Co-convened by

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

# Guidelines for the Safe Disposal of Solid Waste in Humanitarian Contexts

## CHAPTERS

**1. Introduction**

**2. How to plan and design a disposal site**

- 2. 1. Disposal site location
- 2. 2. Disposal site design
- 2. 3. Mitigation measures

**3. How to operate a disposal site**

- 3. 1. Site plan
- 3. 2. Waste placement plan
- 3. 3. Depositing at the tipping face
- 3. 4. Constructing a cell
- 3. 5. Building the disposal site upwards
- 3. 6. Staff requirements

**4. How to further reduce impact**

- 4. 1. Access control and fencing
- 4. 2. Trapping windblown waste
- 4. 3. Rainwater management
- 4. 4. Leachate management
- 4. 5. Gas management
- 4. 6. Impermeable liner
- 4. 7. Monitoring water quality

**5. How to close a disposal site**

## ANNEXES & TOOLS

Annex 1 - Principles of sanitary landfilling

Annex 2 - Evaluation of the level of control of a disposal site

Annex 3 - Disposal site planning steps and timeline

Annex 4 - Disposal site size calculations

Annex 5 - Site selection criteria checklist

Table 1: Key planning steps and activities

Table 3: Summary of key features of a disposal site, risks and mitigation measures

Annex 6 - Disposal site operations activities checklist

Annex 7 - Equipment and materials for manual landfilling operations

Annex 8 - Landfilling processes

## How to use these guidelines

The unsafe disposal of waste can have a critical impact on both public health and the environment. Therefore, it is important to plan for it, including in humanitarian settings. The preferred option of UNHCR would be to rely on existing host community disposal sites, providing support to municipal authorities or local service providers if their capacity to handle these additional waste amounts is insufficient. If existing disposal sites cannot accommodate the waste generated from displacement settings or these sites are severely dysfunctional and polluting, the establishment of a new one can be considered. Multiple challenges can hinder the proper management of waste, such as the lack of funding, space availability, related site capacity, and the reluctance of governments to provide designated spaces for waste disposal.

These guidelines aim to support practitioners on the ground in making decisions regarding the sound disposal of domestic solid waste in refugee camps/settlements as recommended by UNHCR in its Operational Strategy for Climate Resilience and Environmental Sustainability. The overarching objective is to mitigate the impact of waste on the environment and public health, in harmony with the Sustainable Development Goals (SDGs) adopted by all United Nations Member States in 2015. Poor solid waste disposal practices directly affect SDGs 3, 6, 11, 13, 14 and 15. Early involvement or collaboration with local authorities and non-transactional actors is crucial to ensure funding for initial capital costs and ensure long-term operation and maintenance .

**The following Decision Tree (Figure 1) will help you navigate these guidelines efficiently: you can follow the box/step/tool that is relevant to your context, and you will be directed to the relevant section of the guidelines**. Blue boxes show key issues that need to be considered, green boxes refer to the different chapters and sections of these guidelines, and orange boxes refer to the annexes.

First, assessing if there is already a defined disposal site (several designated areas can work for big settlements) is necessary. If a defined disposal site is currently in use, the next step is to check if the location is adequate. If the site is adequate, assess its level of control, check for potential actions and measures for risk mitigation and determine the impact reduction strategies.

In case an already functioning site is not adequate, or if no disposal site is available, a new site should be selected following the planning steps outlined in **Table 1**. Once the site location is validated, the next step is to decide on the mitigation measures to implement, with the help of **Table 3**. These will depend on the available resources and the intended level of control. After selecting a site, it can be designed, the waste handling procedures defined, and the staff requirements estimated. The development of the site should ensure that minimum occupational health standards are met.

These guidelines focus only on domestic solid waste disposal; they do not cover other types of waste (e.g. hazardous waste from health care facilities, agricultural waste, sanitation waste, etc.) as they should be managed separately. Furthermore, the collection and transport of waste are also excluded. However, it is essential to consider how the waste collection is done and how it will reach the disposal site. The collection scheme, including the related budget, staff and equipment required, should be determined before any final decision is made on the landfill. The priority is for the waste to reach the disposal site and not lay around or be burned in the settlement. Ideally, collection and disposal are planned and improved together as part of a system. You can find more information on how to collect waste safely and efficiently in Wasteaid (2017) and Coffey (2010).

The figures presented in these guidelines are adapted from Jaramillo (2013) unless otherwise noted. For more illustrations and detailed information on the design, construction and operation of manually operated disposal sites, please consult the above reference.

Throughout the guidelines, you will come across light pink boxes with an attention icon indicating important issues.

> *Box highlighting an important issue*


***Figure 1:*** *Navigation support for these guidelines*

# Table of Content

# 1. Introduction

Safe waste disposal is necessary to limit the impact of waste on human health and the environment. Waste should be deposited in a specific space designed to receive it, called a disposal site. At a safe disposal site, the waste is actively managed following some key principles to minimise its impact (**Annex 1 - Principles of sanitary landfilling**). The mitigation measures taken will define the level of control at a disposal site, which can be evaluated using **Annex 2 - Evaluation of the level of control of a disposal site**. **Figure 2** shows two examples of disposal sites along with the control level ladder. When there is no control or limited control, waste is deliberately and indiscriminately deposited without (or very limited) control measures that protect the environment and public health. Disposal sites with basic and improved control are fenced areas with controlled access, organised waste disposal, regular compaction and covering of the waste, but without liners, leachate collection systems or gas management. Sites with full control are engineered sanitary landfills designed and operated to minimise environmental impact. Waste is compacted and covered daily, the disposal site is lined at the base, and it is designed to manage gas emissions and leachate. Thorough planning and active operations at the site are requirements that allow for higher levels of control.


***Figure 2:*** *Illustration of two disposal sites along the level of control ladder. Left picture* ***(ELS-EG, 2018)*** *shows an open dumpsite without control. The right picture is the engineered sanitary landfill in Cox's Bazar* ***(photo credit: UNDP)*** *and shows an improved level of control with site planning, waste compaction and covering, and leachate management.*

It is important to highlight that a significant fraction of the solid waste might be organic and, if possible, the organic waste should not be disposed of in a landfill, but treated and valorised (e.g. animal feed, composting, biogas or insect farming). The selection of organic waste treatment technologies is described in detail in the SOWATT manual (Zabaleta, 2020). Based on local recycling markets, recyclable materials that could have valuable reuse or recycling potential should also not be brought to the landfill, but segregated upstream. Proper handling of recyclables and organics can decrease transportation costs to the landfill and concomitantly increase its lifetime. Hazardous waste, such as infectious waste generated from healthcare facilities, or electronic waste (e-waste), should not be disposed of at landfills. Instead, they should be processed at a distinct location that has been established to safely handle and dispose of such materials (please refer to national guidelines and WHO recommendations for safe management of waste from healthcare facilities (World Health Organization, 2014) and United Nations Environment Program E-waste management manual (UNEP, 2007)).

The following **Video 1** introduces what can be done to improve solid waste disposal. Even though it is not specifically geared towards humanitarian contexts, it gives a visual overview of some key measures presented in these guidelines.


***Video 1****: MOOC Video … Municipal Solid Waste Management In Developing Countries – Upgrading a dump site*

# 2. How to plan and design a disposal site

Several steps are recommended to plan and design a disposal site:

- **Assessment of solid waste management system needs**, such as collection and transport, as well as the potential of source separation and recycling;
- **Disposal site location:** estimate the size needed for the new disposal site, identify and select potential sites with due consideration of distance, sensitive areas, local legislation, permissions required, etc.;
- **Disposal site design:** define the methods of waste disposal;
- **Mitigation measures:** decide which measures to implement to limit the risks and potential negative impact of inadequate waste disposal practices;
- **Operation & maintenance:** determine the waste deposit procedures to follow at the tipping face (i.e. the specific spot where the waste is disposed of) and estimate the staff requirements.

The key planning steps and related activities are summarised in **Table 1,** with references to the corresponding chapters if covered in these guidelines and/or to significant literature for further reading. **Annex 3 - Disposal site planning steps and timeline** provides a similar table to print, including a planning timeline that can be filled out.

***Table 1:*** *Key planning steps and activities*

| Steps & Activities | References<br>Section(s) in this guideline or key literature |
|---|---|
| **PREPARATION STEPS** | |
| Assess waste management system needs and start planning and/or improving the collection and transportation of solid waste to the disposal site. | Wasteaid (2017a) (1)<br>Wasteaid (2017b) (2)<br>Coffey et al. (2010) |
| Start an awareness programme for and with the community to ensure that organics and recyclables are managed separately. | Wasteaid (2017b) (2), Ch.5 |
| **DISPOSAL SITE LOCATION** | **2. 1** |
| **Evaluation of disposal site size**<br>■ Conduct a waste characterisation and quantification study<br>■ Evaluate the size required | 2. 1. 1 |
| **Identification of potential sites**<br>■ Consultation with local stakeholders<br>■ Consider site selection criteria, including the required disposal site size<br>■ Consultation with hydrogeologist: analysis of hydrogeological conditions at the proposed sites | 2. 1. 2 |
| **Selection of disposal site location**<br>■ Ensure local stakeholders' approval<br>■ Land allocation by the authorities<br>■ Topographical survey<br>■ Site plan preparation | Jaramillo (2003), Ch.4.4 |

| Steps & Activities | References<br>Section(s) in this guideline or key literature |
|---|---|
| **MITIGATION MEASURES** | **2. 3** |
| **Identification of mitigation measures to be implemented**<br>■ Check the list of key features, risks and mitigation measures<br>■ Prioritise the mitigation measures to be taken | 2. 3 |
| **DISPOSAL SITE DESIGN** | **2. 2** |
| **Development of the operational plan**<br>■ Define the site plan (long-term) and placement plan (short-term) | 3. 1 & 3. 2 |
| **Evaluate budgeting** | Jaramillo (2003), Ch.9.4 |
| **Project presentation to authorities and stakeholders** | |
| **Secure funding**<br>■ Initial investment for the disposal site, as well as for the collection and transport services<br>■ Guarantee the funding for operation & maintenance | |
| **Preparation of the land**<br>■ Cutting and clearing away the vegetation and trees<br>■ Preparation of the ground surface (ground levelling, compaction, impermeable liner, etc.) | Jaramillo (2003), Ch.6.1<br>4. 6 |
| **Peripheral infrastructure**<br>■ Site access road<br>■ Rainwater drainage | 4. 3 |
| **Construction of landfill infrastructure**<br>■ Internal access roads<br>■ Impermeable liner<br>■ Leachate drainage, containment, and treatment system<br>■ Gas drainage system (and flaring or usage) | Jaramillo (2003), Ch.6<br>4. 6<br>4. 4<br>4. 5 |
| **Auxiliary construction**<br>■ Perimeter fence<br>■ Planting a green perimeter barrier<br>■ Control building and sanitary facilities<br>■ Monitoring wells | 4. 1<br>3. 6. 3<br>4. 7 |

| Steps & Activities | References<br>Section(s) in this guideline or key literature |
|---|---|
| **OPERATION & MAINTENANCE PLANNING** | **3** |
| **Finalise and validate site plan and placement plan** | 3. 1 & 3. 2 |
| **Waste deposit and handling**<br>■ Establish waste deposit procedures at the tipping face<br>■ Determine the frequency of covering and compaction | 3. 3<br>3. 4 |
| **Staffing**<br>■ Estimate the staff requirements<br>■ Ensure minimum occupational health standards | 3. 6<br>3. 6. 1<br>3. 6. 2 & 3. 6. 3 |
| **Training of supervisors and operators** | |
| **Beginning of landfill operations** | |
| **Operation and maintenance of the landfill** | 3 |
| **Monitoring and evaluation of the functionality of the site** | |
| **CLOSING A DISPOSAL SITE** | |
| **Closure of dumpsite(s)**<br>■ Extermination of rodents/pests<br>■ Covering with soil and sealing the dumpsite<br>■ Install a sign that states this is a closed dumpsite<br>■ Publicly communicate about the closure | Jaramillo (2003), Ch.8<br>5 |

## 2. 1. Disposal site location

### 2. 1. 1. Sizing of the disposal site

For proper sizing of the waste disposal site, it is required to know the amount and type of waste produced. A quantification and characterisation study is essential to better understand how much waste will be disposed of at the site. Waste quantification and characterisation methodologies are explained in UN-Habitat, 2021 and Wasteaid (2017c) (3), as well as in the following videos: Planning a Waste Generation and Characterization Study and Conducting a Waste Generation and Characterization Study. UNHCR recommends evaluating the waste generation and composition within three months after the dump site has opened, as well as annually.

