ammonia or both. It is for these components that biological techniques offer the most reliable and economic treatment. Biological treatment methods are classified as aerobic and anaerobic according to microbial metabolism.

In aerobic processes, micro-organisms generate energy by enzyme-mediated electron transport using molecular oxygen as electron acceptor. Examples of aerobic processes include: the activated sludge process, a suspended growth biological treatment system that uses aerobic microorganisms to treat ammoniacal nitrogenic substances and organic contaminants; aerated lagoons, used to undertake extended aeration treatment to ensure a wide range of flows and strengths of leachate; and the rotating biological contactors, an aerobic fixed-film biological treatment process. Appendix 2 shows examples of biological treatment methods.

In anaerobic processes, inorganic compounds such as nitrate, sulphate and carbon dioxide are used as electron acceptor. The process offers several benefits over aerobic processes such as lower sludge production, lower energy demand (because no oxygen is required), and recovery of methane. Anaerobic treatment may, however, be unsuitable for leachate treatment where methanogenic conditions exist in the landfill mass and the anaerobic treatment process is unable to remove ammonia.

Many biological processes are also able to treat or tolerate hazardous components such as cyanides, phenols and pesticides. Certain organic compounds may be degraded more easily either by aerobic or anaerobic micro-organisms. For example, aromatic pollutants with several chloro, nitro and azo substituents are readily reduced by anaerobic microorganisms while the reduced end products may be easily mineralised by aerobic bacteria. Thus, a combination of anaerobic and aerobic treatment may enhance mineralisation of complex compounds.

6.4.4 Physical-chemical and biological treatment of leachate

Compact systems for the treatment of concentrated wastewater are becoming increasingly more important. Combinations of biological treatment and membrane technology are used in the treatment of leachate. For instance, 1m with a hydraulic conductivity less than or equal to 1x10-7m/s or a 0.5m artificial layer of enhanced soil or similar susbtance.

Examples of physical-chemical and biological treatment methods are in Appendix 3, and include; membrane bioreactor configuration, powered activated carbon (biological), and filtration, among others. It should be noted, however, that membrane technology is efficient but expensive, complex and energy-demanding. Attempts should, therefore, be made to find affordable but still efficient technologies.

6.4.5 Advanced treatment methods

The following methods are more commonly used for tertiary treatment of leachate especially prior to discharge to surface waters.

(a) Activated carbon adsorption

This method involves constructing a vessel filled with particles of carbon which are porous and have a high surface area. When leachate is passed through activated carbon, contaminants within the leachate are adsorbed or attached to the carbon. The system has to provide for the carbon to be regularly back-flushed or replaced.

(b) Reverse osmosis

If a semi-permeable membrane is placed between two solutions of differing concentration, pure water will travel through the membrane until equilibrium of concentration is achieved. This process is called osmosis. If the pressure in the more concentrated solution is increased, the flow will be reversed.

(c) Chemical oxidation

Chemical oxidation is used for the destruction of cyanides, phenols and other organics and the precipitation of some metals. This treatment technology is well established for large-scale industrial applications. The redox reactions are those in which the oxidation state of at least one reactant is raised while that of another is lowered.

(d) Evaporation

This is a two to four stage process which concentrates contaminants in leachate by evaporation and distillation. The process includes the steps below;

(i) The leachate is pre-treated by the addition of acid to reduce the pH value and to convert volatile ammonia into soluble ammonium salts.
(ii) The leachate is evaporated and separated into distillate and residual liquor. The leachate is evaporated using a relatively low heat source and is separated into distillate and concentrate.
(iii) The distillate may require further treatment prior to discharge as it would contain volatile substances left in the leachate after pre-treatment.
(iv) The concentrate could be distilled further into distillate and sludge, the sludge requiring either thermal treatment or disposal to landfill.

(e) Constructed wetland treatment method

This treatment method relies on the ability of the wetland vegetation (such as reeds) to transfer oxygen to their extensive rhizomatous root system, stimulating the growth of bacteria in the surrounding soil medium, which break down organic substances in this root zone. Other constituents of the effluent may be immobilised or adsorbed by the plants themselves. Constructed wetland systems have found applications for the tertiary treatment of industrial effluents and landfill leachate. Table 6.2 presents the general principles for the design of constructed wetland.

It should be noted, however, that wetlands should be used only as final polishing filters, with the intention that the plants in these wetlands will use nutrients available in the leachate, and partially evaporate part of the liquids.

Table 6.2: General principles for constructed wetland design

General principles for constructed wetland design include those below.

i. A typical design loading of 11 g of BOD per m2 of bed.
ii. A flat surface to the bed to allow flooding to be used as a means of weed control.
iii. An adjustable discharge outlet to assist in the flooding of the bed.
iv. Fill media with a hydraulic conductivity of at least 1x10-3m/s. The media should be washed before placement. Gravel beds of high permeability enable very flat gradients to be designed and flooding can readily be accomplished, to achieve weed control. Gravel beds also allow rapid and controlled changes in water level raising it to ground level to prevent drought, and lowering it to aerate the bed and encourage deep rhizome growth.
v. A minimum depth of soil or gravel in the bed of the constructed wetland of 0.6m at the inlet end. This corresponds to the maximum depth to which Phragmites australis (the common reed) will grow; The outlet end being deeper (dependent on the hydraulic conductivity of the media) to allow for 0.5% - 3% slope on the base. This enables the reed bed to be drained if necessary.
vi. Provision of a lining system beneath the reed bed. The make-up of the lining system should follow the general guidance given under Leachate Storage in section 6.3.

Constructed wetland systems are generally good for the removal of organic components (including residual BOD5, COD and suspended solids) and some denitrification takes place. Poor removal of ammoniacal nitrogen is, however, also a common occurence when these systems are used. This is why they are more suitable for tertiary treatment of leachates prior to discharge, and not for treatment of raw leachate.

6.4.6 Management of residues

One of the most significant issues encountered in designing leachate treatment systems is the management and disposal of residues generated from the treatment processes. These include residues below;

(i) Suspended solids sludge resulting from wastewater sedimentation or filtration processes.
(ii) Concentrated brine solutions generated from reverse osmosis separation processes.
(iii) Metal sludges produced by chemical precipitation.
(iv) Spent carbon from activated carbon adsorbers.
(v) Concentrated ion exchange regenerant solutions.
(vi) Waste biological sludges.

The management and disposal of residues from a leachate treatment system should be a key consideration for a waste handler, to avoid secondary harm to human health and the environment. The disposal of the residues may vary depending on the type, concentration and quantities of pollution. Normally, safe re-disposal may be the most relevant option after treatment, but this must be assessed when analysis has been carried out. The disposal should, as appropriate, be by way of incineration, landfill or other method in accordance with the National Environment (Waste Management) Regulations, 2020 or the Petroleum (Waste Management) Regulations, 2019.

6.4.7 Life cycle considerations

Many factors need to be considered when designing a leachate treatment system. The leachate flows and characteristics are dependent on the type of waste landfilled, the age of the landfill, and the prevailing weather conditions and geology around the site. Leachate flows may increase during the raining season. Organic acid production usually increases in the early years, then decreases as the landfill contents age. The leachate will require treatment during the active years of the landfill and many more years, possibly decades, after the facility is closed. To successfully engineer a leachate treatment system, therefore, the waste handler should take into account these considerations, and develop a life-cycle design.

As the life cycle of the project develops, physical or chemical changes may occur that require adjustment of the original design. The waste handler should incorporate flexibility into the design. Where special waste is to be handled for a short period of time at the landfill and specialised equipment/processes are required, it is advisable to consider use of package plants; equipment that may be easily converted from one configuration to another. Otherwise, permanent treatment structures should be installed.

It is essential that leachate treatment plants are designed using relevant process expertise and be use of appropriate and adequate technology and solutions, such as would be applied to the design of a treatment system for effluent from an industrial process.

Chapter Seven

Landfill Gas Management

7.0 Landfill gas

Landfills produce gas usually right from the first year after waste disposal and for decades thereafter. For this reason, landfill gas should be collected as soon as its generation has been registered at sufficient volumes and quality for realistic extraction. Landfill gas should also be collected during the aftercare phase of a landfill, until gas utilisation is no longer feasible and flaring is no longer possible. Landfill gas results from the biodegradation of waste. The major components of landfill gas are methane and carbon dioxide (typically in a 3:2 ratio) with a number of minor constituents in low concentrations. Methane is flammable and can be an asphyxiant. Carbon dioxide is an asphyxiant. Fires and explosions can occur when landfill gas mixes with air and ignites when within certain concentration limits. The concentration limits are known as the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL). The LEL and UEL of methane are approximately 5 and 15%v/v, respectively.

Gas production within the landfill takes place at Low to medium temperatures (typically 30-40 °C). The formation of methane and carbon dioxide commences approximately 6 months after deposition of wet organic waste in a landfill. The production of landfill gas peaks at approximately 10-20 years, then declines over the course of several decades.

7.1 Requirements – principles

The gas produced from the landfill should be extracted by means of an active gas extraction system. The landfill cells or sub-cells must have landfill gas extraction systems installed with or as soon as possible after placement of the waste. These sub-cells may have temporary caps that may have different performance requirements than the final landfill cap. Temporary caps placed over the cells have the primary function of preventing the escape of landfill gas to the atmosphere and to maintain anaerobic conditions during vacuum extraction. The temporary cap must accommodate high levels of settlement during the operation of the landfill.

Temporary caps and bunds should be removed when additional waste is placed against them if they are constructed of materials that will form low-permeability layers or barriers within the landfill.

Landfill gas extraction systems are commonly installed with the waste as horizontal systems. Systems with vertcal wells are also widespread. The systems must be constructed from strong, crush-proof pipes and should be installed with a slope (of 3-4%) to prevent blockage from leachate or condensate.

Horizontal gas collection systems may also be used to introduce water into the waste mass. The basal leachate collection system may be used as an additional gas collection layer in the early stages of the operation of a cell. Vertical gas extraction systems are also used.

The design and location of the gas management infrastructure should minimise damage by settlement, vandals, animals, natural processes or operational machinery. Landfill gas extraction wells should be monitored and maintained or replaced as required.

An appropriate level of construction quality assurance must be completed during the installation of a landfill gas management system. Any variations from the design made during the construction phase should be recorded and taken note of by the landfill site owner/waste handler.

7.2 Objectives of a landfill gas management system

The purpose of a landfill gas management system is to:

(i) minimise the impact on air quality, odour and the effect of greenhouse gases on the global climate;
(ii) minimise the risk of migration of landfill gas into the service area and premises in the landfill and beyond the property boundary of the site;
(iii) avoid unnecessary ingress of air into the landfill and thereby minimise the risk of landfill fires;
(iv) minimise the damage to soils and vegetation within the restored landfill area;
(v) ensure effective control of gas emissions. One resource efficient way of achieving this is by composting of sanitary biodegradable waste; and
(vi) where practicable and appropriate, permit energy recovery.

7.3 Landfill gas quantities and properties

7.3.1 Models for estimating landfill gas generation over time

The rate of gas generation at a landfill site varies throughout the life of a landfill and is dependent on factors such as waste type, depth, moisture content and degree of compaction, landfill pH, temperature and the length of time since the waste was deposited. Predicting gas quantities is, therefore, subject to significant uncertainty and local conditions. As a result, a number of methods should be used to estimate the likely landfill gas production rates. Methods include; rule of thumb method, a pumping method and computer modeling method, as explained in Text box 7.1.

At the beginning, the rule of thumb may be more applicable; however, as more waste is landfilled, pumping trials can be undertaken. Subsequently, as more information about the landfill gas produced becomes available, modelling methods can be used. The methods in Text box 7.1 should be reinforced by detailed analysis and appropriate investigation techniques at a later stage of the development of the landfill.

Text box 7.1: Methods to estimate likely landfill gas production rates

Rule of thumb

As a rule of thumb it can be assumed that every tonne of degradable waste will produce about 6m3 landfill gas per year for ten years from the time of placement of waste.

Under optimum conditions, one tonne of degradable waste can realistically produce 200-300 Nm3 of landfill gas. In practical terms, the rate at which landfill gas may be collected for utilisation purposes will be much lower. Typically, a value of 100-200 Nm3 or less of landfill gas per wet tonne of non-hazardous biodegradable waste may be produced.

Pumping trials

Gas pumping tests enable analysis of gas composition and estimates of production of landfill gas in addition to determination of well performance. Pumping trials have the advantage of being site specific. The gas generation rate obtained from pumping tests can be assessed for the whole site or for part of the site. Pumping tests in selected areas of a site are scaled up and are assumed to be representative of the whole site.

The pumping test involves pumping at a gas well and if applicable include monitoring surrounding wells or include gas flow rate, pressure, applied suction and gas quality. The zone of influence may be determined from the data at the monitoring points.

The pumping trial test should run until steady state conditions are met. At this stage, the landfill gas quality should stabilise and the flow of the landfill gas at the wellhead should essentially be the gas generation rate. An important factor in the use of pumping trial data is the accurate estimation of radii of influence of test wells.

Models

An estimate of gas yield can be obtained using appropriate software modelling methods either as an alternative to pumping trials or preferably in combination with the pumping trials. The reliability of the models prediction will depend upon the availability of site specific data.

Input data that may be required for a model includes; the date landfilling starts, the date landfilling ends, mass of waste in place, rate of infilling, waste type, baled/shredded/compacted waste, gas extraction and composition, moisture content of the waste, packing density, gas and waste temperature, pH of waste in place, fraction of waste components, waste degradation rates, fraction of degradable carbon, and gas recovery effectiveness.

The gas yield can be used to size the control plant and determine the economics of utilisation.

Note: The Landfill gas generation in countries like Uganda may be different from what is assumed in most models; hence, the estimates of landfill gas referred to in the rule of thumb (text box 7.1) must be based on local conditions.

7.3.2 Landfill gas properties and limitations

Landfill gas by its nature migrates from one place to another. It may diffuse from an area of high concentration to an area of low concentration; or move by convection from an area of high pressure to one of low pressure. It may further migrate in solution of leachate or groundwater. These modes of migration of gases are independent of each other but may occur concurrently, and it is likely that migration control measures may control one mode of landfill gas migration without removing the risk other modes present.

It is, therefore, important to adopt a combination of landfill gas migration control measures. These measures may include use of barriers, active control and flaring. Barriers used to control landfill gas migration are similar to those used for groundwater/surface water control, and may be vertical barriers or horizontal barriers. A physical barrier such as a composite liner of compacted clay or enhanced soil, in very close contact with a flexible membrane liner, may be used. Whichever control measure is used, attention should be given to how fast and how far the gas travels due to the ease of the migration path and the pressure the gas presents in the landfill.

7.4 Landfill gas extraction – design and function

A landfill gas collection and extraction network should be established based on the expected end-use of the gas extracted. This network may also serve as a gas collection station, and will typically comprise gas wells, wellheads, collection pipes and extraction equipment. It will also include: blowers to extract gas from the landfill; filters to remove solids; instruments for the control of gas extraction and transport; measuring and control equipment.

7.4.1 Gas wells

Gas wells may be installed during landfill site development or after the waste is deposited. The most common gas well types include; vertical gas wells, horizontal gas wells, hybrid wells, and gabion wells. Even where gas wells are installed early on in the development of the landfill, experience shows that vertical wells drilled down to within 2m of the liner may be advantageous for active gas extraction when the landfilling is complete. Examples of gas wells are in Appendix 4.