If no waste generation information is available, the SPHERE standards values can be used for a quick estimation. Assuming one person generates 0.5 kilograms of solid waste per day, this equates to a volume of 1–3 litres per person per day, based on a typical density for stabilised waste at the disposal site of 500 to 600 kg/m$^3$. Based on experience with field data, this is typically an overestimation of the waste generated per capita and is, therefore, a conservative assumption that might underestimate the lifespan of the disposal site.

An initial estimation of a minimum of 10 years can be used to size the disposal site. Since finding an adequate location for a disposal site is challenging and due to the need of it staying in operation at least 10 years it is worth the effort, time and resources to select and prepare a good site. To use the space efficiently, a landfill is constructed with several layers of waste. The recommended height of a landfill is from 3 to 6 m maximum for a manually operated landfill (see chapters **3. 4. 1** and **3. 5**). If you already have a site, you should estimate its remaining lifetime and be prepared to find a new location once the current one has reached its capacity. Guidance on disposal site size calculation is provided in **Annex 4 - Disposal site size calculations**. **Table 2** shows quick estimates for 10 year lifetime disposal sites, with a generation rate of 0.5 kg/person/day, a height of 4 m, a density of compacted waste of 400 kg/$m^3$, a density of stabilised waste of 550 kg/$m^3$, a 20% ratio for cover material and a 25% additional buffer area.

***Table 2:*** *Disposal site area requirement estimation for three population sizes for a duration of 10 years*

| Population | For 10’000 people | For 50’000 people | For 100’000 people |
|---|---|---|---|
| **Required area [$m^2$]** | 13’200 | 66’000 | 132’000 |
| **Filled volume [$m^3$]** | 42’000 | 211’000 | 423’000 |

### 2. 1. 2. Site selection

Selecting the site should take into consideration health and environmental issues, such as the protection of neighbouring communities and habitats, flooding risks, surface water and groundwater protection, the dominant wind, as well as geology, hydrology and the distance from the collection sites. The costs related to construction and operation, especially the transport of waste to the site, are also important aspects to be considered. It is necessary to remember that the service chain to bring the waste from the points of generation to the disposal site should be secured for the system to work. The criteria that should be met for site selection are provided in **Annex 5 - Site selection criteria checklist.**

The site selection should be done in close collaboration with local stakeholders from the government, local population representatives, displaced communities’ representatives, and other organisations present in the area. The impacts that should be minimised are odour, air pollution (smoke), water pollution, insects and animal vectors. Groundwater and surface water pollution risks are critical to consider, especially if the water is used downstream for drinking purposes. The selection of the site should always be discussed with a hydrogeologist, as water contamination could be caused by the disposal site. Local stakeholders will be knowledgeable about such conditions as dominant winds, flooding, etc., and should be able to inform you about the relevant local aspects that are important to consider. The goal of the participatory approach is to ensure that the selected location is locally approved. Furthermore, legal ownership of the land should be secured before constructing and operating the landfill.

The perfect disposal site location usually does not exist, and compromises will have to be made. Usually, the failure to comply with some of the criteria should not totally exclude a location. Nevertheless, care should be taken to limit the risks and compensate for the noncompliance of any given criteria.

**Risk of water contamination**

*Contamination of water is one of the most problematic risks to consider when selecting a landfill site. Check with relevant experts and stakeholders about the selected location and the associated risks. Protection of surface water and groundwater that are used or planned to be used for consumption or irrigation is of paramount importance.*

## 2. 2. Disposal site design

There are **four main ways to design and operate a disposal site:** the “trench”, the “area”, the “combined” and the “natural terrain” methods. The type of method used will depend on the terrain characteristics of the site. The following sections illustrate and describe the four options.

Local conditions, such as the groundwater table, the type of soil and its permeability, the availability of cover material, and how easy it is to excavate, are the parameters to evaluate when deciding which method to use. Keep in mind that excavation requires mechanised equipment as well as expert design and supervision.

### 2. 2. 1. Trench method

For the trench method, trenches are excavated and filled with waste. The length of trenches can vary widely, spanning tens of meters depending on available space. It is recommended to have a height ranging from 2 to 3 meters and a width between 3 to 6 meters (**Figure 3**). An advantage is that the excavated soil can be used to cover the waste (**Figure 18**).

This method is appropriate for flat terrain that is easy to excavate and that has a deep water table. If the terrain is rocky, this method is not suitable.

Liner preparation can be complex for this method (especially with narrow trenches). The trench method works best when there are natural, impermeable layers of soil present at the site.

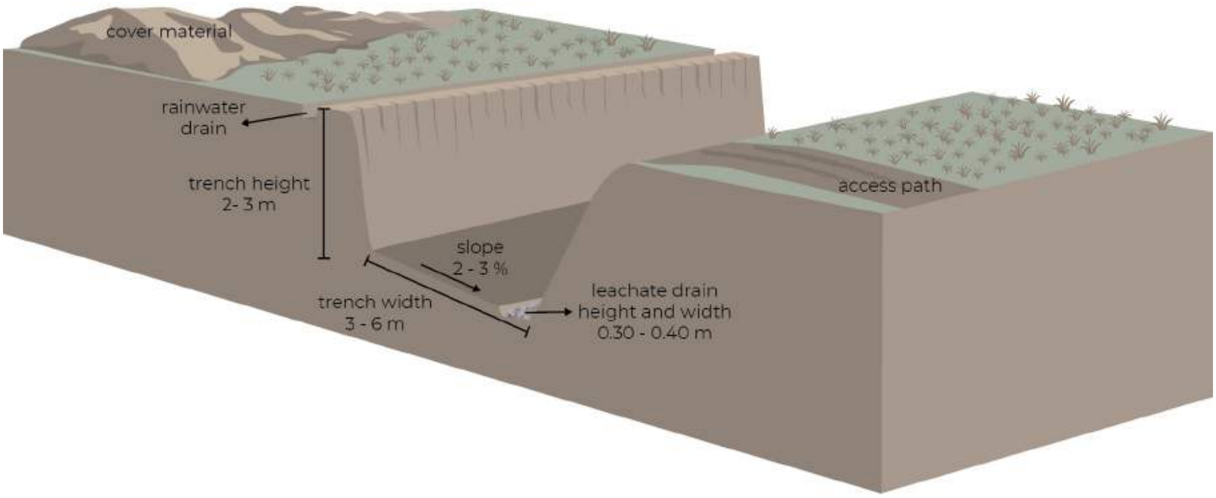


***Figure 3:*** *Trench method for landfilling*

### 2. 2. 2. Area method

With the area method, the waste is disposed of on top of the existing or excavated terrain. Several meters of waste can be stacked, and this requires the construction of access ramps (**Figure 4**) that facilitate the compaction of the waste layers when unloading the waste from the top of the tipping face. The area method is useful for flat areas where trenches are unsuitable or to fill natural depressions. If it is not excavated onsite, cover material, such as clay or any fine inert material, should be available nearby and transported to the site for the waste covering process (**Figure 10** and **Figure 11**).

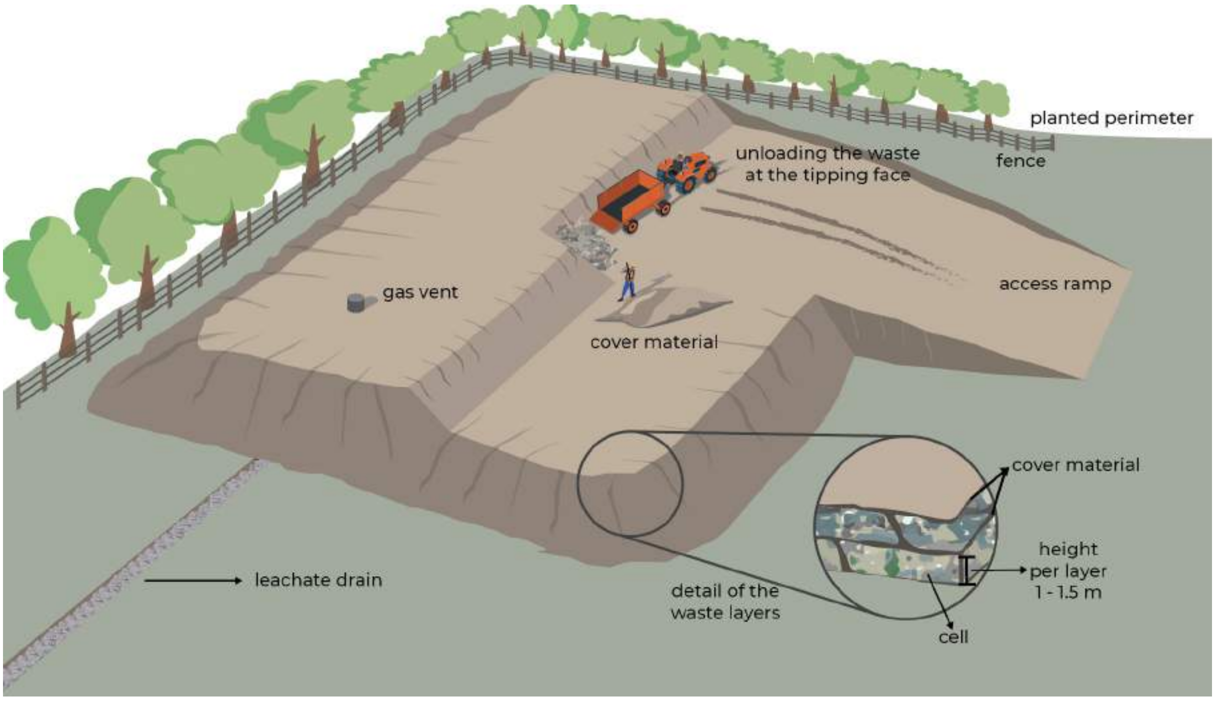


*Figure 4: Area method for landfilling*

### 2. 2. 3. Combined method

The trench and the area methods can also be combined when conditions allow for this to make the best usage of cover material and land availability (**Figure 5**). Trenches are excavated and then filled up to soil level before being covered as per the area method. This increases the lifetime of the site because it allows for a higher available disposal volume per surface area.