7.4.2 Wellheads

Wellheads should be fitted to the top of gas wells to control the extraction of gas. Wellheads should be encased in lockable headworks to prevent vandalisation. They should be joined to connecting pipework using flexible piping to allow for settlement. The alternative is to use direct but flexible connection to the pipework without wellheads.

Wellheads have been developed to cover a number of aspects, and components vary depending on the required functions, including: flow rate measurement fittings, to allow for the flow from individual wells to be monitored; flow regulators; dewatering wellheads; combined leachate and gas extraction; and telescopic fittings to account for movement of the landfill surface with site settlement. Wellheads should also provide for monitoring of gas quality and suction pressure. When no wellheads are installed, the measurement, monitoring and regulating functions for each well may be installled subsequent to the transport pipeline in a central plant.

7.4.3 Collector pipes

A collection pipe network should be constructed to convey the gas from the point of generation or collection to the point of thermal destruction or energy production. The pipeline material should be chemically resistant to landfill gas, condensate and leachate, and should have appropriate mechanical strength to withstand loading and settlement of waste. The pipework should be of a dimension that allows maximum possible gas flow rate from the site and should be laid at a recommended minimum fall to assist drainage of condensate.

Dewatering points should be provided at all drop-legs in such a system. The pipeline should have sufficient valves to allow isolation of sections. Pressure testing of the collection pipe network should be carried out to ensure integrity of the pipe material and of joints. All pipes laid underground should have a minimum cover of 600mm over the top of the pipe.

7.4.4 Condensate removal

When landfill gas enters cooler zones, condensate may be generated which may be corrosive and may contain volatile organics. The main constituents in condensates are volatile fatty acids, ammoniacal-nitrogen and in some samples metals such as zinc or iron that result from corrosion of galvanised or metallic components of gas collection systems.

The primary components of the condensate system may include; condensate water traps, sumps, drain lines, oil and water separator, pumps, treatment equipment, air compressor and storage tank.

Condensate must be removed from the pipeline to prevent blockages and restriction of gas flow. This can be achieved by use of syphon tubes or by condensate knock out drums. Syphon tubes allow condensate to flow through them to a ground soakaway. Condensate knock out drums allow expansion of the gas flow, with a resultant drop out of condensate which may be collected within the drum and discharged or pumped to a suitable reception point. Where condensate is collected, it should be diverted to the leachate collection system.

Landfill gas condensate may be treated before disposal, but primarily in the leachate treatment system. Treatment and disposal options for condensate include; biological treatment, physical and chemical treatment, ultra-violet (advanced oxidation potential) and ozone treatment, combustion destruction (incinerator or flare), waste reclamation discharge (for irrigation), leachate management system discharge and hydrocarbon phase recycling. Condensate may, in some cases, also be treated, stored and disposed as hazardous waste, depending upon the contaminants present, compliance requirements, and available treatment options.

7.4.5 Extraction pumps

Centrifugal compressors or side channel blowers are normally used for gas extraction. An extraction plant is typically designed on a modular basis to provide cost effective and flexible solutions.

Parameters that should be specified for a landfill gas extraction system include; inlet suction and outlet pressure, flow capacity, and power consumption. Flame arrestors should be fitted so that if pumping a gas/air mixture within the explosive range, the risk of propagation of an explosion is minimised. Instrumentation to allow measuring and regular rebalancing of the gas flows from each well is also required. It may be good practice to connect each well to the central facilty with a separate pipeline, to allow for monitoring and adjusting of the extraction from each well from one loction. Other factors to consider are included in Text box 7.2.

Text box 7.2 Extraction pressure and other equipment

A suction pressure of 100mbar or more may be required. The pressure required at the outlet of the extraction plant is a function of the use to which the fuel is to be put and the pipework sizes that will be involved. Centrifugal blowers typically have a pressure lift of 50-100 mbar (single stage) and these, therefore, restrict wellhead suctions to, for example, 25mbar. Sites which require higher gas delivery pressure for utilisation purposes will use other types of gas compressor.

Other extraction equipment that may be considered include; liquid ring compressors, regenerative gas boosters, roots-type blowers, reciprocating compressors, sliding vane compressors, and multi-stage centrifugal gas boosters.

7.5 Movement of landfill gas

The movement of landfill gas within a waste mass is affected by many factors, including:

(i) permeability of waste;
(ii) geologic conditions that determine the potential for off-site migration of gas;
(iii) depth of groundwater since the watertable surface acts as a no-flow boundary for gas;
(iv) human-made features such as underground utilities that may produce short-circuiting of airflow associated with an active landfill gas collection system;
(v) landfill cover and liner systems; and
(vi) barometric pressure which may impact on the amount of gas escaping from a landfill surface.

When waste decomposes in a landfill, naturally there is a tendency of the gas produced to migrate from an area where the concentration of the gas is highest to the direction where its concentration is lowest or to where the pressure is lowest. This is by a process known as diffusion. The concentration of a volatile constituent in the landfill gas will almost always be higher than that of the surrounding atmosphere, so the constituent will tend to migrate to the atmosphere.

Wind often serves to keep the surface concentration at or near zero, which renews the concentration gradient between the surface and the interior of the landfill and thus promotes the migration of vapours to the surface. Geomembrane liners in the landfill cover will significantly reduce diffusion because the geomembrane prevents gases from diffusing to the atmosphere. Specific compounds exhibit different diffusion coefficients. Liners in the cap will, however, also prevent any water entering the waste and consequently cause conditions devoid of adequate moisture needed for the generation of landfill gas.

Landfill gas movement is also a function of advection. Advective flow occurs where a pressure gradient exists. The rate of gas movement is generally much faster for advection than for diffusion. Gas will flow from higher pressure to lower pressure regions. In a landfill, advective forces result from the production of vapours from biodegradation processes, chemical reactions, compaction, or an active landfill gas extraction system. Variations in water table elevations can create small pressure gradients that either push gases out (rising tide) or draw gases in (falling tide). Changes in barometric pressure at the surface can also have an impact on the advective flow of gas.

7.6 Operational criteria and principles

7.6.1 Safety aspects

The flammability, toxicity, and asphyxiate characteristics of landfill gas require personnel involved in the monitoring, operation, construction or any other aspect of a gas management system to be adequately trained. A documented safety system with rehearsal emergency procedures should be provided to cater for preliminary preparation of the workforce before commencement of landfill gas management.

There should be stringent safety requirements regarding equipment and their use in landfill gas collection, utilisation and flaring. The requisite equipment should include detectors, flame arrestors, automatic slam shut valves, and a standby flarestock which would burn off any excess gas should an engine fail.

7.6.2 Landfill gas flaring

To reduce the risk of the combustible gas migrating to neighboring areas or causing explosions, the level of methane in landfill gas should be as guided by the National Environment (Air Quality) Regulations, 2021 before it is released into the atmosphere. Burning landfill gas reduces the methane content to carbon dioxide and water. This may be done through flaring or by utilising the landfill gas in a gas engine or furnace to generate energy.

If the gas quality is too low for use as fuel, it can be flared for normal operational purposes or in emergency situations, subject to the Petroleum (Exploration, Development and Production) Act, 2013, the Petroleum (Refining, Conversion, Transmission and Midstream Storage) Act, 2013 and the National Environment Act, 2019. Typically, a methane content of at least 20% or more realistic 30% by volume is specified for operation of a landfill gas flare unit. A flare system may also be used to burn off excess gas for operational safety and emergency reasons or to act as a standby system during periods of plant shutdown. Text box 7.3 shows flare equipment and advises regarding preferred aspects.

Text box 7.3 Flare equipment

Two basic types of flare unit - an elevated stack and a shrouded flare type, may be used. Landfill gas may be flared at a temperature range of between 1000˚C and 1200˚C to remove minor constituents in the landfill gas. For adequate destruction, combustion retention time is typically between 0.3 and 0.6 seconds.

With elevated stacks, it is not possible to obtain extended residence times at elevated temperatures. The shrouded flare type can hold the gas at the design temperature for a specified period of time within a combustion chamber of adequate volume. The height of the flare is also important.
Tall flares are preferable to shorter flares since tall flares:

(i). are better able to induce sufficient combustion air;
(ii). are more likely to provide an adequate retention time for the entire gas stream;
(iii). enable more uniform temperature distribution, while with short wide stacks there is an increased risk of poor mixing of gases near the walls. Thus tall flares are less likely to develop cold spots where combustion will be poor; and
(iv). allow better dispersion of the off-gases into the atmosphere.

As with the siting of gas extraction/utilisation plants, flaring equipment should, among other factors, take into account sensitive receptors and prevailing wind, and should be located so as to minimise odour nuisance and visual intrusion.

7.7 Optional/supplementary schemes

7.7.1 Landfill gas venting

Under the Petroleum (Exploration, Development and Production) Act, 2013, the Petroleum (Refining, Conversion, Transmission and Midstream Storage) Act, 2013 and the National Environment Act, 2019, venting of landfill gases may only be undertaken for normal operational purposes or in emergency situations. Passive ventilation, may in some cases be advantageous in reducing the levels of methane gas emissions. This is by use of natural forces such as wind and thermal buoyance to circulate air to and from a landfill without use of mechanical systems. Nevertheless, mechanisms should be put in place to capture the gas and to convert it into energy if the quantities and quality of the gas are sufficient.

7.7.2 Methane oxidation

About 80% of methane oxidation is attributed to methanotrophs, which are prokaryotes that metabolise methane, and in the process act to reduce methane concentration in the atmosphere. This is an important process around landfill sites where methanotrophs are selected because of the high concentration of methane in and around landfill soils. In a way, this may have an impact on the amount of methane emitted by landfills to the atmosphere. It is an option to supplement the extraction system with a top layer providing good methane oxidation conditions.

7.7.3Composting of waste

Non-hazardous waste deposited at a sanitary landfill can be converted into composed manure. By so doing, escape of greenhouse gases such as methane into the air is minimised.

Uganda is part of the Clean Deevelopment Mechanism (CDM) under the Kyoto Protocol and a number of sanitary landfills were established for the composting of waste in order to manage the waste and to reduce the emissions of greenhouses.

When the facilities for composting are designed and managed in accordance with the requirements set by the CDM Board, the facility may be registered and become eligible for carbon credits under the Kyoto Protocol. A landfill gas extraction and utilization plant may also be part of the CDM system.

7.8 Utilisation

Methane is estimated to be 20 - 30 times more potent (per molecule) than carbon dioxide due to its greenhouse (heat trapping) effect that affects global climate. The combustion of landfill gas either in flares or as part of an energy recovery process converts methane to carbon dioxide and should be undertaken whenever the landfill gas yield is capable of supporting combustion. Active landfill gas systems should be designed to enable easy conversion to a passive system when gas production diminishes.

Landfill gas should, where practicable, be collected from all landfills receiving biodegradable waste and converted to energy or flared for normal operational purposes or in emergency situations. In any event, the landfill gas control measure that achieves the best environmental outcome should be used in accordance with applicable law andenvironmental standards.

The gas extraction system should also be appropriately located to minimise odour nuisance and visual intrusion. The landfill gas extraction process has to be closely monitored to ensure that good quality methane is captured for energy production.

7.8.1 Methods, energy potentials, design

The utilisation of landfill gas as an energy resource may be a commercially viable proposition and can offset some of the costs of control. Gas utilisation depends on the quality of the gas, the gas yield and on the economics of production to available market. The potential end use of the landfill gas depends on the volume and methane content of the gas. For safety reasons, the collection and utilisation of methane gas must operate above the upper explosive limit.

It is widely accepted that the minimum amount of landfilled biodegradable waste required to sustain a commercially viable landfill gas electricity scheme is about 200,000 tonnes. Without a well constructed cap, it is unlikely that the utilisation of landfill gas will be a realistic commercial possibility, unless the site is very deep and contains a volume in excess of 0.7million to 1 million cubic metres.

7.8.2 Direct uses

Landfill gas can be used directly in firing boiler, burning bricks in kilns, cement manufacture, stone drying, greenhouse heating, augmenting national gas supply, and as vehicle fuel.

The size of direct use schemes typically range between 0.5 - 3.5MW. Minimum methane concentration will vary depending on the application.

7.8.3 Power generation

Normally, the size of power generation schemes arein the range of 100 kW to 5MW. Typically, some 600/700m3 of landfill gas (containing 50% methane) are required to generate 1 MW of electricity. The type of plant for power generation will depend on the quantity and quality of gas generated. Power generation is feasible at a landfill when the methane content range is 35% to 60%, but a minimum of 40% is preferred. Obviously, there is a clear economy-of-scale with bigger power plants which have a much lower cost or kWh compared to smaller units.

Power generation plants used include gas turbines, dual-fuel engines and spark ignition engines. Minimum methane content for these plants vary but typically around 35% to 40% methane content is required. Gas turbines start at about 3MW and are suitable for larger schemes with gas flow rates in excess of 2500m3/hr.

As with the flare unit, the waste handler should ensure the testing of the products of combustion from the utilisation plant in order to verify that the predicted performance is being achieved. Specific limits for engine emissions may be set at the time of licensing, but as a general guide emision standards may also be referred to.

7.8.5 Cost considerations

The cost of setting up a landfill management system should be considered and planned for during the landfill design phase, to ensure that a manageable landfill plant is put in place. It is equally important to have a well-costed and effective management system that does not compromise landfill operational safety and the environment.

Chapter Eight

Site Development – Infrastructure

8.0 Site infrastructure

Principal site infrastructure elements, some of which are discussed in greater detail in these Guidelines, include; access and traffic control, administration facilities, weighbridges, wheel cleaners, site services, domestic waste facilities, landfill cells, leachate collection and treatment facilities, gas collection and preferably utilisation structures, waste inspection area, monitoring and security infrastructure. There may also be facilities for composting of sorted suitable organic waste types.

8.1 Site services

Site design should include provision for fencing, controlled access gates, security cameras, lighting, water supply and wastewater management, among others.

Perimeter fencing should be provided at all sites. When designing a fence, consideration should be given to the probability that unauthorised persons may want to gain entry to the site. Hence, fencing should be to an adequate standard and sufficient height (approximately 2.3m) to prevent unauthorised access.

Fencing should be regularly inspected and any damage to the fence that would allow unauthorised access should be repaired as quickly as possible. Suitable fencing should be undertaken to prevent access by animals, including crawling and burrowing animals.

Access gates should be provided at the reception area. It may be necessary to provide a number of gates at points around the site for access. All gates should be to a standard similar to that of the specification for the security fencing. When unattended, the gates should be securely locked.

Security cameras may be used at the access point/reception area and at other strategic locations around the site. Intruder alarms may be fitted to the reception facilities/compound stores and linked to a call out system.

Adequate lighting systems should be provided in all areas of operation, including at night. This should include lighting of roads of access from the public road to the reception area. Lighting should also be provided at site facilities such as weighbridge and wheel cleaner which may require maintenance outside normal working hours.

A water supply is required for general on-site everyday purposes. In addition, fire-fighting equipment should be available at the site.

Areas designated for storage, handling or treatment of organic waste or construction/demolition waste should comprise of a hardstanding surface with an impervious base, peripheral bunding and access ramp. A sealed drainage system should be used to collect effluent stemming from these areas. Collected effluent should be channelled to leachate storage or treatment facilities.

8.2 Access and internal roads

In the design of a landfill site, access should have been planned. Access can be by road, rail or water but in Uganda it is typically by road.

In cases where access to the landfill site is by road, the impact of the proposed development on the existing road network should be examined. The results of a traffic analysis will determine if specific provisions are required to deal with the anticipated traffic flow and vehicle impact.

The existing road network may need upgrading to deal with the increase in traffic and vehicle load to the site or a dedicated road linking the nearest primary/secondary route to the proposed site may be required. In any case, an analysis prior to detailed design should ensure that the potential to damage existing road surfaces is mitigated; and that build-up of traffic on public roads as a result of waste transportation is addressed.

The access road, including the reception area, should be paved to national road standard and should have a minimum width of 6-7m. Entry and exit points should be provided. In any event, road design should be carried out in accordance with national law and standards for roadworks.

Haul roads from the reception area to the entrance to each phase should be designed to a standard adequate to allow traffic flow of heavy vehicles. Haul roads may need to accommodate the passage of heavy construction vehicles such as steel wheel compactors and tracked bulldozers. In the alternative, separate roads may be provided for those heavy vehicles. The haul roads should not be accessible to other vehicles except for collection and transport trucks.

Traffic signs within the landfill area should include speed limits, stop signs and directional signs to the reception area, weighbridge, car park and landfill cells.

In addition to traffic signs, provision should be made for adequate facility signage as detailed in section 9.2 of these Guidelines.

8.3 Operational facilities

8.3.1. Equipment

Equipment falls into three functional categories; waste movement and compaction, earth cover transport and compaction, and support functions. Each site must be studied before a determination can be made of the exact equipment necessary for preparation of the site, daily operation, and special situations.

The amount of waste influences the appropriate machine size. Heavier equipment provides more compaction and flexibility in handling a variety of materials using thicker compaction lifts. The condition in which the waste is received may, however, affect equipment choice.

Transport vehicles should, as much as possible, be separated from the operating equipment.

8.3.2. Garages and workshop

Equipment breakdowns of a day or more result in the accumulation of waste in a landfill, with all the attendant health hazards or nuisances. Systematic, routine maintenance of equipment reduces repair costs, increases life expectance, and helps to prevent breakdowns that interrupt landfill operations. Prompt repair of equipment and availability of standby equipment ensures continuity of operations.

Garages and workshops at the landfill should be controlled areas; and access to these facilities shouldbe guided by the requirements of occupational health and safety.

8.3.3. Scale and recorder

A weighbridge is required to accurately determine the weight of incoming waste. This facilitates accurate record keeping for the purposes of invoicing clients, landfill levy documentation and monitoring waste disposal rates. The weighbridge should be located adjacent to the waste reception area or site entrance, and sufficiently far away as possible from the public road to avoid queuing onto the road. Weighing facilities should be adequate to accommodate the weighing of both incoming and outgoing trucks transporting waste, as appropriate.

When selecting a weighbridge, consideration will have to be given to:

(i) accuracy and ease of calibration;
(ii) required length; and
(iii) load capacity.

It is recommended that the weighbridge should be, at a minimum, 15m long and 3m wide, with a minimum load bearing capacity of 40 to 60 tonnes; however, the size may be adjusted as long as it is compatible with the vehicles to transport waste to the landfill.

The weighbridge should be installed to a standard specification supplied by the weighbridge manufacturer. Foundations to receive the weighbridge must be constructed to the details supplied by the manufacturer.

Suppliers of the weighbridge unit will also normally provide computerised software for recording details of the incoming waste. When selecting the computerised software, consideration should be given to the information required under the license to manage waste. The waste handler shall ensure that the weighbridge is calibrated and certified by the competent standards body in Uganda. These measures should help in record keeping, data transfer and information analysis to meet regulatory requirements and to ensure that the landfill is operating efficiently and profitably.

8.3.4. Facilities for composting of waste

There may be separate facilities for receiving organic or biodegradable waste which is not hazardous. This is especially so for sanitary landfills. Hence, there should be a sorting bay for sorting of waste and removal of non-organic matter from it before it is composted. Where a decision to make compost manure is taken, at least 6 windrows should be designed and constructed at the identified location within the site. The windrows should be constructed at reducing lengths largely because the waste mass also reduces in volume and weight with time as it is composted. There should also be roofed composting concrete platforms, complete with a drainage system with drainage channels and a leachate collection tank, or transfer to the leachate management system. Once the compost is produced, it should be tested in the demonstration garden to assess its mineral content and usefulness in increasing the organic content of soils.

The equipment needed may include wheel loaders, tractors and trailors, skip loaders, turning equipment, weighing scales, computers and printers.

8.3.5. Health, safety and security measures

The developer should establish, implement and maintain a health, safety and security management system in accordance with legal requirements and international best practice. A health, safety and security risk assessment should be done to determine the best control measures required during the landfill project cyle.

Structures and welfare facilities should meet health and safety standards and provide a pleasing amenity, including providing the requisite security for persons at the site. Hence, minimum standards below should be observed.

(i) Adequate signage schemes at the site, showing prohibitions, mandatory action, precautionary measures and warning of danger. These should be visible and understood by all persons that access the landfill.

(ii) Well located guardhouse, access gate, perimeter fencing, personnel manning of the facility, among other similar measures.
(iii) Areas where access is restricted, especially high risk areas where only specific workers may be permitted. The public should be prevented from accessing heavy equipment, chemicals and other susbtances with potential risk to human health and safety.
(iv) Facilities for emergency first-aid equipment to treat persons who have had accidents.
(v) Appropriate and adequate Personal protective equipment (PPE).
(vi) All buildings on the site should be constructed and maintained in a manner that prevents the harbouring of rodents and other vermin.
(vii) Clean and safe drinking water supply should be provided and maintained on the premises.
(viii) Adequate resting and eating area.
(ix) Adequate sanitary facilities, including washrooms and cloakrooms with clean and dirty zones. These facilities should be gender sensitive and available for use by workers and other peole visiting the site.
(x) Minimum appropriate communication facilities (including mobile phones and radio) must be provided to enable rapid communication in case of personal or environmental accidents at the landfill.
(xi) Clearly marked emergency assembly points and exit routes.

8.3.6. Washing/cleaning schemes

Wash-off or tyre spray decontamination facilities, including trenches to collect run-off from the wash off or cleaning, are useful to prevent contamination. A wheel cleaner is essential to prevent waste mud and any contaminants from being carried out onto the public road.

The design of the wheel cleaning unit should ensure that there is a stable foundation below the unit and that the structure of the unit is capable of taking the weight of the trucks. It is possible to design the wheel cleaner facility in a manner that enables cleaning of waste residue that might have hang on the body of the truck during tipping.
Where water is to be used as part of the wheel cleaner facility, a water supply, drainage area and an area of hard-standing is required. All washup water must be channelled to the leachate collection and treatment system for pretreatment prior to reuse or release to the environment.

8.4 Administration facilities

The landfill facility may have an administration area which should be separate and distinct from the operational area. The administration area should be designed, constructed and maintained in accordance with national building standards.

The administration area should as a minimum include the facilities below;
(i) Administration building consisting of an administration office, first aid area and general reception area. All buildings should be well ventilated.
(ii) Sanitary facilities: including washrooms and toilets. These should be gender sensitive.
(iii) Staff facilities: including lockers.
(iv) Dining area.
(v) Waste reception area.
(vi) Monitoring equipment store.
(vii) On-site laboratory, where applicable.
(viii) Equipment maintenance and fuel storage.
(ix) Parking area.

It is recommended that purpose-built facilities are constructed. The administration building should include appropriate communication facilities including a working telephone/mobile phone and CCTV, and should be suitable for the storage of records.

The waste reception area is an important part of the infrastructure of a landfill facility as it is used to determine if the waste should be accepted for disposal to the site or not. The waste inspection facility should be located so as to cause minimum disturbance to other traffic using the landfill facility. It should be constructed on an impervious hard-standing area with retaining bunds. Drainage from this area should be independent of the rest of the reception area and shall be channelled to the leachate collection and treatment plant.

On-site, compounds are required for equipment maintenance and fuel storage. Fuel and oil should be stored in clearly marked and controlled areas. Tanks or containers for fuel and oil should be surrounded by a secure bund which is able to contain at least 110% of the capacity of the largest tank.

The parking area should provide sufficient parking spaces for staff and visitors. This space should be located adjacent to the administration building with easy access to the reception area and should not be accessible to traffic hauling waste to the landfill. Trucks and heavy plants should be away from the administration parking. The area where heavy trucks are parked should be well maintained and should drain towards a channel dedicated to stormwater ponds. This is to prevent cross-contamination of vehicles.

Best practice for a landfill is to have a gatehouse at the entrance to the site or at a point that cannot be bypassed when entering the landfill. The gatehouse is the first line of active measures to check the incoming waste stream to detect non-conforming waste and divert materials to the recycling area. There should be facilities such as a viewing platform, elevated mirrors or video camera which allow the gatehouse attendant to readily scrutinise the incoming waste load.

Chapter Nine

Operating and Managing a Landfill

9.0 Introduction

The basic factors influencing site operations and maintenance management are the waste type and quantities to be handled. The waste type and quantity determine the machinery and equipment to be used and staff deployment schedules.

A well-organised site management system prepared during the site design shall be used to guide management of the site. The site management system should outline the specifics of operations at the landfill site and indicate aspects of daily, periodic, unscheduled and emergency activities and alternatives for operations during different weather conditions, so that landfill volume is effectively used and environmental standards are met. It should also set out detailed aftercare procedures. Local operations will vary according to conditions at individual sites, including the nature of the terrain and the availability of equipment and personnel.

9.1 Environmental mitigation measures

9.1.1. Air pollutants

Assessment of air pollutants should be undertaken as part of the landfill gas risk assessment under the National Environment (Environmental and Social Assessment) Regulations, 2020. Landfill gases can contain a range of air pollutants, depending on the type of waste that has been deposited in the landfill. Consistent with world best-practice and to ensure protection of public health, a monitoring plan should be developed and implemented for air pollutants, where required. Advice should be sought from an environmental auditor during the development or review of the landfill gas risk assessment in accordance with the National Environment (Air Quality) Regulations, 2020.

9.1.2. Odours

Landfill odour is a key consideration in landfill siting. Landfill odours have two main sources; odour from the aerobic decomposition of freshly deposited waste and odour from landfill gas generated by the anaerobic decomposition of waste. Leachate ponds can also be a source of offensive odours. While the major constituents of landfill gas, methane and carbon dioxide, are odourless, other minor constituents of landfill gases, including organosulfur compounds, can be very odourous.

Landfill gas odour should, therefore, among others, be managed by oxidising it. Odour from aerobic waste deposition should be managed by minimising the exposure of such waste to the atmosphere.

Offensive odours should be prevented from going beyond the boundary of the premises, and adequate buffers and other appropriate measures should be put in place to manage the odour.

9.1.3. Dust

Any large area where the land has been disturbed and is subject to vehicular traffic has the capacity to generate dust. Other potential dust sources are stockpiles of earth and the delivery of dusty loads of waste.

The magnitude of the impact will depend on; type and size of the operation, prevailing wind speed and direction, adjacent land use, occurrence of natural and/or constructed wind breaks, and wind-abatement measures or buffers.

Dust suppression measures to be applied at the site include:

(i) vegetating or mulching of exposed areas, including sealing roads that are used regularly;
(ii) use of water or other dust suppressants on roads or stockpiles that are not sealed or vegetated; and
(iii) where leachate is to be used for dust suppression, it may only be applied to areas that are within the active landfill cell to ensure the leachate does not contaminate storm water run-off.

9.1.4 Litter

Domestic waste, especially plastic bags, can be spread over a wide area by the wind. This litter not only looks unsightly but might also foul drains and waterways, as well as interfere with neighbouring activities such as quarrying or farming.

Litter control at landfills will vary throughout the year depending on wind strength and the orientation and elevation of the tipping area. No single control option will be entirely successful for the entire life of the landfill.

A litter control strategy should be developed and must be flexible and include both engineering solutions and management options. At a minimum, litter screens should be used and staff should be trained in the appropriate placement of the screens to trap as much litter as possible. These litter screens should be portable to be able to follow the tipping area, and should be capable of withstanding wind loads when loaded with litter. Litter screens should be at least four metres high.

The size of open tipping areas should be minimised and fences and surrounding areas should be cleaned of litter daily. Frequent cover operation must be carried out, with weekly cover as a minimum and preferably with daily cover.

Contingency plans should be put in place and resources planned to deal with extreme events that cause gross litter problems. In areas where litter is especially problematic, this may involve a dedicated litter crew, more frequent covering and enhanced litter screens.

Dedicated areas for waste deposition that are more sheltered from winds from particular directions should be considered in order to minimise litter from the landfill. As a matter of course, it should be expected that trucks delivering waste to the landfill cover the waste mass they are carrying and avoid overloading. This should ensure that waste is not spewed along the way to the landfill. Hence, the waste handler should stipulate conditions related to how much a truck of a particular capacity should carry and the load limits. This must be monitored and enforced when the truck is entering the site.

9.1.5. Noise

Noise from landfill operations and equipment should be minimised to the limits prescribed by the National Environment (Noise Standards and Control) Regulations, 2003 so as not to impact detrimentally on the amenity of surrounding areas.

Where noise is considered an actual or potential concern (due to changing land use), an acoustics specialist should predict the noise levels at the nearest current or future sensitive receptors, and recommend measures to control the noise.

Site operations should be set out to minimise noise impacts by using natural and/or constructed features such as earthen bunds and depressions as well as minimising steep-haul roads. Operating hours should also be managed to limit noise disturbance, especially at night.

Alternative types of reversing beepers could be adopted. Broadband reversing alarms or smart beepers are less disturbing to neighbours and could meet occupational health and safety requirements.

9.1.6. Vermin, birds and other pests

Regular inspections for the detection and destruction of rodents shall be carried out. Anti-fly measures (earth cover, removal of reasonable preventable condition and spraying) for the destruction of flies shall be carried out to reduce and eliminate fly nuisance. Adequate signs shall be displayed to inform landfill workers, visitors and waste pickers of possible dangers during vermin control. Measures to control birds should be advised by a responsible regulatory institution.

9.1.7 Fire

Fire is a landfill hazard and control measures should be in place to manage it. These measures include installing fire-fighting equipment and training staff on how to use them. The waste handler should also plan to install smoke detectors at the landfill to enhance quick response.

Open burning on landfill sites must not be permitted in any case, since such burning and its attendant smoke, ash deposition and particulate matter cause public nuisance and health hazards in areas several kilometers away from the landfill. Hence, fire should be extinguished immediately to prevent it from spreading.

Accidental fires should be managed in accordance with standard operating procedures and industry best practice. Fire management measures may include thorough inspecting and testing of waste for flash points (lowest temperature at which vapours of a substance ignite if given an ignition source), construction of trenches around the fire and application of adequate cover material. These measures should be contained in a fire prevention and management plan.

9.2 Landfill operation

The site operation and maintenance procedures should be so as to minimise pollution. Size of working/ treatment platform and the method used for the treatment of the waste all influence the effort required in controlling pollution.