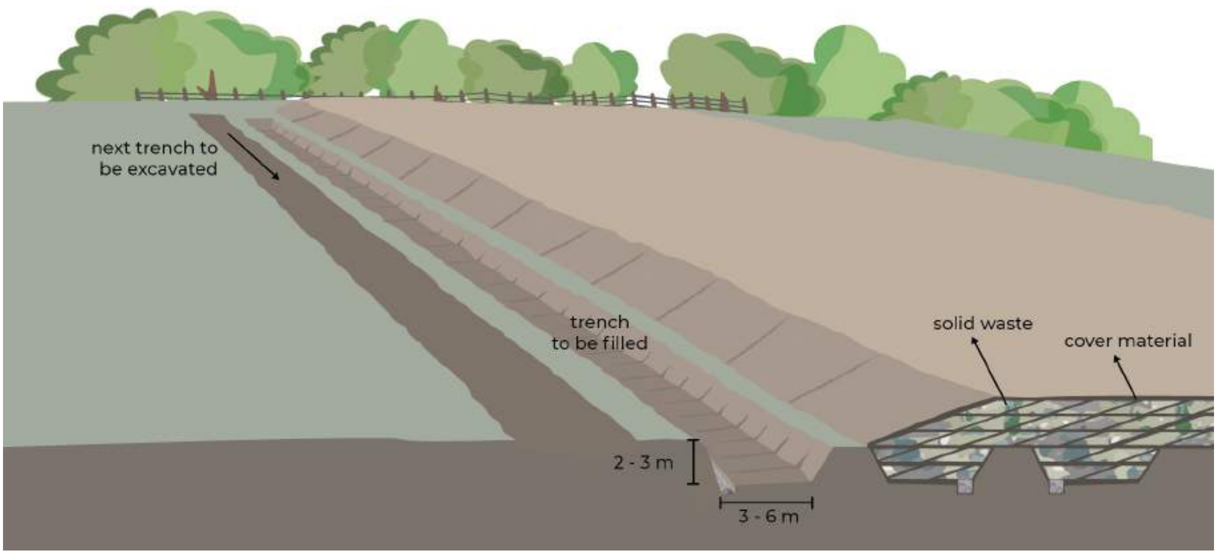


*Figure 5: Combined trench and area methods for landfilling*

### 2. 2. 4. Natural terrain method

Uneven natural terrain can be taken advantage of for waste disposal. Natural cavities can be used as disposal areas and filled with waste. Hills can also be part of the support structure for the disposal site, as shown in **Figure 6**. This method requires adapting the site design and operation to the given natural environment, and there is more flexibility in selecting a disposal site location. Cover material is often available onsite, for example, from the natural slope stabilisation work, as shown in **Figure 8.**

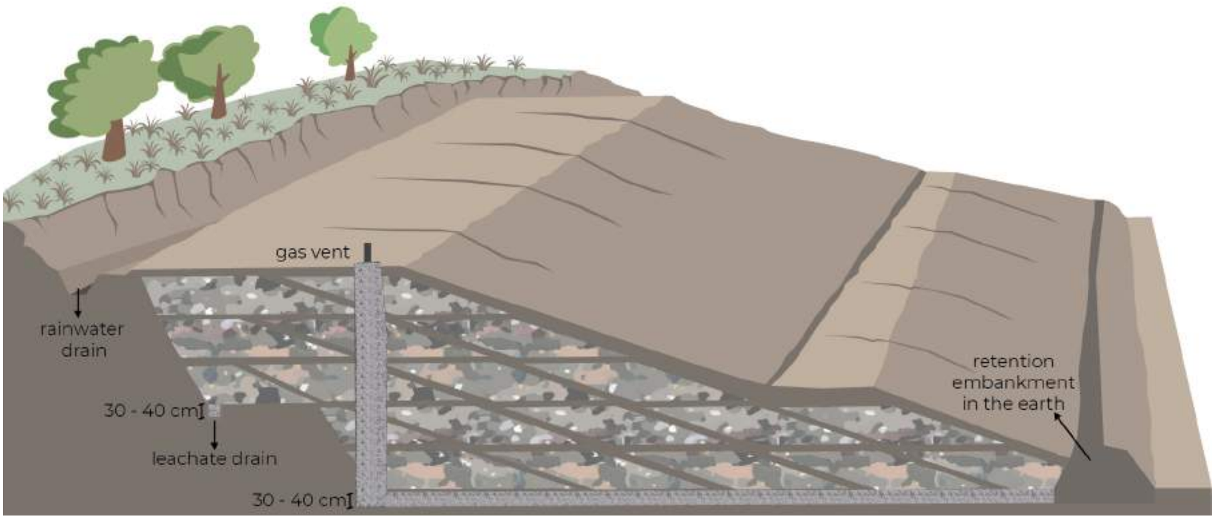


***Figure 6:*** *Cross-section of a landfill using the natural terrain*

## 2. 3. Mitigation measures

### 2. 3. 1. Mitigation measures for a new disposal site

A properly designed and operated disposal site can limit significant risks. **Table 3** highlights the main features of a disposal site, its related risks, the potential negative impacts if it is poorly managed and relevant mitigation measures. An indication of the main requirements in terms of staffing, operation and maintenance (O&M) and capital investment, as well as the technical skills required, are also listed.

**Considering the key features of a disposal site on this list makes it possible to select mitigation measures and prioritise required actions**. It is important to consider that mitigation measures are easier to implement if planned from the start. **A priority list to improve an existing disposal site is outlined in section 2.3.2**.

### 2. 3. 2. Mitigation measures for an existing disposal site

There are several actions that can be easily implemented to improve the waste management at an existing disposal site that will help limit its negative impact on the environment and public health. **The following key actions are proposed as they are the simplest to implement:**

- Controlling and limiting access **by fencing the site and securing the entrance with a gate ( section 4. 1 )**
  - no animals
  - entering is restricted to authorised people
  - controlled waste reception
- Improving waste placement **by having a waste placement plan and a site plan ( sections 3. 1 & 3. 2 )**
  - plan compartments called "cells"
  - restrict the size of the tipping face
  - ensure accessibility with internal roads and ramps
- Improving waste management by adequately handling the disposed waste at the tipping face ( sections **3. 3** & **3. 4** )
  - spreading
  - compacting
  - covering
  - controlling the slope and height of the waste placement ( section **3. 5** )
- Reducing the environmental impact by implementing mitigation measures ( **Table 3** and **Chapter 4** )
  - capture windblown waste with a portable fence or a green buffer around the site
  - capture rainwater with drains to keep it from entering the disposal site and generating leachate
  - avoid and quickly extinguish fires

The **video** provided in the **Introduction** chapter teaches about these improvements.

Some ameliorative actions might be too complex and too difficult to implement retroactively. Improvements should be made as soon as possible, preferably before waste is deposited. For instance, making the bottom of the disposal site impermeable is only possible before waste has been deposited on it. Besides the recommended priority measures, other actions, such as leachate and/or gas management, should also be considered, and a context-specific assessment plan should be developed to handle them.

***Table 3:*** *Summary of key features of a disposal site, risks and mitigation measures*

| Features of a disposal site | Risks and potential negative impacts if poorly managed | Mitigation measures | Main requirements | Technical skills required |
|---|---|---|---|---|
| **Operational plan** | Unorganised dumping<br>➔ The site may fill up quickly<br>➔ Access to some areas of the site may be blocked by waste, hence, reducing its useful volume | • Have a waste placement plan. Restrict depositing of waste to the tipping face<br>• Have a site plan: dispose waste in specific areas called “macro units” and ensure accessibility to internal roads and ramps<br>• Have a trained manager at the site | Staff and O&M | Low |
| **Access control and fencing** | Animals entering the site | • Fence the site<br>• Compact and cover the waste at the tipping face | Capital investment,<br>Staff and O&M | Low |
| | Unauthorised persons entering the site for waste picking or to dump waste and/or unauthorised waste deposited at the site (hazardous, healthcare waste, etc.)<br>➔ Safety of intruders (accidents and health) | • Fence the site<br>• Have a gated entrance<br>• Control and register waste entering the site<br>• Have the site under surveillance | Capital investment,<br>Staff and O&M | Low |
| | Spreading of waste by the wind (trapping windblown waste)<br>➔ The site could contaminate the surrounding areas | • Fence the site<br>• And/or plant a perimeter barrier<br>• And/or erect a mobile barrier at the tipping face | Capital investment,<br>Staff and O&M | Low |
| **Depositing at the tipping face** | Waste is disposed of as a pile leading to the impossibility of compacting or covering it<br>➔ Not possible to properly organise the tipping face and compact and cover the waste to prepare the active cell | • Spread the waste evenly at the tipping face (this can be done manually or mechanically) | Capital investment (if mechanised),<br>Staff and O&M | Low |
| **Compaction of waste** | • Waste density remains low<br>• Fire hazard increases<br>• Animals and pests can proliferate<br>➔ Site lifetime is reduced<br>➔ Potential health impact from pests, animals and/or fires | • Compact the waste, ideally daily (it can be done manually or mechanically)<br>• Limit voluminous low density waste disposal, such as plastic bottles or ensure significant compaction | Capital investment (high if mechanised),<br>Staff and O&M | Low |

| Features of a disposal site | Risks and potential negative impacts if poorly managed | Mitigation measures | Main requirements | Technical skills required |
|---|---|---|---|---|
| **Covering of waste** | • Proliferation of animals and pests<br>• Higher fire hazard<br>• Visible waste<br>➔ Aesthetic impact and potential health impact from pests, animals and/or fires | • Cover the waste with cover material, ideally daily (it can be done manually or mechanically) | Capital investment (high if mechanised),<br><br>Staff and O&M | Low |
| **Rainwater management** | Rainwater runs through the disposed waste<br>➔ Site can become unstable: access to trucks impossible and risks of landslides<br>➔ More leachate generated, with higher risk of groundwater contamination<br>➔ Potential flushing of waste out of the site and into water bodies | • Construct a peripheral rainwater drainage system to keep as much rainwater as possible from percolating in the disposed waste<br>• Slopes and ditches in the landfill help evacuate excess rainwater from the surface<br>• Once the landfill is closed, planted vegetation on the landfill helps to limit the infiltration of water into the waste and enhances evaporation | Capital investment (high if mechanised),<br><br>Staff and O&M | Low |
| **Leachate management** | Contaminated leachate infiltrates the soil and reaches water bodies<br>➔ Site can become unstable: access to trucks impossible and risks of landslides<br>➔ Soil, groundwater and surface water can be contaminated | • Leachate collection system, containment, and treatment<br>• Reduce organic waste disposed at the site<br>• Manage rainwater<br>• Monitor ground and surface water quality (monitoring water quality) | Capital investment,<br><br>Staff and O&M | Low |
| **Gas management** | Methane is generated<br>➔ Might cause fires or even explosions<br>➔ Potent greenhouse gas | • Gas collection system<br>• Gas flaring or use for energy production | Capital investment,<br><br>Staff and O&M | Low |
| **Impermeable liner** | Contaminated leachate infiltrates the soil and reaches waterbodies<br>➔ Soil, groundwater and surface water may be contaminated | • Impermeable liner (membrane or impermeable compacted mineral layer) | Capital investment,<br><br>Staff and O&M | Low |

# 3. How to operate a disposal site

Operating a disposal site requires an operation plan that includes a site plan and a waste placement plan. The site plan is the general design plan of the site and details how it will be run in the long term. The placement plan determines where to deposit the waste on a day-to-day basis. **Disposal site operations activities checklist** supports the operator in monitoring the operations at the disposal site.

## 3. 1. Site plan

A disposal site can be divided into macro units, where only one is operational at a given time based on the site plan, as shown in **Figure 7**. For example, each of the five macro units could be active for two years; therefore, the site would have a 10-year lifetime for waste disposal. A specific – easy to access – area of the disposal site should be reserved to allow for operation to continue without interruption during the rainy season. Monitoring the filling speed of the landfill is useful to update the plan and to determine if the lifetime of the landfill will be shorter or longer as forecasted. This also makes it easier to anticipate the steps to take after the closure of the site. Once a landfill macro unit is full, it should be closed and adequately sealed, following the recommendations in **Chapter 5**.