9.2.1. Traffic management

The operator of the landfill should limit the number of access roads to the landfill and speed of vehicles in order to address safety concerns, noise and road grime. The other reason for limiting the number of access road (in-roads) is in order to have only the number of roads that can be adequately maintained.

In addition, trucks should be encouraged, where possible, to use access roads that will have the least impact on the surrounding community.

The design of the site layout should ensure that areas with the most trafic, such as parking space, the entrance gate and the weighbridge, are away from sensitive land users; and traffic-control devices and signage should be provided near the landfill entry.

Traffic control devices, such as traffic islands and merged lanes at the entrance to the landfill, may need to be considered, to minimise the impact of traffic. Recessing the entrance into the landfill helps to minimise vehicles queuing along public roads. It also assists in the control of dirt from the site.

Soil must be removed from the wheels and underbody of vehicles leaving the landfill before the vehicles enter public roads. The accumulation of dirt on sealed external access roads can be avoided by vehicles exiting via a wheel-wash or some other equivalent wheel and underbody-cleaning mechanism. The road layout within the landfill should encourage the use of wheel-cleaning devices by truck drivers, and be placed so that the gatehouse attendant can visually check that the vehicle has been cleaned.

Where external access roads are sealed, the road from the wheel-wash should also be sealed and regularly cleaned to reduce the dirt re-entrained by the vehicle. Internal roads should also be sealed as far as possible into the site to reduce the amount of dirt accumulating on the vehicle and to allow more time for dirt already accumulated on the vehicle to fall off before it leaves the site.

(a) Access Roads

Access roads shall be kept in good condition, regularly maintained and repaired to allow vehicles to deposit their waste loads quickly and efficiently. Road inspection and maintenance – clearing, grading, and filling of potholes – shall be done on regular basis.

(b) Signage

There should be sufficient signage to guide each operational area of the landfill facility, including at entrances of the site.

At each entrance of the landfill a sign shall be erected and maintained with letters of sufficient size and colour contrast so that it may be read at a distance of at least 30m by a person with normal vision. International colour coding for various types of signage should be used.

The signage should include the aspects below;

(i) Name of facility and facility waste management licence number.
(ii) Schedule of days and hours the facilities shall be opened.
(iii) Speed limit applicable to all vehicles on the site.
(iv) Name and address of operating body.
(v) Telephone numbers for contact and reporting of issues.
(vi) The type of waste received at the site.
(vii) “Unauthorised Persons Not Allowed”.

Signs advising which waste may be deposited at the landfill must be provided. Signs should be provided to show where recyclable materials from waste that has not been through a transfer station or recycling facility may be placed.

(c) Site Controls

Access control is a critical aspect for the security of the landfill site. A single controlled entrance to the site is important to prevent unauthorised entry and illegal dumping on site. Hence, landfill sites should have a locable gate, a gatehouse and office manned during operating hours and monitored 24/7 for checking of vehicles, record keeping, traffic control and direction of vehicles to the working face. The gatehouse is the first part of the landfill that users and visitors encounter, hence the gatehouse attendant should be responsible for controlling who enters the landfill site.

Specifically, the aspects below should always be ensured at the site entrance;

(i) Authorised persons – gate keeper/security guard. These should be on duty at all times during operating hours of the landfill.
(ii) Weighbridge – to check the weight of waste being deposited. If there is no weighbridge, the volume of each incoming load of waste shall be estimated. Weighbrideges are also important for monitoring and control purposes.
(iii) Waste vehicles – shall be inspected at the gate for possible transfer of fire to the landfill site, and for checking that the cover during transport is sufficient.
(iv) Checking of vehicles – to ensure that they do not carry waste not allowed into the landfill site.
(v) Secuirty of premises – secured with fences and locked gates so as to permit no access after operating hours of the landfill.

(d) Fence

The waste handler should ensure that there is appropriate fencing all round the facility to ensure that the site boundaries are preserved and access to the site by stray animals and unauthorised persons is controlled.

The perimeter fence should be inspected weekly as a minimum, and repaired immediately damage is detected.

(e) Drains

Drains should be constructed within the site to collect runoff and leachate around the site perimeter to cut off run-in onto placed waste and for the disposal of stormwater. A good stormwater management system will avoid adverse effects offsite due to sediment, leachate and waste runoff

All drains shall be kept clean and all cracks and uneven areas rectified or repaired to avoid blockages and mosquito breeding. Frequent checking and cleaning of the systems according to schedule must be done.

9.2.2. Waste inspection area and routines

9.2.2.1 Waste Acceptance

Waste to be handled in the landfill should be characterised before it is accepted. Hence, incoming vehicles shall be subject to preliminary inspection for unauthorised waste types.

The transporter of the waste shall declare the type of waste using the accompanying waste manifest. This should be cross-checked by landfill staff at the tipping area. Sanctions shall be applied to persons making false declarations.

The person responsible for the landfill must be vigilant to ensure that only waste specified in the licence issued by NEMA is accepted and deposited at the designated places in the landfill.

(a) Waste load inspection

Landfills must be appropriate for the type and quantity of waste they are to accept for treatment and final disposal. The person who generates the waste must document that the waste fulfils the requirements about waste type, quality and quantity acceptable in the landfill.

Visual inspection of in-coming waste loads should be conducted to identify non-conforming waste. This may be by observing drums on a truck or other unusual characteristics. Facilities such as elevated mirrors, viewing platforms or video cameras may be used to screen incoming waste loads. In addition, operators at the tipping area must check and report if unauthorised waste is being unloaded.

The frequency of inspection will depend on the type and quantity of waste received and whether problems have previously been identified. A typical inspection frequency is, on average, 1 in 50 to 100 loads being physically inspected. For hazardous waste, however, all waste loads should be inspected, given the possibility of receiving unknown types of waste.

There should be a communication system linking staff at the landfill tipping area to the gatehouse.

Procedures must be developed to deal with the dumping of non-conforming waste at the landfill, including the identification of the violator, isolation of the waste and notification of authorities. These procedures must be contained in the site environment management system.

Where sites are licensed to accept restricted waste such as asbestos or contaminated soils, the waste handler is required to ensure compliance with the licence acceptance criteria.

As a monitoring tool for the environmental impacts of waste disposal, municipal authorities are responsible for monitoring both public and privately operated waste reception, including inspection, weighing and recording of waste loads, and collected tipping fees.

(b) Tipping area

Where required, a transfer station with recycling and drop-off areas should be provided so that the person who generates waste or a waste handler has no need to unload their vehicles at the tipping area. This reduces the mixing of both private and commercial vehicles at the tipping face and minimises safety risks to the public. It will also result in less supervision of the tipping area and encourages sorting of waste. A tipping fee is normally charged, depending on the weight of each load of waste received or other arrangement, taking into account the type of waste, the cost of waste management, andthe ability and willingness to pay for the waste management service rendered.

(c) Record Keeping

Proper records for quality control, monitoring and management purposes should be available for inspection at any time by the NEMA or other regulatory institutions. These include records for each vehicle load, incidence reports, training reports, compliance monitoring reports, among others. In addition, a register of all monitoring data on leachate, surface water and groundwater must be kept.

As applicable, the information below may be reported on.

(i) Time of entry.
(ii) Type of waste (household, commercial, hazardous, industrial, demolition debris, among others).
(iii) Detailed descriptions of all hazardous waste.
(iv) Origin/source of the waste.
(v) Transporter of the waste.
(vi) The identification code of the vehicle delivering the waste.
(vii) Weight (or if the weighbridge is out of service, the estimated volume) of the waste.
(viii) The cell in which any special waste is placed in the landfill.
(ix) Quantities of reclaimed waste.
(x) Staffing levels, daily attendance at work, and employment details of all personnel.
(xi) Accidents and their causes.
(xii) Items of equipment, uniform, and personal protective equipment issued.
(xiii) Equipment maintenance.

9.2.3. Sorting facility

Sorting facilities should be planned in the landfill, especially where mixed waste is anticipated.

(a) Waste picking

Waste picking should not be allowed for hazardous waste landfills.

For non-hazardous waste landfills, waste picking may be allowed to recover recyclable and re-usable materials. Waste picking must be assessed in each case, comparing it with increased sorting and recycling at source.

For aesthetic and safety reasons, however, waste picking should be a controlled and organised activity, confined to a specific area of the facility so that it does not interfere with normal operations. The landfill operator may also impose stricter measures, including restricting waste picking to take place only after regular hours. Management shall have the absolute right to allow or disallow access to the site; in which case, part of the tipping face may remain accessible to the waste pickers at the end of each working day.

The aspects below should be observed regarding waste picking operations in non-hazardous waste landfills.

(i) Waste pickers should be organised and provide a regularly updated list of recognised or registered waste pickers to the Management team of the facility.
(ii) No minors shall be permitted to engage in waste picking on the site.
(iii) Waste pickers may operate only at times and places designated by Management, and in any case, with some distance away from heavy equipment.
(iv) An area should be designated by Management for the temporary storage of recovered materials.
(v) Only material of types agreed between the waste pickers and the Management may be removed from the site.

(vi) Waste pickers shall be informed about health and occupational risks and how these risks can be avoided or minimised in general.

(vii) A basic minimum of appropriate personal protective equipment (nose masks, hand gloves and heavy boots) is required to be used by all waste pickers, at their own cost. Waste pickers who refuse to use such equipment should be excluded from waste picking at the site.

(viii) Waste pickers shall have access to the first aid services of the facility in case of injury.

(ix) Sanitary facilities shall be provided (either special facilities or access to the site facilities) for the waste pickers so as to avoid open defecation and other unsightly practices at the landfill.

9.2.4. Filling operation

Filling operations are an important part of landfilling and require care on how the filling is undertaken for the first time. Damage to the base liner system can very easily occur if initial cell filling is not carefully managed and such damage can soon negate good design and construction, and compromise the containment performance of a landfill. It is important to direct the vehicles/ trucks as they access the area. At the end of the access road, a relatively wide temporary area must be constructed for the maneuvering of trucks. Also, the trucks that arrive first must dispose off the waste at the end of the access road or a temporary movement area formed on the landfill base.

The first layer of waste placed in a cell is crucial for the landfill operation. This layer needs to be placed as a loose cushion layer, sometimes referred to as a “fluff” layer. This loose first layer is essential in order to avoid damage to the liner and leachate collection system as a result of equipment tracking, or the waste itself penetrating the liner components during initial cell filling.

Depending on the type of waste, the first load of waste should be deposited at a vertical layer thickness of at least 50cm (often up to 1m or more if bagged street collection waste is used), and this layer must be moderately compacted to constitute a protection layer to the liner and leachate drainage system. The above procedure ceases when the whole area of the landfill cell base is covered with waste to a depth of at least 50cm (1m recommended), so that no landfill equipment can track in close proximity to the liner or the base drainage system of the landfill. It is also important to compact the waste so as to ensure maximum use of the cell. Compaction should be undertaken by a skilled person in order to avoid damaging the cells.

9.2.5. Daily and intermediate cover material

Daily cover (preferably about 150mm of soil cover used) is material spread over deposited waste at the end of every work day. Daily cover should ideally be permeable to allow water to pass through, thereby preventing ponding/perched water build-up. The adjusted operational approach may require accepting relaxed standards for daily cover. The application of a daily soil cover often proves a heavy burden on the landfill’s operating budget.

At landfills, an intermediate cover may be applied periodically, achieving the same objective as daily soil cover. An intermediate cover, in this case, refers to the area covered with soil where the work face will not be used for some time. Intermediate cover refers to placement of material (preferably a minimum of 300mm of soil used) for a period of time prior to restoration or prior to further disposal of waste. Intermediate cover should significantly reduce rainfall infiltration. The use of movable waterproof liner cover is an alternative to prevent rain ingress and control nuisances like odour, vermin, flies, birds and other pests.

Daily or intermediate cover material should be used to control nuisances such as windblown litter, odour, vermin flies, birds and other pests. This is different from the capping system discussed in 9.3.

9.2.6 Settlement of waste

Biodegradable waste should be managed in such a manner that allows it to decompose, reduce in size and eventually settle. The majority of waste settlement occurs over a period of 5-10 years and gradually reduces with time until the waste mass becomes stable. Typically, however, moisture levels within the waste mass are less than those required to achieve rapid rates of waste decomposition. Moisture should, therefore, be added to the waste. Adding water to waste to achieve uniform levels of saturation may be difficult due to heterogeneity of the waste mass, which can lead to preferential flow paths and differential settlement developing in the waste mass.

Strategies to be employed to achieve uniform moisture content in the waste to allow proper settlement in percentage to the starting height/depth include; spraying of water directly onto the tip face, wetting waste prior to placement, use of injector wells and horizontal trenches.

The degree and rate of waste settlement are difficult to estimate. Estimates of settlement can be obtained through conventional consolidation methods. Total settlement should be estimated in order to predict surcharge contours. In general, a total settlement of 10% and in extreme circumstances upto 20% of the initial waste depth may be expected over a period of several decades.

9.2.7 Landscaping

A buffer zone with landscaped berms and other tree cover should be planned and established around the landfill to lessen the visual intrusion associated with the landfill. The development sequence of the site should allow for early screening of the landfill. The waste handler should take into account the proposed end-use of the site after completion as this, to some degree, will dictate the final landform. This final landform will be required to blend into the surrounding environment.

9.3 Capping design and purpose

When the landfill has reached its end of life, final capping must be done to minimise infiltration into the waste and consequently to reduce the amount of leachate being generated, as well as to control landfill gas migration. The capping system comprises engineering and restoration layers. The design of the restoration layers must be consistent with the proposed after-use of the facility.

9.3.1 Capping system design considerations

A capping system should be designed, taking into account the aspects below;

(i) Temperature and precipitation extremes.
(ii) The effects of rodents and other burrowing animals on the integrity of the cap.
(iii) Robustness of the cap against settlement stresses.
(iv) Stability of slopes.
(v) Vehicular movement.
(vi) Vehicle access tracks and public footpaths.
(vii) Surface water drainage.
(viii) Leachate recirculation.
(ix) Installation of gas wellheads and collection pipework.
(x) Installation of leachate collection manholes and pipework.
(xi) Ease of repair.
(xii) Aesthetic appearance.
(xiii) End-use.

9.3.2 Components of capping systems

The components of the capping system and the materials to be used should be evaluated on a case by case basis. Not all components will be necessary for every site. These components may include; topsoil, subsoil, a drainage layer, barrier (infiltration) layer, a gas drainage layer and a system for leachate recirculation. These components are discussed below.

(a) Gas collection layer

The gas collection layer transmits gas to collection points for removal and disposal or utilisation. Materials that can be used for gas collection include sand or gravel with soil or geotextile filters, geotextile drainage fabrics, and geonet drains with geotextile filters. The thickness of natural material gas collection layers is usually between 150mm to 300mm.

(b) Barrier layer

The principal functions of the barrier layer are to control leachate generation through minimising infiltration of water and control of movement of landfill gas.

The barrier layer will usually consist of a compacted low hydraulic conductivity mineral layer or a synthetic layer such as a geomembrane or geosynthetic clay, similar in nature to those used as liners. The minimum thickness of the natural compacted layer should be 0.6m with a hydraulic conductivity of 1x10-7m/s to 1x10-9m/s. For enhanced landfill gas generation, a semi-permeable barrier layer may be considered, allowing some moisture to seep down through the waste. Where a geosynthetic material is used, it should provide equivalent protection.

(c) Drainage layer

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

Drainage layers are used below the topsoil/subsoil and above the barrier layer to:

(i) minimise the head of water on the underlying barrier layer, which reduces percolation of water through the capping system;

(ii) provide drainage of the overlying topsoil and subsoil, which increases the water storage capacity of these layers and helps to minimise erosion by reducing the time during which the surface and protection layer materials remain saturated with water; and

(iii) increase slope stability by reducing pore water pressure in the overlying soil materials.

Ultimately, the cap drains are permanent secondary drainage features on the site and so need to be durable, require minimal maintenance and should accommodate ongoing settlement.

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

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

Water collected by the drainage layers will be discharged to surface waters. The drainage layer can consist of granular material, of minimum thickness 0.5m or a geosynthetic drainage medium. The hydraulic conductivity should be equal to or greater than 1x10-4m/s. The slopes for the drainage layer in the final capping system should be no less than 4%, that is, 1 vertical:25 horizontal, to assist gravity drainage.

(d) Filter material

Filter layers may be required at the boundaries of coarse granular layers or geosynthetic drainage layers in order to prevent the ingress of fines. If a coarse drainage layer is to be placed onto a geomembrane, a protection layer is required to protect the geomembrane from puncture and over stressing.

(e) Topsoil and subsoil

The primary function of the topsoil is to enable the planned after-use to be achieved. The topsoil should be suitable for plant growth, preferably soil material low in clay content, high in organic matter and low in bulk density. The soil should be uniform and have a minimum slope of 1-30 to prevent surface water ponding and to promote surface water run-off. The maximum slope will depend on the after-use but it is recommended that the slope be no greater than 1 in 3.

The topsoil should be thick enough to:

(i) accommodate root systems;
(ii) provide water holding capacity to attenuate moisture from rainfall and to sustain vegetation through dry periods;
(iii) allow for long term erosion losses; and
(iv) prevent desiccation of the barrier layer.

It is recommended that the combined thickness of the topsoil and the subsoil should be at least 1m.

9.3.3 Recommended capping systems

Alternative systems may be used but typically these should meet the minimum requirements set out below:

(a) Hazardous waste landfill capping system

The capping system for this type of facility should, at a minimum, consist of:
(i) a compacted mineral layer of a minimum 0.6m thickness with a hydraulic conductivity of less than or equal to 1x10-9m/s in very close contact with a 1mm flexible membrane liner;
(ii) a drainage layer of 0.5m thickness with a minimum hydraulic conductivity of 1x10-4m/s;
(iii) top soil (150 - 300mm) and subsoil of at least 1metre total thickness.

(b) Non-Hazardous biodegradable landfill capping system

The capping system for this type of facility should, at a minimum, consist of:
(i) a gas collection layer of natural material (minimum 0.3 metres) or a geosynthetic layer;
(ii) compacted mineral layer of a minimum 0.6m thickness with a hydraulic conductivity of less than or equal to 1x10-9m/s or a geosynthetic material (such as geosynthetic clar liner) or similar substance that provides equivalent protection. When landfill gas extraction is in place, this layer shoud be semi-permeable;
(iii) drainage layer of 0.5m thickness with a minimum hydraulic conductivity of 1x10-4m/s; and
(iv) top soil (150 - 300mm) and subsoil of at least 1m total thickness.

The inclusion of leachate recirculation systems should be considered for landfill sites that have liner systems in place.

(c) Inert waste landfill capping system

The capping system for an inert landfill should consist of top soil and subsoil, thickness dependent on after-use but to a minimum of 0.5m.

9.3.4 Cap stability

It may be necessary to carry out an analysis of the cap stability. This may be especially the case for steep restoration slopes (steeper than 1:6) and components that may have a low friction interface (such as, interface between a geomembrane and a wet compacted clay).

Stability will depend on the shear strength properties of the soils, waste and geosynthetic components of soil used in the cap system. Additionally, the presence of water acts as a destabilising agent in reducing the strength and increasing the destabilising force.

To improve slope stability, geogrids or geotextile reinforcement layers may be incorporated into the cap.

To compensate for differential settlement of waste, the capping system may be designed with greater thickness and/or slope. If geomembranes are used, they should be able to withstand high tensile strains induced by differential settlement; linear low density polyethylene is particularly suitable. Even if precautions are taken, post closure maintenance may still require regrading of the final capping due to total and differential settlement.

To avoid damage to the final cap system, it may be necessary to wait a number of years, particularly if large scale and uneven settlement is expected. A temporary cap may have to be installed between completion of filling and installation of the final cap. The temporary cap should be at least 0.5m thick. Components of the temporary cap should be capable of meeting the objectives of a good capping system.

9.4 Occupational safety, health and security

Occupational safety, health and security requirements need to be addressed over the entire lifespan of the landfill development, and occupational safety and health legislation, standards and other requirements complied with. Hence, operational staff should be properly trained in safety, health and security, and personal protective clothing (overalls, wellington boots, gloves, nose marks, goggles and hard hats, among others) provided.

The health, safety and security measures below should be observed.

(i) Landfill personnel should undergo pre-employment medical examination. Thereafter, this shall be repeated at least once annually.
(ii) Regular in-service training for all personnel in personal hygiene, waste classification, hazardous waste disposal procedures, possible hazards, emergency procedures in case of fire, exposure to toxic waste, among others, should be organised.
(iii) Fire/emergency evacuation drills should be held, without notice, at least annually.
(iv) All staff should undergo basic first aid training.
(v) A specific employee should be designated and trained to be responsible for first aid and to ensure that the first aid cabinet is adequately stocked.
(vi) All accidents, however minor, should be recorded and reported monthly. A safety culture should be encouraged through incentives for extended individual and collective accident-free periods and accidents should be analysed with the full involvement of all staff.
(vii) Smoking is prohibited on the site.
(viii) Sale and consumption of food should be restricted to designated areas.
(ix) Personal protective equipment and other safety equipment should be worn by workers and visitors when in areas that call for personal protection and security, and should be kept clean and serviceable at all times.
(x) The Site Manager should ensure that workers who are in direct contact with waste, wash down and change their clothes after the day's work and before leaving the landfill site.
(xi) In general, drivers of haulage trucks need to be alert on site to avoid accidents.

The landfill operator should establish contingency planning, preparedness and response as part of the facility's Safety, Health and Environment Management System.

9.5 Community engagement

It is important to engage with the communities in the vicinity of the landfill, irrespective of the class of landfill, for their social, environmental and economic wellbeing. The benefits of community engagement include those below.

(i) Enabling the community to be better informed and to be actively involved in decision making regarding siting of the landfill, as well as in the grievance resolution mechanism during the construction and operation of the landfill. For this purpose, a clear grievance redress mechanism with readily available contact information should be displayed around the landfill, in addition to emergency contacts.
(ii) Supporting behavioural and attitudinal change in the community, to ensure social acceptability of the landfill.
(iii) Enabling industry to be a good neighbour through building trust and confidence by its openness, transparency and listening and responding to community needs.
(iv) Agreement on corporate social responsibility projects, including infrastructure development and provision of public amenities.
(v) Considering communities first, where there are benefits arising from the landfill, for instance, where compost manure is one of the projects of the landfill. In such cases, free compost may be given to the community engaged in agriculture.

Chapter Ten

Environmental Monitoring of a Landfill

10.0 Environmental monitoring

The environmental management and monitoring system emanating from an environmental and social impact assessment should be used to provide clear directions and procedures for the workers at the landfill to follow, to ensure the environmental and social issues are adequately handled. Self monitoring by the waste handler is of paramount importance, even while monitoring by regulatory institutions will follow.

The Environmental management and monitoring system should be continuously reviewed; and mechanisms to implement improvements instituted, including the designation of responsibilities, communication processes, document control and operation procedures. Training of all relevant staff in the implementation of improvements is a significant part of the process. Besides, the local community and other stakeholders like the private sector, research institutions and academic institutions should be empowered in the environmental monitoring of a landfill, although at different scales.

International Standards ISO 14001 and ISO 9001 provide guidance on environmental management systems and quality management systems, respectively.

Sampling and laboratory analysis are critical aspects of environmental monitoring. Sampling is important in analytical procedures. Errors at sampling will compromise the integrity of the entire analytical process and management interventions. It is, thus, imperative that sampling and sample handling is done by well qualified persons with demonstrated expertise.

10.1 Baseline situation

Prior to the establishment of a landfill, a survey must be carried out to register the existing baseline conditions at the site. This should include:

(i) climatic factors;
(ii) groundwater level and quality (see parameters in next section);
(iii) if applicable, surface water quality and flow with variation over time;
(iv) local environmental situation (wildlife, natural resources and vegetation, among others);
(v) existing water uses and sources; and
(vi) the socio-economic situation of the people in the area.

10.2 Groundwater monitoring from non-hazardous landfills

10.2.1 Location of test wells

Due to the potential for groundwater contamination by landfill leachate, test wells must be established to monitor the groundwater. There must be a minimum of one test well upstream the landfill and three downstream (if applicable, more test wells may be installed).

The test well upstream should be located where there is no risk of contamination from the landfill but should still be along the groundwater flow to the landfill. The test wells downstream must be located where they will capture the potential contamination at an earliest stage (shortest range).

The location of test wells must be based on a detailed hydro-geological mapping and assessment that will provide information on the required depth of the wells and flow direction of the groundwater in and around the site.

10.2.2 Test wells – design and function

The test wells for groundwater must be adequately designed according to applicable national law for groundwater observation wells.

The wells must have a design allowing for easy access and sampling over a long time. They must be clearly marked and the coordinates registered.

10.2.3 Frequency

During the active/operational phase, groundwater should be sampled at least 2-4 times a year, representing the seasonal variation.

During the aftercare phase, groundwater should be sampled at least once every year, representing an average of the seasonal variation.

10.2.4 Sampling

The wells must be emptied prior to taking samples, so that fresh groundwater is sampled. The samples should be based on spot tests.

Pumps, containers and like equipment must be properly cleaned between sampling each well.

During sampling, pH, temperature and conductivity should be measured at site, and weather conditions noted. At the same time, groundwater level should be measured.

10.2.5 Parameters for analysis

The regular sampling and analysis should include parameters that are most likely to rapidly indicate contamination from the landfill; these include pH, conductivity, chemical oxygen demand, total nitrogen, chloride, ammonia, iron and heavy metals. Additional requirements may be included in the waste management licence issued by NEMA and other approvals issued by the relevant lead agency.

At a minimum, groundwater monitoring indicators should conform to those in Table 10.1, guided by the potential presence of these parameters as a result of landfill operations.

Table 10.1 Groundwater monitoring

Parameters	Detection Limit	Frequency
Temperature	0.1°C	2 or 4 times a year
Ph	0.1	2 or 4 times a year
Electrical conductivity	1 mS/cm	2 or 4 times a year
COD	10 mg/l	2 or 4 times a year
BOD5	3 mg/l	2 or 4 times a year
Total suspended solids	0.1 mg/l	2 or 4 times a year
Ammonia-nitrogen	0.2 mg/l	2 or 4 times a year
Nitrate	0.5 mg/l	2 or 4 times a year
Total kjeldahl nitrogen (total concentration of organic nitrogen and ammonia)	0.4 mg/l	2 or 4 times a year
Sulphate	5 mg/l	2 or 4 times a year

Sulphite	2 mg/l	2 or 4 times a year
Phosphate	0.01 mg/l	2 or 4 times a year
Chloride	0.5 mg/l	2 or 4 times a year
Iron	50 mg/l	2 or 4 times a year
Zinc	10 mg/l	2 or 4 times a year
Metals (aluminium, arsenic, barium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, zinc)	mg/l	Quarterly
Coliform Count	1 cfu/ 100ml	Quarterly
Static water level	m BGL	Daily
Dissolved landfill gas in groundwater to monitor potential migration of landfill gas	28m/l	Twice a year

10.3 Surface water monitoring

Surface water monitoring will be conducted to keep the ammonia-nitrogen and COD below the following trigger levels:

(i) Ammonia Nitrogen : 0.5 mg/l
(ii) COD : 30 mg/l
(iii) Suspended Solid : 20 mg/l

In the event that any one of the above parameters was exceeded, the landfill operation should implement a corrective action plan. The key elements shall include:

(i) surface water interception and temporary storage of the contaminated surface water;
(ii) installation of surface barriers, such as sand bunds, along the surface water channel/site boundary to avoid overflow off-site;
(iii) active pumping of the contaminated surface water to the leachate lagoons/leachate recirculation system/on-site leachate treatment plant;
(iv) additional monitoring locations to determine the pollution source;
(v) installation of surface barriers, such as intercepting bunds, to separate the active and inactive tipping area;
(vi) change of working methods to prevent surface water contamination; and
(vii) implementation of diversionary works.

10.3.1 Location of sampling points

When there is a potential for contamination of surface water, sampling points must be established to monitor this. There must be a minimum of one sampling point upstream the landfill and one sampling point downstream.

The location upstream should be at a point where there is no risk of contamination from the landfill but should still be along the flow direction to the landfill area. The location downstream must be at points that will capture the potential contamination at an earliest stage (shortest range). This must be based on assessment of the flow conditions of the surface water.

10.3.2 Sampling points – design and function

The sampling points must be the same over time. Access must be available at any time.

The sampling points should be located at a site where estimation of flow is possible, such as by a stream with regular cross section that is pre-measured, allowing for estimate of volumes (velocity multiplied with area of cross section).

10.3.3 Frequency

During the active/operational phase, surface water should be sampled four times in a year, representing the seasonal variation.

In the aftercare phase, surface water should be sampled two times in a year, representing the seasonal variation.

10.3.4 Sampling

Sampling must be done by persons with technical expertise and should follow applicable sampling procedures. All equipment for sampling must be readily available and free from contamination. Specifically, the sampling equipment must be properly cleaned between each sampling point.

The samples should be based on spot tests. Additionally, during sampling, pH, temperature and conductivity should be measured at site, and weather conditions noted.

10.3.5 Parameters for analysis

The regular sampling should include parameters that are most likely to provide an understanding of the pollution potential in the landfill and provide early warning for surfacewater contamination arising from the landfill. These parameters include; pH, conductivity, chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen, chloride, ammonia, iron and indicators of faecal contamination (E.coli, total coliform). In addition, once a year, a sample analysis should include the main heavy metals.

The National Environment (Standards for Discharge of Effluent into Water or Land) Regulations, 2020 and other applicable written law should be used to enable assessment of the various paremeters in order to increase understanding of the pollution potential in the landfills and provide an early warning for surfacewater contamination. Table 10.2 lists suggested indicator parameters for surface water monitoring. Appropriate methods must be used to analyse each of the parameters indicated in the table.