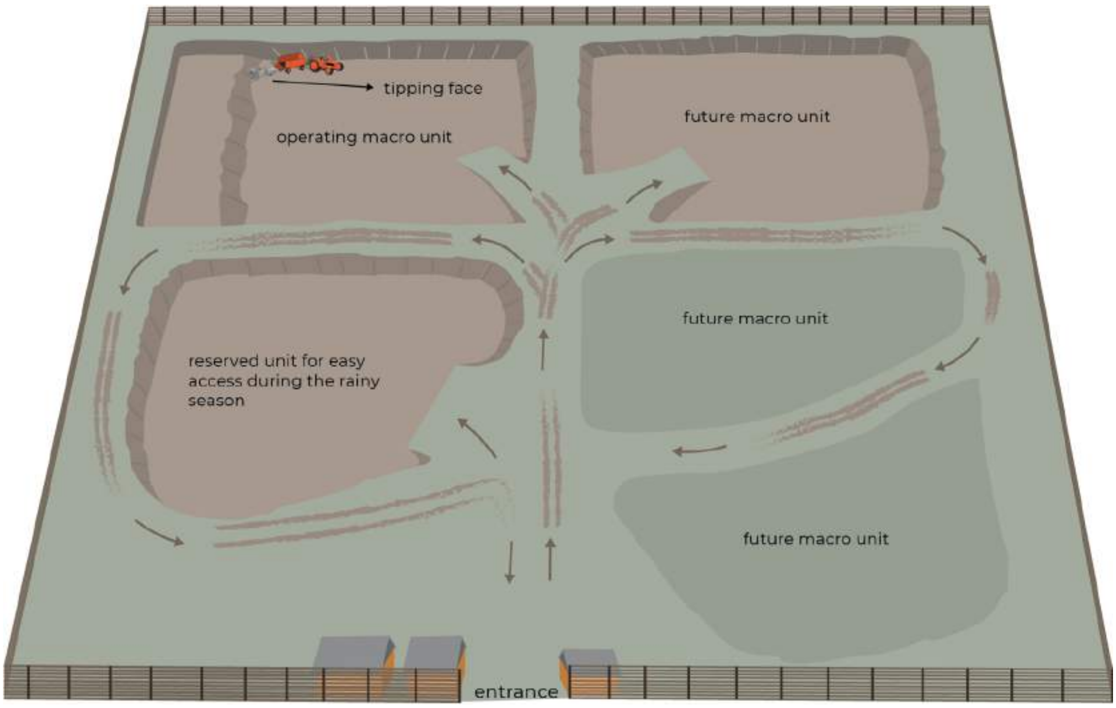


***Figure 7:*** *Illustration of a landfill site plan*

**Accessible macro unit during bad weather conditions**

*An easy to access macro unit should always be reserved for bad weather conditions to allow for trucks to easily deposit waste when the terrain is too muddy for them to make deposits at the current active macro unit.*

## 3. 2. Waste placement plan

The placement plan indicates where to deposit waste within a macro unit. The area where the waste is deposited is called the "tipping face" and is the only place where waste should be visible. The waste should be spread, compacted, and covered at the tipping face to construct a cell, as shown in **Figure 9** (referred to as a "daily cell" in the literature).

The landfill is filled with waste one cell at a time. The cells should be organised to construct a stable landfill and to make it possible for collection vehicles to transit when necessary. **Figure 8** shows a possible waste placement plan and the planned cells to fill the landfill. The cells are constructed one next to the other to use the whole space. The base layer should have a slope of 2-3% for leachate management (see **section 4.4** for more information on leachate management). Additional layers of cells can be added on top of the previous ones, as shown in the cross-section. This leads to a landfill such as that shown in **Figure 6.**

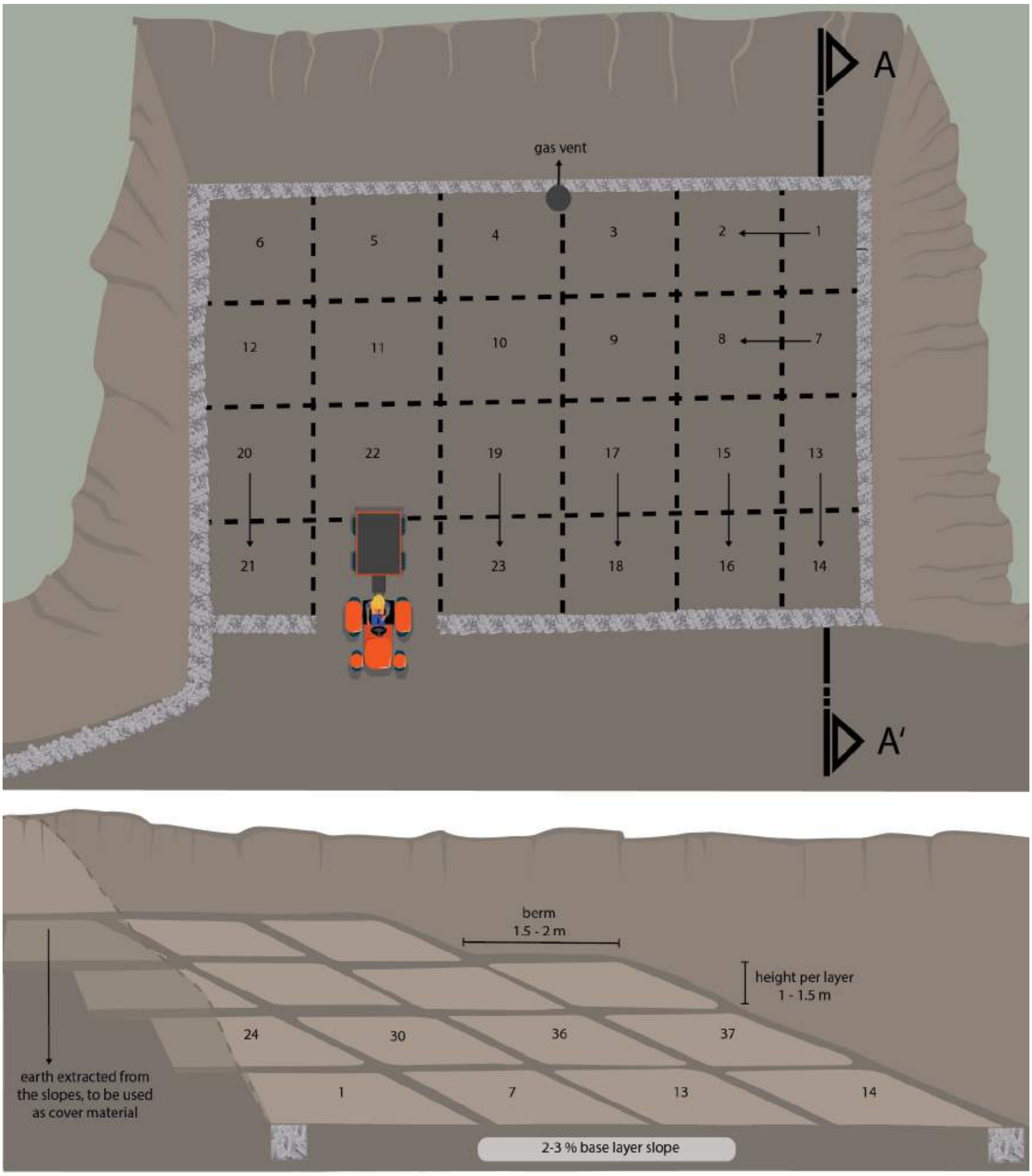


*Figure 8: Waste placement plan and planned cells to fill the landfill*

## 3. 3. Depositing at the tipping face

Waste should be brought and deposited at the tipping face of the active macro unit. This helps limit the waste from spreading all over the disposal site. The first layer of waste is deposited at the ground level (**Figure 7**). It might be necessary for vehicles to transit on top of previously deposited waste to build up the landfill. **Figure 4** shows a collection truck accessing newly covered and compacted waste. It is essential that proper compaction and covering are done so that vehicles can transit on top of the waste. To ensure that the vehicles do not slip or sink into the waste, steel or plastic gratings, railway sleepers, wood planks, or any resistant, flat, and large surface items that grip the tires should be used. The passage of the vehicles on the waste helps to compact it. Internal roads should be planned, prepared, and maintained to ensure that the vehicles can always reach the tipping face. Access ramps and internal roads will have to be permanently constructed and maintained. The ramps should be constructed with low slopes so that trucks can safely transit on the site, even on rainy days.

## 3. 4. Constructing a cell

Once the waste is deposited at the tipping face, it should be evenly spread to make it level, compacted, and then covered with cover material to build the core component of a disposal site: a cell (**Figure 9**, **Figure 10** & **Figure 11**).

For practical, technical and stability reasons, slope ratios at the edges of the cells should be 1/3 vertical/horizontal, waste height 1-1.5 m and the cover material should have a thickness of 0.1-0.15 m.

To avoid additional transportation and labour costs, it is recommended to use cover material available onsite. Clay is the best cover material, but any inert material can be used: inert construction waste, soil or other earth-like materials.

Building a properly compacted and covered cell is an important step for the stability of the site and to increase its lifetime, as mentioned in section **3. 5**. Compaction and coverage can be done manually or mechanically as described in the following sections (**3. 4. 1** & **3. 4. 2**). The benefits of covering are to minimise:

- The presence of flies, birds, rodents, and other animals;
- Prevent fires and smoke;
- Reduce bad odours;
- Reduce infiltration of rainwater into the site;
- Improve the aesthetic appearance;
- Improve stability, which permits the preparation of internal access roads.

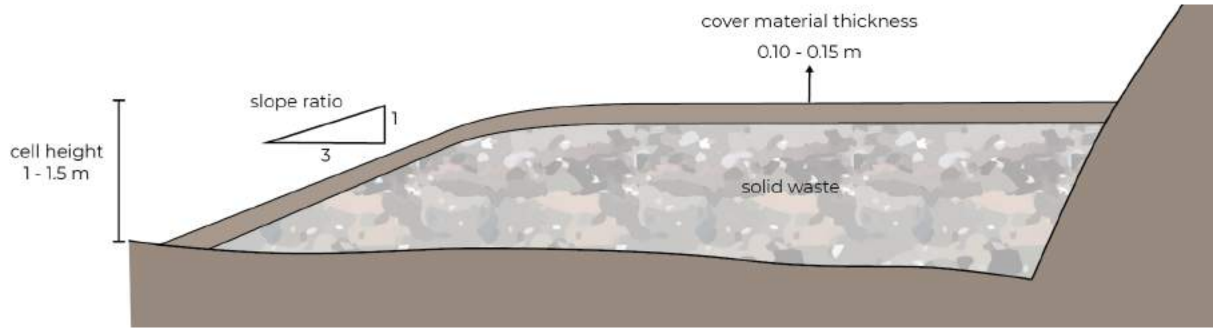


***Figure 9:*** *Typical cell profile*

**Cover and compaction frequency**

*As waste might attract animals and pests, it is important to cover the waste as frequently as possible. For high-capacity disposal sites, a daily cover is recommended. For low-capacity disposal sites, the covering of waste can be done every few days and the site could still be kept in a sanitary condition. Remember that compaction is key to increase the lifetime of the landfill and for its stability, especially when building vertically.*

### 3. 4. 1. Manual operation

Manual operation at the tipping face is illustrated in **Figure 10**. The process is to deposit the waste, spread it evenly to make it level, and manually compact it. Each layer of waste (20-30 cm) is compacted until the desired height of the cell is reached (1-1.5 m). Compaction is done by hitting the surface of the waste layer multiple times with a heavy tamper (**Figure 12**) or by rolling a heavy manual roller (**Figure 13**) over the waste.

Compacting should be done every time waste is deposited at the tipping face. Once the active cell reaches the desired height, the waste is then covered and compacted again to close the cell, as shown in **Figure 10** and **Figure 11**.