Table 10.2: Indicator parameters for surface water monitoring

Parameter	**Unit**	**Maximum limit**	**Frequency**
pH		5.0 -8.5	Quarterly (4 times a year)
Dissolved oxygen	mg/l		Quarterly (4 times a year)
Electrical conductivity	µS/cm	1000	Quarterly (4 times a year)
Total suspended solids	mg/l	100	Quarterly (4 times a year)
Nitrogen – ammonia	mg/l	10	Quarterly (4 times a year)
Total organic carbon	mg/l		Quarterly (4 times a year)
Thermotolerant coliforms (only when downstream waters are used for stock water, drinking water or recreational uses)	cfu/100ml	2500	Quarterly (4 times a year)
Total dissolved solids	mg/l	1200	Quarterly (4 times a year)
Potassium	mg/l		Quarterly (4 times a year)
Total hardness	mg/l	500	Quarterly (4 times a year)
Chloride (Cl-)	mg/l	500	Quarterly (4 times a year)
BOD5	mg/l	70	Quarterly (4 times a year)
COD	mg/l	100	Quarterly (4 times a year)
Ammonium (NH4+)	mg/l		Quarterly (4 times a year)
Nitrate nitrogen (NO3-N)	mg/l	20	Quarterly (4 times a year)
Manganese (Mn)	mg/l	1	Quarterly (4 times a year)
Zinc (Zn)	mg/l	2	Quarterly (4 times a year)
Copper (Cu)	mg/l	0.5	Quarterly (4 times a year)
Chromium (Cr)	mg/l	0.5	Quarterly (4 times a year)
Cadmium (Cd)	mg/l	0.01	Quarterly (4 times a year)

Mercury (Hg)	mg/l	0.01	Quarterly (4 times a year)
Total Iron (Fe)	mg/l	3.5	Quarterly (4 times a year)
Lead (Pb)	mg/l	0.1	Quarterly (4 times a year)
Total Organic Carbon	mg/l	50	Quarterly (4 times a year)

Note : samplying should be manly done during rainy seasons

10.4 Leachate and leachate sediment monitoring

In order to minimise leachate production, all run-off from outside the site, from capped areas and from unused areas awaiting fill, must be intercepted by suitable drainage ditches. Where necessary, culverts shall be constructed to allow the water to pass under site roads, bunds or other obstacles. These waters, which may be discharged without treatment, should be strictly segregated from leachate and run-off from operational areas of the landfill.

Leachate recirculation through the landfill can help to reduce leachate volume through evaporation as well as speeding up bio-degradation, and may thus be beneficial.

10.4.1 Leachate infrastructure

The aspects below should be observed;

(i) Leachate collection pipes shall be constructed and maintained to ensure free flow of leachate.

(ii) Leachate disposal systems should be inspected frequently (if possible, on a daily basis) and maintained in good operating condition.

(iii) Once every 2 weeks, all main leachate drainage channels should be cleared of growing weeds, accumulated sand and objects that could cause blockage. The frequency of cleaning of drains may change, depending on how fast they get blocked.

(iv) Once every 2-3 years, all main leachate drainage channels should be drained and cleaned of accumulated sludge. Where the channels are filled with gravel, such gravel should be removed, and the channels washed and dried before placement of leachate. Clogging should be dealt with as soon as it is detected.

10.4.2 Location of sampling points

There should be a minimum of one sampling point, being as close to the landfill as possible to avoid dilution from downstream clean water. The sample point may be re-located when new phases of the landfill are established. In addition, a sampling point for leachate should be established where the leachate is collecting, for example, in a manhole.

When treatment of leachate is taking place, there must be one sampling point immediately downstream the leachate treatment plant to monitor the treatment efficiency of the plant.

10.4.3 Sampling points – design and function

The sampling points should, if possible, be the same over time. Easy access must be available at any time.

The sampling points should be located where estimation of flow is possible, such as in a pipe with a cross section that is pre-measured, allowing for estimate of flow. A manhole with a V-notch should be preferred, allowing for continuous flow measuring.

10.4.4 Frequency

During the active/operational phase, leachate should be sampled for analysis of standard parameters four times a year, representing the seasonal variation. Once a year, an extended analysis should be added to the standard parameters. On site measurement of pH, temperature and conductivity may be carried out more frequently.

During the active/operational phase, leachate sediment should be sampled for analysis of a standard list of parameters two times a year, representing the seasonal variation. Once a year, an extended list of parameters should be added to the standard list of parameters to be analysed.

In the aftercare phase, leachate sediment should be sampled once a year for selected parameters and every third year, an extended list of parameters may be sampled.

10.4.5 Sampling

The samples for analysis of leachate should be composite/mixture samples based on a mixture of samples taken.

During sampling, pH, temperature and conductivity should be measured at site, and weather conditions noted. Pumps, containers and other like equipment must be properly cleaned between each sampling point.

10.4.6 Parameters for analysis

Table 10.3 below summarises the proposed parameters to be included in the standard and extended analysis of selected parameters in the operational phase.

In the aftercare phase, these parameters may be reduced based on the results of the analysis in the operational phase. Consequently, the aftercare programmes will be site specific.

Table 10.3 Parameters for leachate monitoring

		Leachate		**Leachate Sediment**	**Frequency**
Parameter	**Unit**	**Detection limit**	**Unit**	**Detection limit**	
On Site					
pH					2 Or 4 times a year
Temperature	0C	-			2 Or 4 times a year
Conductivity	mS/m	1			2 Or 4 times a year
Standard Program					
Suspended matter (SM)	mg/l	5			2 Or 4 times a year
Chlorine	mg/l	-			2 Or 4 times a year
BOD7	O/l	1			2 Or 4 times a year
COD	mg/l	5			2 Or 4 times a year
TOC	mg/l	0.5	%	0.05	2 Or 4 times a year
Ammonia nitrogen (NH4-N)	mg N/l	0.04			2 Or 4 times a year
Total-N	mg/l	0.1			2 Or 4 times a year
Total-P	mg/l	0.01			2 Or 4 times a year
TSS			%		2 Or 4 times a year
Sulphate	mg/l				2 Or 4 times a year
Iron (Fe)	µg/l	20	mg/kg TS	3	2 Or 4 times a year
Manganese (Mn)	µg/l	0.9	mg/kg TS	0.5	2 Or 4 times a year
Zink (Zn)	µg/l	4	mg/kg TS	1	2 Or 4 times a year
Copper (Cu)	µg/l	1	mg/kg TS	0.1	2 Or 4 times a year
Lead (Pb)	µg/l	0.6	mg/kg TS	1	2 Or 4 times a year
Cadmium (cd)	µg/l	0.05	mg/kg TS	0.1	2 Or 4 times a year
Nickel (Ni)	µg/l	0.6	mg/kg TS	5	2 Or 4 times a year
Chrome (Cr)	µg/l	0.9	mg/kg TS	0.25	2 Or 4 times a year

Arsenic (As)	µg/l	1	mg/kg TS	0.5	2 Or 4 times a year
Mercury (Hg)	µg/l	0.02	mg/kg TS	0.2	2 Or 4 times a year
Total Hydrocarbon compounds (THC)	µg/l	5-30 v/ GC-FID 100 v/ IR	mg/kg TS	10-30	2 Or 4 times a year
PAH (16 PAH)	µg/l	0.01	mg/kg TS	0.01	2 Or 4 times a year
PCB7	µg/l	0.0008-0.002	mg/kg TS	0.002	2 Or 4 times a year
Phosphate	0.01 mg/L				2 Or 4 times a year
Chloride	0.5 mg/L				2 Or 4 times a year
Sodium	50 mg/L				2 Or 4 times a year
Alkalinity	1 mg/L				2 Or 4 times a year
Volatile fatty Acids	2 mg/L				2 Or 4 times a year
Extended Program					
Bisphenol A	µg/l	0.05	mg/kg TS	0.1	2 Or 4 times a year
Alcylphenols and -etoxilates (APE)	ng/l	10-100	mg/kg TS	0.01-0	2 Or 4 times a year
Phenols	µg/l	0.1	mg/kg TS	0.1	2 Or 4 times a year
Chlorinated phenols	µg/l	0.1	mg/kg TS	0.1	2 Or 4 times a year
Tinorganic c	ng/l	1	mg/kg TS	0.01	2 Or 4 times a year
Acute toxicity screening (microtox)	TU	-			2 Or 4 times a year

Note: Frequnecy of monitoring can as well be determined by regulatory tools depending on the nature of the leachate.

10.5 Landfill gas monitoring

Landfill gas should be monitored differently from leachate management. Landfill gas, mainly methane, has the potential to cause harm to human health by asphyxiation or explosion, and also to harm the local environment. Hence, care must be taken in monitoring landfill gas.

10.5.1 Principle schemes

The main principle should be to have the possibility of monitoring and adjusting the extraction from each individual well. This may be done through sampling and regulation points near each well or more preferably through more centralised collection points for many wells.

10.5.2 Parameters for monitoring

Under normal operation, CH4, CO2 and O2 must be monitored on a continuous basis together with gas flow in the central facility. Flow must be summarised.

The same parameters should be monitored in each extraction well at regular intervals, minimum monthly.

If the landfill gas is utilised, there should be frequent monitoring of hydrogen sulphide and other corrosive elements to avoid corrosion in the equipment and engines.

10.5.3 Frequency

The landfill gas parameters should be logged daily or at a minimum weekly, for the purpose of collecting relevant data to determine the trends and to provide operational support. The values for each monitoring well should also be logged and stored at weekly intervals.

10.5.4 Monitoring of diffuse emissions from landfill surface

The diffuse emissions from the surface may be very difficult to adequately monitor by use of instruments. In normal operations, a visual and onsite inspection should be carried out, focusing on dead vegetation, steam, cracks, odours, among others. When observed, areas with these conditions should be immediately sealed of, and the National Environment (Air Quality) Regulations, 2021 applied.

10.5.5 Flaring conditions and emissions after flaring

The landfill gas, if not utilised, may be flared for normal operational purposes or in emergency situa-tions. The extraction must be kept at a volume that can support sustainable flaring, represented through methane content in the range of 20-30%, depending on the flare design. The flare must be designed specifically for the relevant volumes of landfill gas and have sufficient retention time (0.3 to 0.6 seconds) within the casing with maximum dimensioning landfill gas flow and adequate air supply for full combustion above the specified minimum temperature (normally in the range between 800 and 1200oC). The flare should normally have an adequate stack, as open flares have inadequate combus-tion of the landfill gas. The flare stack should be of such height as to ensure that the flue gases are released far above the existing structures.

The normal monitoring will be of the inlet landfill gas and of the combustion temperature. The flame will also be monitored; preferably, having a clear bluish flame. Flame with yellow and red zones is a sign of inadequate combustion conditions.

If applicable (larger facilities), more sophisticated monitoring of emissions after flaring may be carried out periodically and when changes appear. Parameters for this may be O2, CO, CO2, NOx and THC. This monitoring scheme will depend on the local conditions and should be set specifically for each facility. Efforts should be made at all times to recover energy whenever methane gas is generated. As such, co-generation may be integrated to generate more volumes of energy.

The products of combustion from the flare unit should be tested to verify that the predicted performance is being achieved. An example of monitoring requirements for a flare unit are presented in Table 10.4.

Table 10.4: Monitoring combustion products from flare units

Level	Type	Inlet gas	Emissions
First	Routine inputs and outputs	CH4, CO2, O2	Bulk composition (O2, CO) Temperature and gas flow rate
Second	Combustion products	As above	Bulk composition (O2, CO, NOx, CO2, THC) Temperature, retention time and gas flow rate
Third	Trace species	As above	As above plus HCL, HF, SO2 and a range of oxygenated and sulphuretted organics

Notes:

1. First level monitoring should be carried out regularly since it provides the basic information needed for controlling the flare.
2. Second level monitoring should be carried out periodically or when there is some significant change in, for example, the composition of landfill gas. It provides more information bout the completeness of combustion products and the major emissions.
3. Third level monitoring is likely to be infrequent but should be considered for large flares close to where people are settled or other environmentally sensitive areas since it is targeted at obtaining relevant indicators regarding potentially hazardous components in flare emissions.

The flare system should not exceed the emission concentrations below when referred to normalized temperature and pressure (NTP) and 3% oxygen:

- ❍ Carbon monoxide (CO) - 50mg/m3
- ❍ Oxides of nitrogen (NOx) - 150mg/m3
- ❍ Unburnt hydrocarbons - 10mg/m3

10.5.6 Safety monitoring

There must be detectors in the central facility(ies), monitoring the content of methane to avoid fire and explosions, when exceeding LEL of 5%. There should also be a mobile unit to monitor CH_4, CO and CO_2 in closed rooms and manholes and other areas at the site.

10.5.7 Utilized Landfill Gas

The following must be measured:

(i) volumes and quality (% of methane) of landfill gas to utilisation (through instruments in the central landfill gas facility);
(ii) if applicable, energy delivered through combustion and heat utilization;
(iii) if applicable, electricity and surplus heat delivered from installed generator(s)/gas engine(s); and
(iv) if applicable, energy delivered through other methods (such as fuel).

10.6 Monitoring of other environmental impacts and mishaps

10.6.1 Dust

Reactive dust management strategies include real-time monitoring of PM10. The monitoring may be required1 at the boundary of the premises, both upwind and downwind of the active landfill area to assess any impact and guide mitigation actions.

If applicable and measurement is possible, an hourly trigger level of 80µg/m3 should be used to assess the real-time data. If exceeded additional dust management practices, such as increased water sprays and dust suppressants should be applied.

10.6.2 Noise

If the local conditions require this, the noise level shall be measured in terms of the A-weighted equivalent continuous sound pressure level over a period of 30 minutes (A Leq, 30mins) and A-weighted 10% of time over a period of one hour (A Leq10, 1hr) for operational noise and operational traffic noise, respectively. As supplementary information for data auditing, statistical results such as A Leq10, A Leq and A Leq90 shall also be obtained for reference.

Noise measurements should not be undertaken in the presence of fog, rain, wind with a steady speed exceeding 5m/s or wind with gusts exceeding 10m/s. The wind speed shall be checked with a portable wind speedmeter capable of measuring the wind speed in m/s. The National Environment (Noise Standards and Control) Regulations, 2003 apply.

When alternative monitoring locations are proposed, the monitoring locations should be chosen based on the criteria below;

(i) At locations close to the major site activities which are likely to generate noise.
(ii) Close to the noise sensitive receivers.
(iii) For monitoring locations in the vicinity of the sensitive receivers, care should be taken to avoid disturbance to the occupants during monitoring.
(iv) Routine assessment of background noise by determining noise levels when the noise generating operations at the landfill have been stopped.

10.6.3 Odour

Odour intensity analysis is conducted by independent trained personnel/competent persons patrolling, sampling and if applicable, taking measurements using olfactometers around the air sensitive receiver to detect any odour at the relevant hours.

Subject to the prevailing weather forecast conditions, odour intensity analysis shall be conducted, if and when required, at the downwind locations. During the analysis, the sequence should start from less odorous locations to stronger odorous locations. The independent trained personnel/competent persons shall use olfactometers to detect odours at different locations. The main odour emission sources and the areas to be affected by the odour nuisance shall be identified.

The perceived odour intensity is to be divided into 5 levels below, which are ranked in descending order.

(i) 0 - Not detected. No odour perceived or an odour so weak that it cannot be easily characterised or described.
(ii) 1 - Slight identifiable odour, and slight chance to have odour nuisance.
(iii) 2 - Moderate identifiable odour, and moderate chance to have odour nuisance.
(iv) 3 - Strong identifiable, likely to have odour nuisance.
(v) 4 - Extreme severe odour, and unacceptable odour level.