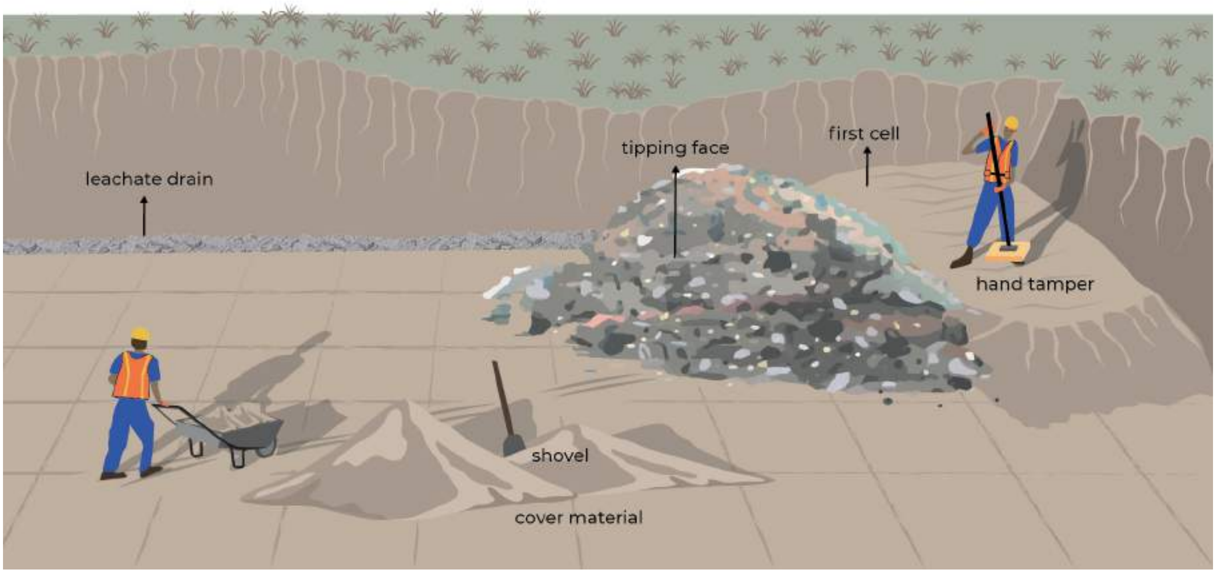


***Figure 10:*** *Manual landfill operation*


*Figure 11: Final compaction and closure of the cell*

To manually handle the waste, some basic equipment is required:

- Spreading the waste: ▢ pick ▢ shovel ▢ fork ▢ rake
- Compacting: ▢ hand tamper (**Figure 12**) ▢ manual roller compactor (**Figure 13**)
- Covering: ▢ shovel ▢ wheelbarrow ▢ iron bar ▢ pickaxe.

A list of the equipment and materials required for a manual landfill operation can be found in **Equipment and materials for manual landfilling operations**.

*Figure 12: Hand tampers for manual landfilling*

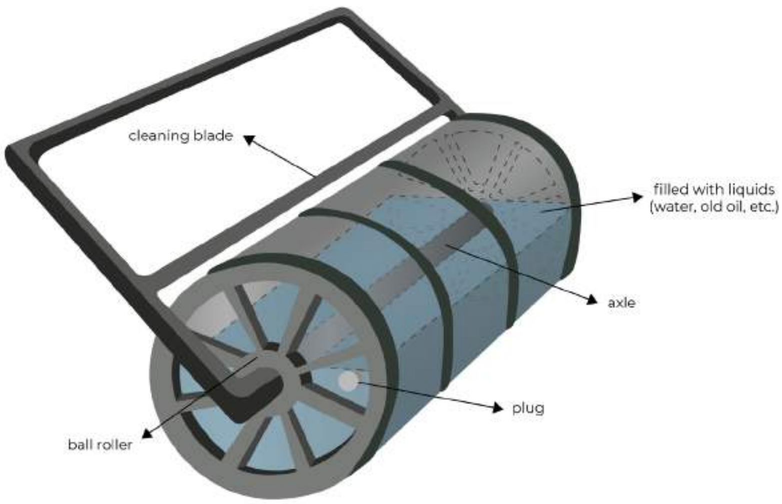


*Figure 13: Manual roller compactor for manual landfilling*

### 3. 4. 2. Mechanised operation

Mechanised landfilling is very similar to a manual landfilling operation, but is used for larger scale landfills and is, therefore, less likely to be implemented in humanitarian contexts. The waste is evenly distributed and compacted with a bulldozer or other kinds of heavy-duty vehicles. The use of a track-type tractor or landfill compactor is recommended. A cost-effective option when resources are limited is to use a 75hp four-wheel-drive tractor equipped with a wide front loader bucket, a rear digging bucket, and a grader attachment. **Figure 14** shows such a tractor with a front-end loader and rear digging bucket – an additional grader attachment could be useful for spreading the waste. Most operations can be handled by this tractor, including digging, making it a good option if a single vehicle can be purchased. However, spreading and compacting are less efficient with this truck as compared to a specialised compactor. For more stability and improved compaction, a vehicle with track chains would be an optimal solution (**Figure 15**). Note that this type of vehicle is necessary for excavation work at the site (**chapter 2.2**) or preparation of the bottom liner (**chapter 4.6**).


***Figure 14:*** *Tractor with front-end loader and rear digging bucket* ***(photo credit: Farming Base, n.d.)***

***Figure 15:*** *Landfill preparation in Cox's Bazar: excavator preparing the clay bottom liner* ***(photo credit: UNDP)***

## 3. 5. Building the disposal site upwards

Layers of waste are constructed on top of each other (**Figure 4**) and making the layers stable is critical. To allow for the landfill to reach heights of 3 to 6 m, the waste should be well compacted and covered, leachate and rainwater controlled, and outer slopes well designed with a ratio of 1 to 3 vertical to horizontal, as shown in **Figure 6** or to have reinforced outer slopes with retention embankments, as shown in **Figure 16**. These embankments can be constructed with compacted soil and/or with stacked old tires filled with soil. Berms further support the stability of the slopes and can be planned every 3-4 m of landfill height and can be 1.5–2 m in width, as shown in **Figure 8**.

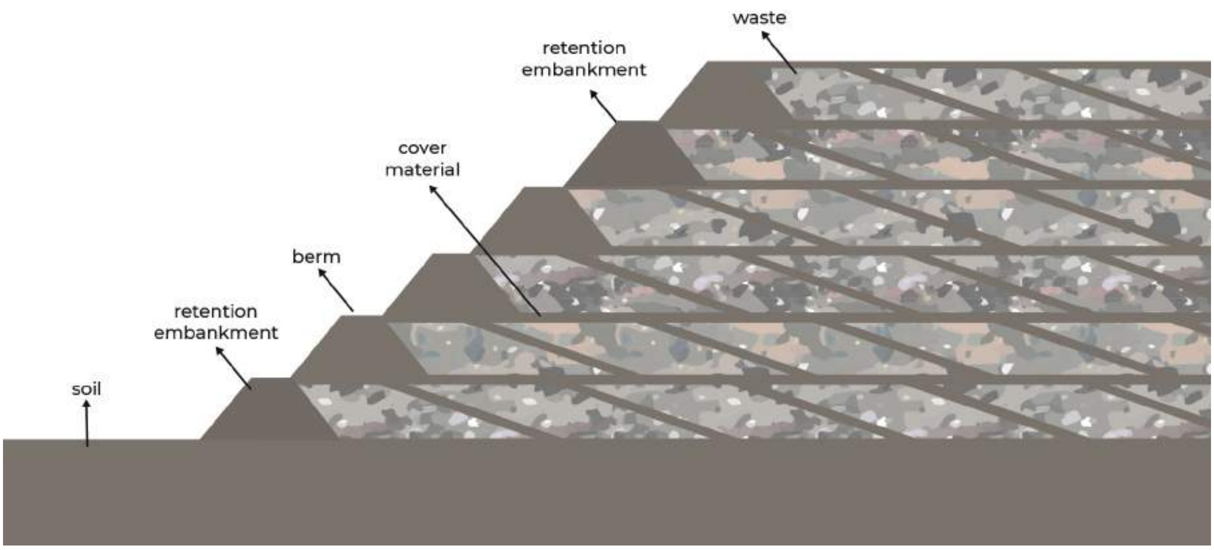


***Figure 16:*** *Reinforced outer slope* ***(adapted from Colomer-Mendoza, 2013)***

## 3. 6. Staff requirements

### 3. 6. 1. Personnel requirements

According to the Rushbrook et al. (1999), up to 50 tonnes of waste per day can be managed through manual landfilling. This is equivalent to a population of about 100'000 persons, with a daily per capita generation of 0.5 kg/person/day. **Table 4** shows the number of labourers required for manual operation of a landfill.

For a mechanised operation, much less labour is required as spreading, compacting and covering can be done with a vehicle operated by one person.

***Table 4:*** *Suggested number of labourers for a manual landfill (adapted from Jaramillo, 2003)*

| Tons of waste [ton/day] | Volume of waste [m³/day] | # of labourers |
|---|---|---|
| 2.5 | 7.5 | 2 |
| 5 | 15 | 3 |
| 10 | 30 | 4 |
| 25 | 75 | 10 |
| 50 | 150 | 19 |

**Staff at the site**

*It is recommended to assign a site manager who will oversee the proper planning and operation of the waste disposal. A minimum of two labourers are needed for daily tasks.*

### 3. 6. 2. Personal protective equipment

For the operation of a landfill, all the staff should have personal protective equipment (PPE). This includes thick and long clothing, impermeable and resistant gloves, steel-toed and/or steel mid-sole impermeable boots, goggles, particle face masks and hard hats. Especially for manually operated landfills, the equipment should be of high quality as the workers will work closely with the waste, and on top of it. Note that face masks only protect against dust and large particles; they do not offer protection against the vapours, gas or liquids that might also be present. For full protection, consider using masks with filters for gas and vapours. You can find a PPE checklist in **Annex 7 - Equipment and materials for manual landfilling operations**.

#### 3. 6. 3. Staff facilities and safety

For the staff to work in proper conditions, there is a need for the following facilities:

- Changing rooms with bathing space
- Washing and drying facilities
- Toilet
- Handwashing stations that always have soap available
- A clean place for breaks and lunch

All landfill staff should get relevant vaccinations. Typically, immunisations are required for hepatitis A, hepatitis B, polio, tetanus, diphtheria, and typhoid. Local health professionals should be consulted about the immunisation requirements. Regular health check-ups are recommended to ensure that the health of the staff is not overly affected by the work conditions and that the protection measures are working.

# 4. How to further reduce impact

Along with proper operations at the disposal site (**Chapter 3**), further impact reduction measures can be implemented as listed in **Table 3**.

## 4. 1. Access control and fencing

The landfill site should be fenced and controlled at the entrance gate to stop unwanted access and to control what type of waste enters the landfill. It is important to ensure that the placement plan is followed and that the waste is deposited at the tipping face. Visual inspection and registration of the waste ensure that the type of waste delivered is suitable for disposal at the location (e.g. to avoid the disposal of hazardous waste). Access should not be permitted outside of the hours of operation. The operations manager should control and record what waste enters the site and the amounts.

The scavenging of recyclable and other materials at the disposal site should be regulated. Totally forbidding informal recyclers from having access to the site could be a solution, but this would eliminate their income. Regulations could be implemented that support the recovery of materials and to improve their working conditions. For instance, the following support can be provided: donating personal protective equipment (PPE) to the informal recyclers, helping them access recyclable materials at an earlier stage of waste disposal (e.g. via source segregation), occupational health training, and integrating the informal sector into the collection system by formalising their activities.