The independent trained personnel/competent persons shall record the findings including odour intensity, odour nature and possible odour sources, and also the local wind speed and direction at each location. In addition, some relevant meteorological data, such as daily average temperature and daily average humidity, on that surveyed day shall be obtained from the nearest Uganda National Meteorological Authority Observatory Station for reference.

Apart from odour intensity analysis, routine odour patrol by competent persons shall also be conducted to detect odour nuisance.

10.6.4 Impacts on ecosystems

Ecosystem monitoring should be undertaken throughout the design, construction, operation, restoration and aftercare phases of the landfill to ensure that all mitigation measures are fully complied with.

The purposes of ecosystem monitoring are:

(i) to verify the accuracy of the predictions of the ecosysteml assessment study;
(ii) to detect unpredicted ecosystem impacts arising from the project;
(iii) to monitor the effectiveness of the mitigation measures; and
(iv) to recommend action plans in response to unpredicted impacts, and/ or failed mitigation

10.6.5 Natural and cultural heritage monitoring

The ESIA may make recommendations regarding the protection of natural and cultural heritage from the impacts of the landfill operations.

The details of the natural and cultural heritage should be documented and archived. It is the responsibility of the contractor and/or operator of the landfill to fully implement the mitigation recommendations contained in the ESIA and the certificate of approval of environmental and social impact assessment. The results of this mitigation work should be approved by the Department of Monuments and Museums of the Ministry of Tourism, Wildlife and Antiquities prior to any construction works. Cartographic and photographic surveys may also be needed. During operations, landfill closure and aftercare, the affected natural and cultural heritage resources should be preserved by detailed record.

10.7 Environmental monitoring of landfills of Class 1 for hazardous waste

In general, the environmental monitoring of Class 1 landfills for hazardous waste should be similar to monitoring of non-hazardous waste regarding frequency and sampling points, among others. The selection of sampling parameters must, however, reflect what is actually being landfilled at the site, including various hydrocarbons and other sector specific parameters.

Normally, landfill gas will not be generated at significant levels in landfills of Category 1 for hazardous waste;

consequently, monitoring of the landfill gas could be omitted in those landfills.

10.8 Environmental monitoring of landfills for inert waste

In general, the environmental monitoring of landfills for inert waste should be less stringent than for other Class 2 - non-hazardous waste category, with regard to frequency, sampling points and parameters, among others.

A site-specific evaluation should be carried out, recommending a selection of sampling parameters reflecting what is actually being landfilled at the site.

Normally, landfill gas will not be generated at significant levels in landfills for inert waste; consequently, monitoring of landfill gas could be omitted in those landfills.

10.9 Operational monitoring of non-hazardous landfills

10.9.1 Solid waste types and volumes

The incoming waste loads must be weighed and information of waste type, tonnage and source of waste should be stored in the scale recorder system. This system should allow for adequate summaries and statistics based on harmonised and standard categorisation.

10.9.2 Local climate monitoring

There should be logging of local climate and weather conditions in each day of operation, registering rainfall, temperature and wind, among other weather patterns. This will not necessarily be for reporting, but for doing water balance calculations, among other monitoring aspects.

10.10 Maintenance monitoring for equipment and facilities

Maintenance and repair should be monitored through logs for the various equipment and vehicles.
Preventive maintenance based on scheduled intervals and routines is highly recommended.

The development of the landfill should be monitored through:

(i) changes in area and height (cells) – annual surveying;
(ii) changes/new infrastructure and measures; and
(iii) use of cover material.

10.11 Reporting – frequency, structure and content

10.11.1 Receiver

Reports from the various environmental monitoring schemes must be sent to NEMA and a relevant lead agency. Reports from the operational monitoring must be available to NEMA and other regulatory institutions upon request.

10.11.2 Frequency

Regular monitoring reports should be sent to NEMA and a relevant lead agency annually and in accordance with relevant written law.

Any occurring irregular events observed during monitoring should be reported to NEMA and a relevant lead agency as soon as possible, together with reports on consequences, actions taken and the result of these actions.

10.11.3 Structure

The reporting should be presented in two summary reports; one for the environmental monitoring (groundwater, surface water, leachate, leachate sediment and landfill gas) and one for the operational monitoring.

10.11.4 Content

The elements below must be included in the annual reporting;

(i) Results from sampling of groundwater, surface water and leachate.
(ii) Connected flows and volumes during sampling.
(iii) Estimates of net total discharge and emissions per year. (Summary of concentrations at sampling times multiplied with simultaneous measured/estimated flows) – after treatment.
(iv) If applicable, impact/result of treatment of leachate.
(v) Water balance for the site (rainfall multiplied with site area + other sources of water compared to registered leachate volumes).
(vi) Assessment of trends related to concentrations and volumes of pollution.
(vii) Recommendation of actions from the above listed items.
(viii) Statistics of received waste.
(ix) Operational logs and when applicable maintenance logs.
(x) Development of the landfill (the phases of the works undertaken).
(xi) Summary record of all complaints received (written or verbal) for each media, liaison and consultation undertaken, follow-up action and procedures taken.
(xii) A record of compliance.
(xiii) Review of validity of environmental and social impact assessment (ESIA) predictions, and identification of shortcomings in ESIA recommendations.
(xiv) Comments (for example, a review of the effectiveness and efficiency of environmental mitigation measures and performance of the environment management system of the overall monitoring programme.
(xv) Recommendations and conclusions (for instance, review of success of the overall monitoring programme to cost-effectively identify deterioration and to initiate prompt effective rectification action when necessary) of the entire reporting project phase.

Chapter Eleven

Landfill Closure, Decommissioning and Aftercare

11.0 Procedural matters

Landfill closure, decommissioning and aftercare, including post-decommissioning environmental monitoring are very important final processes in the operation of a landfill. NEMA and the relevant lead agency should be notified of the intention to terminate operations at the landfill and they will inspect the site to verify that all closure requirements have been met. The proper closure of a landfill should be preceded by a comprehensive decommissioning plan in accordance with applicable law. This is to ensure that the site fits its immediate environs and is amenable to its proposed end-use as determined when the waste management licence was initially obtained or during corrective closure of unplanned existing sites.

Aftercare is required once site operations have ceased, to ensure that the site conditions after closure are environmentally and socially acceptable. For this reason, NEMA may require the amendment of an engineering design and closure and aftercare plan at any time it is deemed necessary during the landfill's operation, closure or post-closure care period.

A copy of the approved closure and post-closure care plan shall be kept on file at the landfill during the course of the landfill's operation.

11.1 Closure and Decommissioning

The closure of a landfill must be preceded by the preparation of a plan clearly setting out requirements for closure, decommissioning and site rehabilitation. Such requirements include remedial work on drainage, leachate management and cover integrity.

The decommissioning plan must form part of the original site selection and design, and should be continuously reviewed during the active life of the site to meet environmental and planning needs of the area and the intended afteruse of the site.

The decommissioning plan, which for new landfills must be included in the initial plan, should include:

(i) remedial design to address identified problem areas;
(ii) final shaping and landscaping;
(iii) final landfill cover or cap design;
(iv) permanent stormwater diversion measures, runoff control and anti-erosion measures; and
(v) any infrastructure relating to the selected end-use.

Once the landfill ceases operation, the closure and decommissioning plan is activated. Site rehabilitation and restoration work will usually be required as part of the closure process.

Further guidance on site closure and restoration can be sought from NEMA and the relevant lead agency.

11.1.1. Volumes and shape

The closure and decommissioning plan should include an assessment of the volumes of waste at the site and shaping of that waste in preparation for capping and final cover. The type of vegetation required to provide cover to the waste mould should be assessed, and plans on how to maintain the drainage system after closure made.

Landfills should be restored progressively during their lifetime as each cell/lift becomes full, in order to minimise health, safety and environmental impacts.

11.1.2. After-use

Properly restored landfill sites can be used to the benefit of society. The planned after-use of the landfill should guide the manner in which the landfill is shaped and subsequently capped. Any after-use and developments should, however, be mindful of the changes taking place in the landfill.

Sites can be restored to productive agricultural uses or passive recreational uses. Buildings should not be developed on a closed solid waste landfill site until complete stabilisation takes place (which may take several decades), given that the landfill will inherently settle and may shift (e.g. shrinking or flattening in mass). The foundations of the buildings may also be corroded by leachate and landfill gas emissions may pose safety risks. Due care should also be taken in the construction of buildings within a 500m from the site, to ensure that risks from landfill gas are minimised. It is, therefore, important to ensure that the after-use of such sites is restricted to activities not subject to these hazards.

11.1.3. Capping

The landfill must be capped in accordance with appropriate design, depending on whether it is a landfill for hazardous waste or non-hazardous waste. Even in the non-hazardous waste category, inert waste landfills may need to be capped differently.

11.1.4. Closing measures – infrastructure, equipment and facilities

The infrastructure, equiment and facilities at the landfill should, as much as possible, be removed as part of closure. Where after-use of the landfill site was planned, this must be considered during closure and site decommissioning, to inform a decision as to how to handle the infrastructure, equipment and facilities.

11.2 Post-closure aftercare

It is important to plan how to maintain the landfill once it is decommissioned. Some of the issues to pay attention to include: erosion control of the top cover; whether the landfill is settling well; groundwater monitoring; leachate and gas control; whether the vegetation cover is in good condition; and control of vermin and odour.

Aftercare requirements will depend on the circumstances of each individual landfill site. As a general rule, however, aftercare will be required for a minimum of 30 years for class 1 and class 2 landfills, save that special cells for inert waste may need aftercare monitoring of a minimum of 20 years. The Petroleum (Waste Management) Regulations, 2019 and the National Environment (Waste Management) Regulations, 2020 apply.

The operational plan and maintenance manual for the landfill should include detailed aftercare requirements and procedures.

11.2.1. Post-closure operation of environmental installations and measures

Restoration of landfill sites is of importance because it ensures that the final state of the site is environmentally safe. Environmental concerns include; the impact on water resources and the possibility of escape of landfill gas. Hence, it is important to pay attention to leachate cover, final landfill cover, capping, top soil application and vegetation.

It is also crucial to manage surface run-off, not only to reduce leachate but also to reduce flooding which could de-stabilise slopes and cause slips. Monitoring of surface and groundwater should, therefore, be carried out regularly in at least two points, preferably one upstream from the landfill and one downstream, and using methods and parameters that record leachate over time. Chapter 10 on environmental monitoring of a landfill refers.

11.2.2. Post-closure maintenance of the landfill area

Post-closure maintenance of a landfill is the responsibility of the waste handler. A financial security may be needed to cover any eventuality during the period of responsibility, in accordance with the Petroleum (Waste Management) Regulations, 2019 and the National Environment (Waste Management) Regulations, 2020.

In some instances, it may be possible to excavate, disrupt or remove deposited material from a landfill. If that is required, written approval must be sought from NEMA prior to any activity of that nature in a defined area.

The request should include the aspects below;

(i) An operation plan stating the area involved, the depth of the excavation with final grades, the site where excavated material is to be re-deposited and the estimated time required for completion of excavation procedures.
(ii) Adequate measures shall be taken during excavation to control dust, odours, fires, rodents, vermin, insects and other pests, blowing litter, surface water run-on and erosion.

The same requirements apply where excavation, disruption or removal of deposited material is from an active landfill.

11.2.3. Post-closure monitoring and reporting

Post-closure monitoring programmes should be adopted to the individual landfill on the basis of its location, content and design. Monitoring requires technical resources to carry out and interpret the end results.

The monitoring procedures should also be established with a view of checking that:

(i) the processes within the landfill proceed as desired;
(ii) the environmental protection systems are fully functioning as intended;
(iii) external threats to the integrity of the landfill are identified and mitigated early enough; and
(iv) the waste licence conditions for the landfill are fulfilled.

The collection of meteorological data, as appropriate, should be done to control water balance in the landfill. This data may be collected at the landfill or from a nearby meteorological station.

Boreholes and sampling points to monitor the quality of groundwater should be installed at site preparation stage.

The monitoring results should be recorded and monitoring reports prepared for the regulatory institutions.

Appendices

Appendix 1

A Brief description of some of the Physical-Chemical Treatment Processes applied to LeachatePre-Treatment.

(a) Air stripping methane

Air stripping to remove dissolved methane is normally a requirement, where leachate is discharged to sewer without any other pre-treatment. Raw leachate is often saturated with methane, containing up to 50mg/l. Concentrations of methane as low as 0.5mg/l in leachate can give rise to explosive concentrations of methane gas (5 to 15% by volume) in atmospheres. Removal of dissolved methane may be necessary to avoid the possibility of forming an explosive atmosphere in the sewer system.

(b) Air stripping of ammonia

The higher the ammonia concentration and the lower the BOD:N ratio the more appropriate physical-chemical methods are likely to be. The BOD:N ratio generally considered optimum for sewage treatment is 100:5, whereas methanogenic leachates may have a BOD:N ratio of 1:1. Of the various physicochemical processes, ammonia stripping offers the best potential as a process for nitrogen removal from leachates.

Ammonia stripping is a mass transfer process using air to remove volatile gaseous ammonia in the leachate. Ammonia is highly soluble and in order to remove ammonia from a liquid, it must be converted to gaseous free ammonia molecule, NH3, before stripping can take place. The pH-value of the leachate is adjusted to values of over 10 prior to being exposed to large quantities of air.

The alkali requirement to reach a pH of above 10 varies considerably from as low as 0.5 kg lime/m3 for some methanogenic leachates to as much as 6 kg/m3 for some acetogenic leachates. The process can be undertaken in a lagoon or in a purpose built stripping tower with relatively high air/leachate ratios. The greater the ratio the more efficient the process and the lower the relative cost. The concentration of ammonia released in a stripping tower exhaust would typically be a couple of 100mg/ m3, which is below the level of toxic effect of 1700 mg/m3, but above the odour threshold of 35mg/m3 and so there would be detectable odour near the plant. Consequently, gas scrubbing or thermal destruction of gases would be required. Ammonia released from a tower stream can be controlled easier than the non-point releases from a lagoon.

During the ammonia stripping process, attention must be paid to other contaminants in the leachate and unacceptable emissions of volatile organic species should be avoided. This process is non-selective and any volatile species present in the leachate would be released. It should be noted that the resulting effluent may be neutralised with acid prior to discharge.

(c) Use of precipitants/flocculants

The addition of chemicals followed by a sequence of mixing, flocculation, coagulation and settlement may be used in conjunction with other treatment processes.

The objectives of precipitation include:

- reduction in suspended solids in order to minimise clogging;
- precipitation of calcium carbonate, iron, manganese and heavy metals to protect physical plant, prevent toxicity and inorganic solids build-up in biological processes;
- removal of turbidity and colour from effluent;
- partial removal of organic loading; and
- removal of powdered activated carbon (during tertiary treatment).

Many chemicals have been used, such as hydrated lime, aluminum sulphate, ferric sulphate and polymeric coagulant aids. Hydrated lime has been found to be the most useful and cost effective precipitant.

During chemical oxidation not all organics are oxidized to carbon dioxide and water. Some organics are only partly oxidized often to biological degradable components. These new biodegradable organics must be reduced by biological treatment. To reduce these relatively low concentrations, a fixed film reactor is an effective solution.