**Waste adequacy control**

*Not all types of waste are suitable to be disposed of at waste disposal sites. Hazardous or infectious waste should be managed through a dedicated facility or there should be a dedicated space at the landfill for this waste that is properly engineered with higher levels of control. Construction and demolition waste should not be disposed of as common waste, but rather could be used as cover material, if not hazardous.*

## 4. 2. Trapping windblown waste

The disposal site should be fenced to stop unauthorised access and capture windblown waste. There could also be a planted/green buffer that serves as a visual and safety barrier to catch any waste that might be blown away from the site. **Figure 17** shows an example of a fenced disposal site, which should be high enough (> 2m) to capture the waste. Another option to control windblown litter is to build a portable litter screen that can be moved and oriented to stop materials at the tipping face from being blown by the wind. The screens could be made with local materials; however, they need to be heavy enough or temporarily secured to the ground so that they are not blown away and cause damage, especially during extreme weather events.

***Figure 17:*** *Fence to stop windblown waste from getting out of the disposal site* ***(Quins, n.d.)***

## 4. 3. Rainwater management

Rainwater should be managed according to these two principles:

- Limit entrance of clean rainwater into the disposal site by diverting it uphill
- Collect and contain or treat contaminated rainwater runoff

Rainwater runoff from areas uphill to the disposal site should be collected with peripheral drains before it can enter the landfill and then discharged into the environment. These drains can be excavated ditches or made from concrete or other materials (e.g. bamboo and rope). **Figure 18** and **Figure 20** show how a simple peripheral drain can divert rainwater from entering a landfill cell filled with waste. The goal of operation and maintenance is to ensure that the drains operate as planned. Regularly cleaning the drains is required to prevent rainwater runoff from entering the landfill.

Rainwater runoff from the disposal site slopes might be contaminated and should be collected and treated. This can be done together with the leachate generated at the disposal site. For this purpose, **Figure 20** shows a toe drain built to collect runoff water from the disposal site slopes and to transport it to the collection sump.

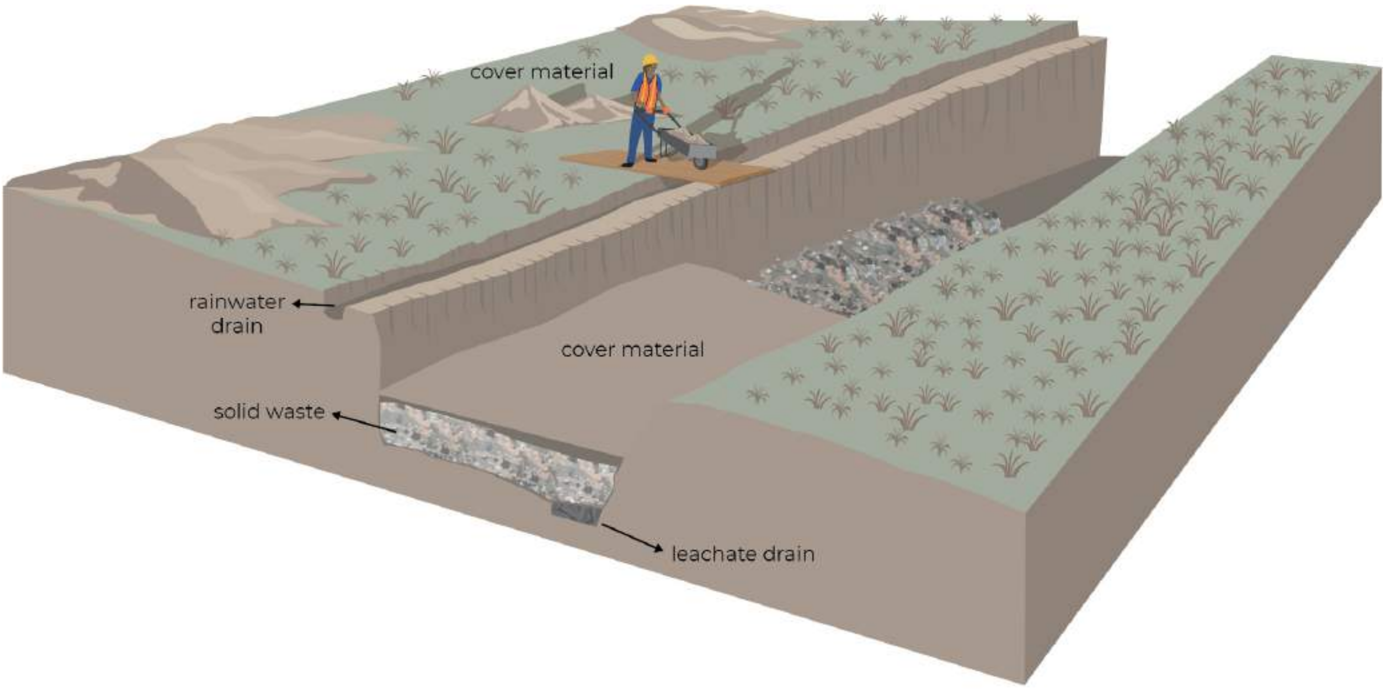


***Figure 18:*** *A trench with a peripheral rainwater drain*

## 4. 4. Leachate management

To manage the leachate, a drainage system should be constructed to extract it from the landfill and direct it towards proper containment and treatment. The drains to collect leachate can be implemented as shown in **Figure 19**, in the form of trenches with a 30x30 – 40x40 cm section filled with stones having diameters between 5 to 15 cm. Polypropylene sacks or other resistant permeable bags should be used to cover the drain; this will allow for leachate infiltration and block the silting of particles. The stones permit the leachate to flow and help to maintain the drain shape when waste is added on top. For larger disposal sites and if resources are available, the drains could be constructed with perforated concrete pipes covered with stones. This would ensure that the drains keep their shape and function for a longer period of time (see right picture of **Figure 2**).

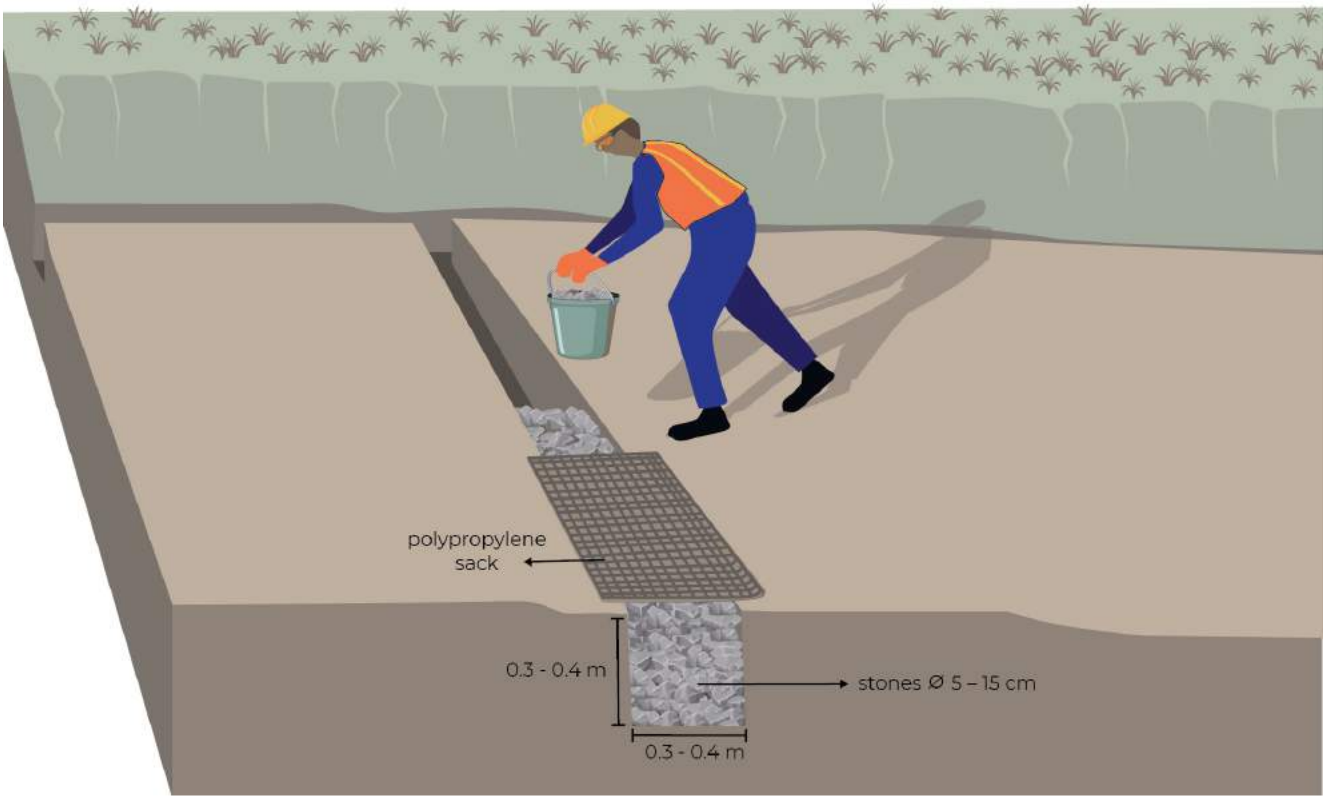


***Figure 19:*** *Construction of internal drainage*

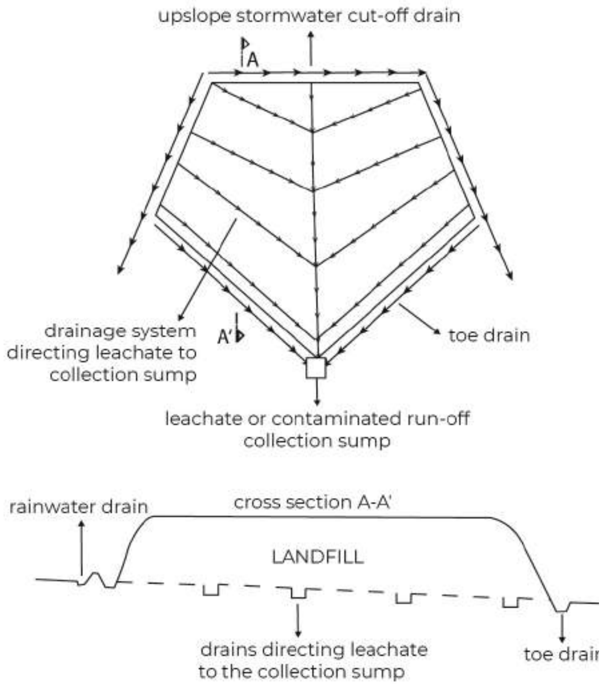


***Figure 20:*** *Leachate drainage system*

***(source: DWAF South Africa, 1998)***

The drainage network should have a slope of 2-3% so that the leachate is directed to the collection sump. **Figure 20** shows how such a network could cover the entire landfill area. The network can be constructed in parts and does not have to be entirely prepared before starting operations at the landfill. Branches can be added after the landfill is in operation. To allow for better collection of the leachate and extraction through the drains, the base of the landfill should have a slight slope (2-3%) as shown on **Figure 8** and **Figure 20**.

Treatment of leachate can be complex. Thus, typical management consists of simple containment, recirculation and evaporation. **Figure 2** shows a collection pond with an impermeable liner where the leachate is contained and evaporates. Pumping the leachate back into the disposal site can be necessary if leachate production exceeds the pond capacity.

Simple infiltration trenches can be constructed at sites where there is a low risk of contaminating the groundwater (**Figure 22**). The leachate drainage system is connected to these infiltration trenches where leachate is stored and can infiltrate into the ground. New infiltration trenches can be constructed if required and should receive regular maintenance so that there are not uncontrolled discharges into the environment. Sediment needs to be regularly removed from the trenches to limit clogging.

For more details on leachate management, refer to Johannessen, 1999b (2).

***Figure 21:*** *Leachate collection pond with an impermeable liner*

***(credit: iStock joruba)***

***Figure 22:*** *Infiltration trench*

***(Deer Lake Conservancy, n.d.)***

## 4. 5. Gas management

Another component of sanitary landfilling is the venting of the gas produced from the decomposing waste. Vent columns can be made from coarse materials that allow for the gas to escape and prevent accumulation inside the waste piles. They should be distributed throughout the disposal site at a distance of 30-50 m from each other. The base of the vents should be prepared before waste depositing begins and should preferably be connected to the leachate drainage system as shown in **Figure 6** and **Figure 8**. The gas generated in the landfill will travel through the leachate drainage system and evacuated through the gas vents. This will allow for more air to circulate in the landfill and promote semi-aerobic conditions for waste degradation (see **Annex 8 - Landfilling processes**).

**Figure 23** shows how the gas vent can be constructed. Metal or plastic drums can be used to build the column and are filled with stones having diameters of 5 to 15 cm. The drum has to be extracted progressively as the waste layers rise. The entire venting column will be raised during the operational phase, together with the layers of waste. A perforated concrete pipe can be added at the centre of the column to reinforce the structure.

All sites will produce different amounts of methane, depending on the landfill conditions and the amounts of disposed organic waste. At small sites, methane could be left to escape into the environment. Nonetheless, the impact of such gas on climate change should be considered. At bigger sites, the methane generated will be more significant and should be properly managed. This should be done not only due to the greenhouse gas potential of methane, but also to limit the risks of methane accumulating inside the disposal site and causing fires and/or even explosions. The collected gas can be flared to reduce its impact on the environment. For more information about gas management, refer to Johannessen, 1999b (1).


***Figure 23:*** *Gas vent construction*

**Methane emissions**

*Methane emissions mostly come from organic waste and from leachate that decomposes anaerobically. Not permitting organics in the landfill reduces problematic gas emissions and allows for longer landfill lifetimes by saving space. In order to achieve that, source separation of organic waste for productive use (for example, composting) are needed.*

## 4. 6. Impermeable liner

An impermeable liner can block the infiltration of contaminated leachate into the soil and groundwater. Several kinds of materials can be used to make the base of the disposal site impermeable: a compacted clay liner or a geomembrane or geosynthetic clay liner. The liner can be made from a single material or a combination of materials. The choice of the liner to use is based on the protection level requirements (permeability), the budget, and the materials, skills and construction equipment available. Geomembrane and geosynthetic materials are expensive and might not be readily available in the country of operation. Furthermore, installing such membranes is highly technical as they are fragile and useless when there are holes in them. They offer the best protection, but require perfect technical execution to install and operate.

Another option to limit leachate infiltration is to use a compacted clay liner. Depending on the local regulations, its recommended thickness should be 50 to 200 cm. The thickness depends on the level of control wanted, the local ground permeability and the compaction rate achievable. Several clay layers (25 cm) are usually compacted one after the other to maximise compaction. Consult with a local hydrogeologist about the recommended thickness at the selected site, as the permeability of the liner should be calculated and evaluated according to the level of protection needed. Compacted clay liners should always be kept wet, starting from the moment they are prepared, until they are covered with disposed waste. Clay cracks easily when very dry and leachate could then infiltrate through these cracks directly to the ground underneath.

Remember that if an impermeable liner is constructed, it is essential that the leachate is also well managed; it should be collected and contained (and treated). Otherwise, accumulation and high hydraulic pressure on top of the liner could cause the leachate to penetrate the liner. Additionally, the waste could become extremely unstable, making it difficult for trucks to transit on the site and might cause them to slide. For more details about liners, see page 10 of Johannessen, 1999b (2). **Figure 15** shows an example of the operations required to prepare the landfill macro unit with a compacted clay liner.

## 4. 7. Monitoring water quality

Because the impact on groundwater could be significant, monitoring the water quality is critical, especially if the groundwater is used or it is planned to use it for human activities. The monitoring needs to be planned with a local hydrogeologist or relevant expert and according to national legislation on disposal sites. **Figure 24** illustrates the location of key monitoring points. The principle is to monitor the water quality both upgradient (Well A) and downgradient (Wells B and C) from the landfill to assess the impact of the landfill on the water quality. The depth of the well will depend on the depth of the water table. If surface water is present, measurements are also recommended upstream and downstream from the landfill to allow for monitoring of the impact of the landfill over time. If water contamination is detected, measures should be taken, particularly if the water is intended for human use.

The following typical pollution factors are usually monitored in developed contexts: colour, turbidity, pH, conductivity, total dissolved solids, solid residue, total suspended matter, BOD5, COD, ammonium nitrogen, nitrite, nitrate, Kjeldahl nitrogen, chlorides, sulphates, sulphites, total phosphor, heavy metals (chromium, copper, lead, zinc, nickel, cadmium, and mercury) and petroleum extract (Koda, 2004). If not all parameters can be monitored given operational constraints, it is recommended to identify and monitor certain key parameters with a hydrogeologist or expert. They can also help to decide and indicate the location and depth of the monitoring wells.

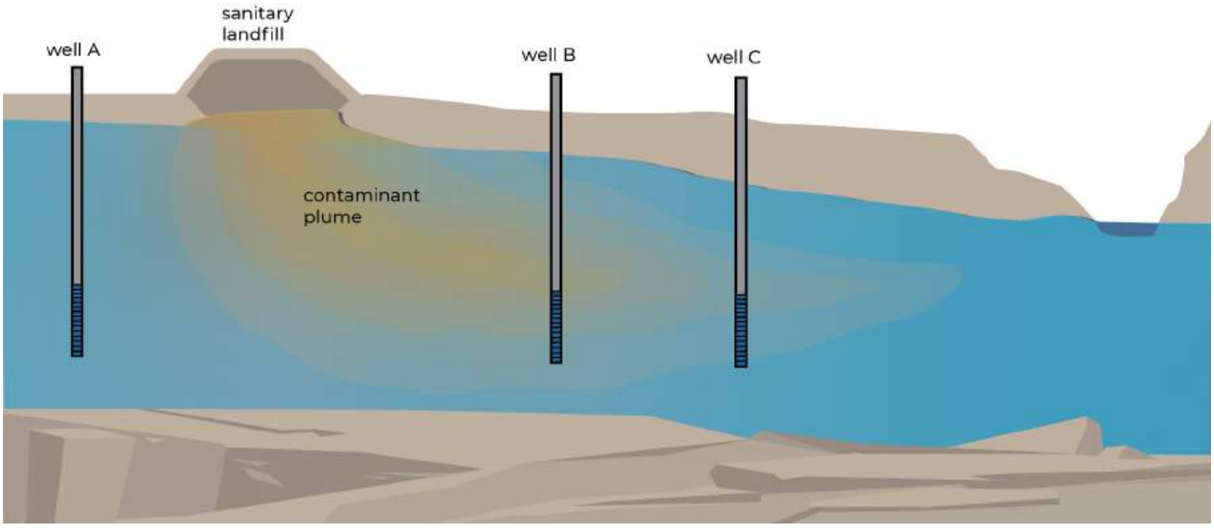


***Figure 24:*** *Location of water monitoring wells*

# 5. How to close a disposal site

To close a disposal site, the top layer should be covered with 50 cm of cover material, with a slope of 2-3% (Jaramillo, 2003; Cointreau, 1996) to minimise infiltration. Planting of grass or other vegetation is recommended to limit erosion and to lessen water infiltration through evapotranspiration. Vegetation also improves the landscape and reduces the visual impact of a closed site. It is, however, not recommended to plant edible crops.

The impact of the landfill on groundwater and downhill surface water should be regularly monitored after the closure of the site and leachate management and rainwater diversion should continue. Leachate will continue to be produced due to the decomposition of the waste and the infiltration of rainwater. Storage and treatment facilities should also continue to operate.

Gas management should also continue after the closure of a site. There can be active production of gas up to 20 years after closure Johannessen, 1999a (1).

Repurposing options for the land are limited. The surface of a closed landfill can be repurposed into a park or football pitch, but these sites still have to be regularly controlled. There should be regular monitoring of gas at the surface, as well as of the quality of the soil, to protect the users of the repurposed landfill. If a high level of control cannot be guaranteed, repurposing is not recommended, and the site should just be closed and covered with vegetation. In any case, any repurposing project requires doing a full risk assessment.

# 6. References and additional resources


**Cited**

Cointreau S. (1996). Sanitary landfill design and siting criteria. The World Bank. PDF

Department of Water Affairs and Forestry South Africa () (1998). Minimum Requirements for Waste Disposal by Landfill. Second Edition. PDF

EPA (1993). Criteria for Solid Waste Disposal Facility: A Guide for Owners/Operators. PDF

Flintoff, F. (1976). Management of Solid Wastes in Developing Countries. South-East Asia Series No.1, Edited by WHO Regional Publications: World Health Organization. PDF

IPT - CEMPRE (2018). Lixo municipal: manual de gerenciamento integrado 4. ed. – São Paulo. PDF

Jaramillo, J. (2003). Guidelines for the design, construction and operation of manual sanitary landfills. PDF

Johannessen, L.M. (1999a) (1). Guidance Note on Recuperation of Landfill Gas from Municipal Solid Waste Landfills. PDF

Johannessen, L.M. (1999b) (2). Guidance Note on Leachate Management for Municipal Solid Waste Landfills. PDF

Koda, Eugeniusz. (2004). Local water quality monitoring on surroundings of the sanitary landfill. Annals of Warsaw University of Life Sciences - SGGW Land Reclamation. 35a. 229-236. PDF

Rushbrook, P., Pugh, M. (1999). Solid waste landfills in middle and lower-income countries a technical guide to planning, design, and operation. The World Bank.

UNEP (2007). E-Waste Volume II: E-waste Management Manual. PDF

UN-Habitat (2021). Waste Wise Cities Tool. PDF

UNHCR (2015). Landfill infrastructure assessment form.

Wasteaid (2017a) (1). Making Waste Work: A Toolkit – How to collect waste safely and efficiently. PDF

Wasteaid (2017b) (2). Making Waste Work: A Toolkit – Community Waste Management in Low and Middle Income Countries. PDF

Wasteaid (2017c) (3). Making Waste Work: A Toolkit – How to measure your waste. PDF

World Health Organization (2014). Safe management of wastes from healthcare activities 2nd edition. PDF

World Vision (2019). Solid Waste Management in Refugee Camps in Jordan. World Vision Policy Paper. PDF

Zabaleta I. et al. (2020). Selecting Organic Waste Treatment Technologies. SOWATT. Eawag - Swiss Federal Institute of Aquatic Science and Technology: Dübendorf, Switzerland, p 235. PDF

**Not cited – but useful further readings**

Davis, J. (2002).Engineering in emergencies: a practical guide for relief workers. London : ITDG.

International Organization for Migration (IOM), Norwegian Refugee Council (NRC) and UN Refugee Agency (UNHCR) (2015). Camp Management Toolkit. PDF

Oxfam (2008). Domestic and Refugee Camp Waste Management Collection and Disposal. PDF

UNHCR (2022). Emergency handbook: waste management standards. PDF

World Health Organization (2013). Solid waste management in emergencies. PDF

#### Pictures

Colomer-Mendoza, F. (2013). Influence of the Design on Slope Stability in Solid Waste Landfills. Earth Sciences. 2. 31. 10.11648/j.earth.20130202.12.

Deer Lake Conservancy (n.d.). Website: https://www.dlcwi.org/wp-content/uploads/2020/12/image6-1-rotated.jpeg. Last accessed on 6th September 2023.

Environmental and Lab Services ELS-EG (2018). Website: https://www.els-eg.com/app-single.php?app=150. Last accessed on 5th September 2023.

Farming Base (n.d.), Website: https://farmingbase.com/can-you-put-a-front-end-loader-on-any-tractor/. Last accessed on 5th September 2023.

Paul, J. et al. (2011). Planning, Establishment and Operation of a Waste Management and Ecology Center in Bayawan City, Philippines.