Appendix 2

Biological Treatment Methods for Leachate

(a) Activated sludge

The activated sludge process is a suspended growth biological treatment system that uses aerobic microorganisms to treat ammoniacal nitrogenic substances and organic contaminants. Influent is introduced into a reactor where a mixed culture of bacteria is maintained in suspension. In the presence of oxygen, nutrients, organic compounds and acclimated biomass, a series of biochemical reactions are carried out in the reactor that degrade the organics and generate new biomass.

Diffused or surface aeration is used to maintain aerobic conditions in the reactor. After a specified period, the mixture of new cells and old cells is passed into a settling tank. A portion of the settled biomass is recycled to maintain the desired concentration of organisms in the reactor, and the remainder is wasted and sent to sludge handling facilities.

Nutrients (nitrogen or phosphorus) are common chemical requirements if they are not present in the leachate. For an aerobic process such as activated sludge treatment, there will be residues generated in the order of 0.1 to 0.6g sludge per gramme COD removed at about 1.0% solids concentration.

The activated sludge system has limitations that will require close monitoring, mainly:

- limited BOD loading capacity; and
- flow balancing needed to maintain stable flow and loading conditions.

A conventional activated sludge system operated without additional process elements is unlikely to achieve the percentage ammoniacal nitrogen removal required in landfill leachate treatment.

(b) Sequencing batch reactors

The sequencing batch reactor (SBR) process is a form of activated sludge treatment in which aeration, settlement, and decanting can occur in a single reactor. The process employs a five-stage cycle: fill, react, settle, empty and rest, as follows:

- wastewater enters the reactor during the fill stage;
- the wastewater is aerobically treated in the react stage;
- the biomass settles in the settle stage;
- the supernatant is decanted during the empty stage;
- sludge is withdrawn from the reactor during the rest stage; and
- the cycle commences again with a new fill stage.

(c) Aeration lagoons

Extended aeration treatment is usually carried out in lagoons to ensure a wide range of flows and strengths of leachate. To prevent seepage from the treatment system into groundwater, lagoons should be lined to the equivalent performance standard as for a landfill. If leachate aeration lagoons become anaerobic, or where odour is a particularly critical issue due to surrounding sensitive land uses, leachate odours can become an issue. Where odour is an actual or potential issue, then the leachate lagoon may need to be covered or mechanically aerated. Where leachate is to be evaporated, it should be within a closed system where no leachate is able to escape to the environment.

Lagoons are typically used to evaporate leachate. Evaporation is enhanced by increasing the evaporative surface area using measures such as microsprays in the evaporation pond or devices such as a leachate evaporation pyramid. At the end of the useful life of the evaporation pond, salt that has accumulated in the pond will need to be appropriately disposed of in accordance with the applicable law and standards. A further element of effective leachate treatment in aeration lagoons is the avoidance of large fluctuations in leachate quality and volume.

It is important, however, to ensure that heat losses due to surface area and mechanical aerators are properly handled, odour/aerosol formation is controlled, and poor settling due to low BOD:NH3 ratio is avoided.

(d) Rotating biological contactors

The rotating biological contactors is an aerobic fixed-film biological treatment process. The rotating biological contactors consist of a series of closely spaced plastic (polyethylene, polyvinyl chloride or polystyrene) disks on a horizontal shaft.

In the usual rotating biological contactor design, the disc (that can measure up to 4m in diameter and 7m in length) is rotated at 1-10 revolutions per minute; the assemblage is placed in a tank, and the media are immersed to a depth of about 40% of their diameter. The rotation of the assemblage ensures that the media are alternately in air and wastewater resulting in the development of a biofilm. Oxygen moves into the biofilm when it is in the air. Oxygen may move into or out of the biofilm when it is in the wastewater; this depends in part, on the relative concentrations of oxygen in the wastewater and biofilm. Carbonaceous oxidation will occur at the inlet end, and if there is sufficient media, nitrification will then occur further along the shaft.

A cover is needed to protect the biofilm from heavy rain and for safety. There are a number of variations of the rotating biological contactor systems which differ, mainly in the way that the media is assembled on the support structure. In general, they are more commonly used for weak leachate (leachate with low concentration). Measures need to be put in place, however, to avoid overloading of the biofilm, accumulation of high organic loads and structural damage.

(e) Anaerobic treatment

In general, biological treatment of leachates has been by aerobic methods. Anaerobic treatment methods have, however, also been used for the biological treatment of leachates. The process offers several benefits over aerobic processes such as lower sludge production, lower energy demand (because of no oxygen requirement), and recovery of methane.

Anaerobic treatment may, however, be unsuitable for leachate treatment where methanogenic conditions exist in the landfill mass and the anaerobic treatment process is unable to remove ammonia.

(f) Biological nitrogen removal

Nitrogen in leachate can be present both in organic (for example, amino acids) and inorganic (for example, ammonia) forms. Nitrogen can be removed biologically by assimilation and nitrification-denitrification.

Nitrification-denitrification involves two process steps. In nitrification, ammonia is converted to nitrate in a series of reactions under aerobic conditions. Denitrification on the other hand, involves the step-wise reduction of nitrate to nitrogen gas under anoxic conditions.

Thus, for leachate treatment, low removal of nitrogen is expected in anaerobic processes since the majority of nitrogen is in ammonia form, whereas aerobic processes designed for nitrification should be feasible for nitrogen (ammonia) removal. Nitrifying bacteria have long doubling times and in order to promote a more efficient treatment regime it is desirable to operate nitrification at 20˚C. Denitrification requires a carbon source in order to convert nitrate to nitrogen gas (C:N ratio c. 3:1) and where this is deficient an external source such as the addition of methanol is required.

Appendix 3

Physical-Chemical and Biological Treatment Methods for Leachate

(a) Membrane bioreactor

In the membrane bioreactor configuration, the wastewater to be treated flows into an aeration chamber, where the biodegradable organic matter and the reduced nitrogen compounds are oxidised. The sludge flow is channelled through an ultra-filtration unit where the mixed liquor and water are separated from each other. The filtrate is drained off as effluent and the concentrate is recirculated to the aeration chamber. Surplus sludge is discharged through a sludge valve.

This compact system differs from conventional systems in the ways below;

(i) It can be operated with a high biomass concentration with sludge concentrations up to 20 to 30g/l feasible. As high biomass concentrations are maintained, this allows for a high volumetric loading rate.

(ii) The high sludge age and high temperature lead to extensive mineralisation, resulting in little net sludge production.

(iii) The specific activity of the biomass is maximised as the process is exothermic and can take place at temperatures ranging from 35˚C to 38˚C.

(iv) Oxygen transfer into the aeration tank is considerably more efficient because the system operates under pressure, which ensures a sufficient oxygen supply despite the high volumetric loading rate and correspondingly high oxygen demand.

(v) The entirely closed system is maintained under pressure by direct air injection. The off-gases are released through a pressure relief valve. Thus, air emissions are manageable and can be treated, if necessary.

(vi) The air emissions are considerably less than in conventional systems, because the volume of air is 4-5 times lower due to more efficient oxygen transfer.

(vii) The use of ultrafiltration membranes for sludge separation improves the quality of effluent. The effluent is free of suspended solids and has low COD, nitrogen and micropollutant levels.

(b) Powered activated carbon (biological)

This system involves the controlled addition of powdered activated carbon to an activated sludge system, achieving a higher degree of treatment than is possible by either method alone. The presence of carbon in the aeration basin removes some refractory organics, enhances settling of solids and buffers the system against load fluctuation and toxic shocks.

(c) Filtration

The filtration process consists of a fixed or moving bed of media that traps and removes suspended solids from leachate passing through the media. Mono-media filters usually contain sand, while multimedia filters include sand, anthracite and possibly activated carbon. In the filtration process, leachate flows downward through the filter media. Particles are removed primarily by straining, adsorption, and microbiological action.

This type of treatment system could also be termed a tertiary or an advanced treatment system in the context of leachate treatment, after primary treatment in a sequencing batch reactor or aeration lagoon. This system is generally effective on leachates with low organic content but can be prone to clogging.

(d) Other treatment systems

Other leachate treatment systems may be explored, taking into account technological advancements.

Appendix 4

Examples of Gas Wells

The most common gas well types are here below;

(i) Vertical perforated pipe - vertical gas well, consisting of a borehole containing a pipe which has perforations through the wall over the lower part of the pipe length. The pipe is surrounded by coarse aggregate fill.

(ii) Horizontal perforated pipe - horizontal gas wells, consisting of perforated pipes laid horizontally in trenches set in the waste or within the gas layer in the final capping system. The pipe is surrounded by coarse aggregate fill.

(iii) Hybrid types. Consist of an array of shallow depth perforated vertical wells connected to a single off-take point by lengths of buried horizontal pipe which may also be perforated.

(iv) Gabion well. Consist of aggregate filled excavations set in the waste from which gas is drawn off through a perforated pipe located within the aggregate.

The design of any gas well should include allowance for settlement of the waste within the landfill and sufficient space should be left between the bottom of the well and the landfill liner to reduce the risk of damaging the liner. Typically, gas wells are drilled to 75% of the waste depth. Connections to pipework should also provide flexibility to allow for settlement of the waste. The material surrounding the perforated section of the pipe should be a non-carbonaceous aggregate.

Gas wells constructed as filling progresses usually have a minimum diameter of 500mm, but a diameter of 600-800mm is preferred. Gas wells retrofitted after filling are typically drilled to 300-1000mm diameter. Gas wells formed during filling are, therefore, often larger than those retrofitted. The slotted well pipe typically has a minimum diameter of 160mm. The well pipe material is usually either HDPE, MDPE or polypropylene.

The well spacing necessary to achieve gas collection is site specific. Vertical gas wells are normally spaced at between 30m and 60m centres. A suitable design is to size pipework for wells on the basis of each 10m of perforated well producing a flowrate of 20-50 cubic metres per hour. The combined flow-rate from individual wells then must be taken into account for the collector system.

Specifications that may be considered in vertical gas well selection include those below;

(i) Minimum well pipe diameter 100mm.

(ii) Sealing of the upper portion of the gas well casing from the ground surface to a depth of at least 3m with bentonite.

(iii) A minimum of 17% of the pipe surface area should be cut away to allow the ingress of gas.

(iv) Slot widths should be 3-5mm.

(v) Pipes should be surrounded by a suitably sized no fines aggregate with well rounded grains of 4-6 times slots width (aggregate size of 12-30mm).

(vi) The best configuration of slots is horizontal, that is, at right angles to the pipe axis; this reduces the collapse strength of the pipe by 30-40% compared to vertical slots which reduce the strength by 65-70%.

(vii) Wells should be located between 20m and 100m apart, depending on whether they are intended for utilisation or control.

Glossary of Terms

Aerobic decomposition – occurs in moist conditions in the presence of oxygen (produces strong leachate and no gas).

Anaerobic decomposition – occurs in moist conditions in the absence of oxygen (produces landfill gas and weak leachate).

Attenuation – gradual reduction in concentrations of contaminants in leachate, due to physical, chemical and biological activities as the leachate passes through soil and various subsoils.

Capping – a process of placing a cover over contaminated material or contaminated soil in a landfill, to prevent intrusion of precipitation into the waste or release of landfill gases from the waste.

Co-disposal – the disposal of chemical waste in an admixture with domestic waste so that full advantage is taken of attenuation and chemical processes operating within a landfill to reduce environmental impacts to an insignificant level.

Cover material – inert material used to cover waste during landfill; usually applied towards the end of the working day.

Hard-standing area – a ground surface with a hard material on which heavy vehicles move or are parked.

Heavy metals – usually refers to lead, zinc, cadmium and copper.

Landfilling – concepts, processes and technologies that promote stabilisation in a landfill and minimise environmental impacts arising from the landfill.

Settlement – lowering of the ground and surface of a landfill over time due to loading and other processes, including chemical and microbial actions.

Special waste – waste that requires special administrative assessment, additional processing, special transportation, packaging and treatment, or additional disposal techniques due to the quantity of the material generated or the unique physical, chemical or biological characteristics of the waste.

Stablisation – a process in which waste is treated or decomposed to the extent that if discharged or released, further decomposition is slowed such that waste will not cause nuisance to the receiving environment. Stabilisation immobilises the hazardous materials or reduces their solubility through appropriate chemical reactions.

Waste slide – occur when poorly managed waste mounds at a landfill collapse, a process that is similar to natural landslides.

References

Akgün, H., et al, 2017: The Use of Ankara Clay as a Compacted Clay Liner for Landfill Sites. Journal: Clay Minerals/Volume 52. Print publication: September 2017.

Basel Convention Technical Guidelines on Specially Engineered Landfill, No. 5, 1995.

Environmental Guidelines; Solid Waste Landfills, Environment Protection Authority New South Wales, 2nd Edition 2016.

Guidelines for the Design, Construction and Operation of Manual Sanitary Landfills. A Solution for the Final Disposal of Municipal Solid Wastes in Small Communities, Jorge Jaramillo Universidad de Antioquia, Colombia, 2003.

Hadžikadić, M and Avdaković, S. (eds.), Landfill Leachate Management – Control and Treatment Springer International Publishing AG 2018.

International Guidelines for Landfill Evaluation, International Solid Waste Association, September 2011.

Komakech, Allan John, Urban Waste Management and the Environmental Impact of Organic Waste Treatment Systems in Kampala, Uganda; Doctoral Thesis, Swedish University of Agricultural Sciences, Uppsala and Makerere University, Kampala October 2014.

Kightley, David, Nedwell, David B. and Cooper, Michael, Capacity for Methane Oxidation in Landfill Cover Soils Measured in Laboratory-Scale Soil Microcosms, Department of Biology, University of Essex, Wivenhoe Park, Colchester, Essex CO4 3SQ, United Kingdom Received 5 July 1994/Accepted 18 November 1994.

Landfill (Aftercare) Decision Support System, at https://landss.soton.ac.uk.

Landfill Criteria for Municipal Solid Waste, 2nd Edition British Columbia, June 2016.

Landfill Gas Management Facilities; Design Guidelines, Ministry of Environment British Columbia, September 2010.

Landfill Manuals; Investigations for Landfills, Environmental Protection Agency, Ireland 1995.

Landfill Manuals; Landfill Site Design, Environmental Protection Agency Ireland, 2000.

Landfill Operational Guidelines 2nd Edition, prepared by International Solid Waste Association (ISWA) Working Group on Landfill, January 2010.

Ojuri, Oluwapelumi O., 2015: Geotechnical Characterization of some Clayey Soils for Use as Landfill Liner. July, 2015. Journal of Applied Sciences and Environmental Management 19(2):211. DOI: 10.4314/jasem.v19i2.6. Federal University of Technology, Akure, Department of Civil and Environmental Engineering, Nigeria.

NEMA

National Environment Management Authority

ENSURING SUSTAINABLE DEVELOPMENT

NATIONAL ENVIRONMENT MANAGEMENT AUTHORITY (NEMA)
NEMA House Plot 17/19/21 Jinja Road
P.O. Box 22255 Kampala Uganda
Tel: +256 -414-251064/5/8
Fax: +256 -414-257521
Email: info@nemaug.org
Website: http://www.nema.go.ug