Quins (n.d.). Website: https://quinsports.com.au/wp-content/uploads/2021/06/Landfill-Nets4.jpg. Last accessed on 6th September 2023.

#### Videos

MOOC Video – Municipal Solid Waste Management In Developing Countries – Upgrading a dump site. URL: https://www.youtube.com/watch?v=euFsNxPhVlY

MOOC Video – Municipal Solid Waste Management In Developing Countries – Planning a Waste Generation and Characterization Study. URL: https://www.youtube.com/watch?v=UgnH9C2b4wY

MOOC Video – Municipal Solid Waste Management In Developing Countries – Conducting a Waste Generation and Characterization Study. URL: https://www.youtube.com/watch?v=LgJ6f2dXS9o

MOOC Video – Municipal solid Waste Management In Developing Countries – Waste disposal / Landfill – part 1. URL: https://www.youtube.com/watch?v=D3Yt7XcxXJc

#### Case study

**Cox's Bazar:** UNDP (2022). Use of the Temporary Solid Waste Facility (TSWF) Camp 20ext, Ukhia Upazila, UNDP Solid Waste Management Team in Cox's Bazar, January 2022 (2nd Report) - Bangladesh | PDF

# Annex 1 - Principles of sanitary landfilling

The following basic principles apply to the construction, operation, and maintenance of an engineered sanitary landfill (Jaramillo, 2003):

**Planning and implementation:**

1. Site selection minimising impact and exposure.
2. Proper sizing of the site.
3. Adequate landfill design.
4. Ease of access through roads.
5. Site fenced and gated, access restricted.
6. Runoff water diversion to prevent water flow into the landfill.
7. Impermeable lining at the landfill base to avoid groundwater contamination.

**Operation & maintenance:**

8. Supervision of the daily operation is required to maintain the landfill in optimal condition. The site should be staffed with supervisors and labourers.
9. Waste entry controlled and monitored.
10. Daily operations are planned and properly executed.
11. Slopes are stabilised to avoid stability issues.
12. Daily covering of waste with soil or similar cover material.
13. Compaction of the waste and final compaction with the soil cover.
14. Drainage, control and treatment of leachate and gases to maintain ideal operating conditions.
15. Monitoring of environmental impact.

**Site closure and monitoring:**

16. Final covering of the site with planted vegetation to integrate the closed site into the natural landscape.
17. Monitoring of the environmental impact of the closed site.

For all the phases, supervision is key to ensure that a high standard of operations and control is maintained.

The following video explains important aspects of a sanitary landfill: Waste disposal / Landfills – part 1.

# Annex 2 - Evaluation of the level of control of a disposal site

Evaluating the level of control requires analysing how the site is operated, the conditions of the site and its technical characteristics. One way to do this is to use the decision-making trees on page 70 of the UN-Habitat WaCT: Waste Wise City Tool (UN-Habitat, 2021). Another tool for doing level of control evaluations is shown in **Table 5** below. The service level with the most ticks gives you the current level of control at the site.

Another option for assessing the landfill sanitary status is to use the UNHCR landfill infrastructure assessment form (UNHCR, 2015) to calculate a risk score for the site.

***Table 5:*** *Service level ladder for disposal sites* ***(adapted from Waste Flow Diagram toolkit, based on UN-Habitat, 2021)***

| Service level | Disposal site characteristics |
|---|---|
| 1: None | ☐ No cover<br>☐ No compaction<br>☐ No leachate control<br>☐ No fencing<br>☐ Fire/smoke<br>☐ No equipment or limited equipment |
| 2: Limited | ☐ No cover<br>☐ Some compaction<br>☐ No leachate control<br>☐ Some level of access control/fencing<br>☐ Some fire/smoke<br>☐ Some equipment for compaction<br>☐ Site staffed |
| 3: Controlled | ☐ Some use of cover<br>☐ Waste compacted<br>☐ No leachate control<br>☐ Site fenced and control of access<br>☐ No fire/smoke<br>☐ Sufficient equipment for compaction<br>☐ Site staffed |
| 4: Improved | ☐ Waste periodically covered<br>☐ Waste compacted<br>☐ Leachate collected and contained<br>☐ Site fenced and control of access<br>☐ No fire/smoke<br>☐ Collection of landfill gas<br>☐ Site staffed |
| 5: Full | ☐ Waste covered daily<br>☐ Waste compacted<br>☐ Impermeable liner at base<br>☐ Leachate collected and contained<br>☐ Site fenced and full control of access<br>☐ Properly sited and designed functional landfill site<br>☐ Gas collection and flaring or utilisation<br>☐ Site staffed<br>☐ Post closure plan |

# Annex 3 - Disposal site planning steps and timeline

The table below shows the disposal site planning steps for a new disposal site and a timeline that can be printed and filled out.

| Activity | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 | Month 7 | Month 8 | Month 9 | Month 10 | Month 11 | Month 12 | Year 2 | Year 3 and + |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PREPARATION STEPS** | | | | | | | | | | | | | | |
| Assess waste management needs and start planning and/or improving collection and transportation of solid waste to the disposal site. | | | | | | | | | | | | | | |
| Start an awareness programme for and with the community to ensure that organics and recyclables are managed separately. | | | | | | | | | | | | | | |
| **DISPOSAL SITE LOCATION** | | | | | | | | | | | | | | |
| Evaluation of disposal site size<br>• Conduct a waste characterisation and quantification study<br>• Evaluate the size required | | | | | | | | | | | | | | |
| Identification of potential sites<br>• Consultation with local stakeholders<br>• Consider site selection criteria, including the required disposal site size<br>• Consultation with hydrogeologist: analysis of hydrogeological conditions at the proposed sites | | | | | | | | | | | | | | |

| Activity | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 | Month 7 | Month 8 | Month 9 | Month 10 | Month 11 | Month 12 | Year 2 | Year 3 and + |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Selection of disposal site location<br>• Ensure local stakeholders' approval<br>• Land allocation by the authorities<br>• Topographical survey<br>• Site plan preparation | | | | | | | | | | | | | | |
| **MITIGATION MEASURES** | | | | | | | | | | | | | | |
| Identification of mitigation measures to be implemented<br>• Check the list of key features, risks and mitigation measures<br>• Prioritise mitigation measures to be taken | | | | | | | | | | | | | | |
| **DISPOSAL SITE DESIGN** | | | | | | | | | | | | | | |
| Development of the operational plan<br>• Define the site plan (long-term) and placement plan (short-term) | | | | | | | | | | | | | | |
| **Evaluate the budget** | | | | | | | | | | | | | | |
| **Project presentation to authorities and stakeholders** | | | | | | | | | | | | | | |
| Secure funding and launch of tender<br>• Initial investment in the disposal site, as well as for collection and transport services<br>• Guarantee the funding of operation & maintenance<br>• Launch tender process if relevant | | | | | | | | | | | | | | |

| Activity | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 | Month 7 | Month 8 | Month 9 | Month 10 | Month 11 | Month 12 | Year 2 | Year 3 and + |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Preparation of the land<br>● Cutting and clearing away the vegetation and trees<br>● Preparation of ground surface (ground levelling, compaction, impermeable liner, etc.) | | | | | | | | | | | | | | |
| Peripheral infrastructure<br>● Site access road<br>● Rainwater drainage | | | | | | | | | | | | | | |
| Construction of landfill infrastructure<br>● Internal access roads<br>● Impermeable liner<br>● Leachate drainage, containment, and treatment system<br>● Gas drainage system (and flaring or usage) | | | | | | | | | | | | | | |
| Auxiliary construction<br>● Perimeter fence<br>● Planting a green perimeter barrier<br>● Control building and sanitary facilities<br>● Monitoring wells | | | | | | | | | | | | | | |
| **OPERATION & MAINTENANCE PLANNING** | | | | | | | | | | | | | | |
| **Finalise and validate site plan and placement plan** | | | | | | | | | | | | | | |

| Activity | Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6 | Month 7 | Month 8 | Month 9 | Month 10 | Month 11 | Month 12 | Year 2 | Year 3 and + |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Waste deposit and handling<br>• Establish waste deposit procedures at the tipping face<br>• Define the frequency of covering and compaction | | | | | | | | | | | | | | |
| Staffing<br>• Estimate staff requirements<br>• Ensure minimum occupational health standards | | | | | | | | | | | | | | |
| **Training supervisors and operators** | | | | | | | | | | | | | | |
| **Beginning landfill operations** | | | | | | | | | | | | | | |
| **Operation and maintenance of the landfill** | | | | | | | | | | | | | | |
| **Monitoring and evaluation of the site's functionality** | | | | | | | | | | | | | | |
| **CLOSING A DISPOSAL SITE** | | | | | | | | | | | | | | |
| Closure of dumpsite(s)<br>• Extermination of rodents/pests<br>• Covering with soil and sealing the dumpsite<br>• Install a sign that states that this is a closed dumpsite<br>• Publicly communicate the closure | | | | | | | | | | | | | | |

# Annex 4 - Disposal site size calculations

**The volume or area calculation can be done using the Excel tool that is provided with these guidelines.**

The area requirements requires first calculating the expected population of the current year and upcoming years:

$$\textit{Projected population for year } i\ (P_i) = Pop(1+R)^{N-1} \qquad (1)$$

With Pop as the current population, R the yearly population growth rate in % and N the year number, with the current or first year being year 1. The volume in cubic meters required for each year is then calculated as follows:

$$\textit{Volume compacted waste } V_{compacted} = P_i * PPC_i * 365 / P_c \qquad (2)$$

$$\textit{Volume soil cover } V_{soil} = V_{compacted} * f \qquad (3)$$

$$\textit{Volume stabilized waste } V_{stabilized} = P_i * PPC_i * 365 / P_s \qquad (4)$$

$$\textit{Volume } V = V_{stabilized} + V_{soil} \qquad (5)$$

$PPC_i$ is the waste Production Per Capita per day for year i [kg/cap/day], f the factor for daily soil cover (0.2-0.25), $P_c$ the density of compacted waste: 400-500 kg/m$^3$, and $P_s$ the density of stabilised waste: 500-600 kg/m$^3$. The PPC should include both household waste and non-household waste generated in the camp. The compacted waste density represents the achieved density through manual landfilling compaction and the stabilised waste density is the final density of the waste once decomposed and compacted by the weight of the layers of waste covering it.

The required area is then calculated considering the planned height/depth of the disposed waste and the buffer needed for infrastructure at the site as follows:

$$\textit{Landfill area } (A) = V \cdot (1+buffer) \ / \ \textit{height or depth} \qquad (6)$$

The height/depth depends on the type of disposal site that is planned. For instance, for a flat area, a height of 4 m can be considered for a manual operation. The buffer corresponds to the area required for the entrance infrastructure, the leachate ponds, and the access roads inside the disposal site. A buffer of 25-30% is recommended. The present estimation does not account for the eventual loss of mass of the disposed waste. This hypothesis might lead to an overestimation of the volume required, especially for waste with high organic content. Nonetheless, this possible overestimation is reasonable and, in the worst-case scenario, would lead to a longer lifetime for the landfill.

A calculation example is shown in **Figure 25** for a camp with an initial population of **50'000 refugees**, with an estimated population growth (R) of 5% per year, a constant waste production (PPC) of 0.5 kg/cap/day, a cover material factor f of 20% a compacted waste density (c) of 450 kg/m$^3$, a stabilised waste density (s) of 550 kg/m$^3$, a height of 4 m, a 25% buffer area, and a 10 year estimated lifetime of the disposal site. It is assumed that all the generated waste is landfilled in a manually operated landfill with compaction and coverage of waste. **This results in an 81'163 m$^2$ area, which represent a dimension of 385 m per 385 m for a flat land.**

| Year | Population [cap] (1) | PPC [kg/cap/day] | Total yearly waste [kg/year] | Yearly volume of compacted waste [m3/year] (2) | Yearly volume of cover material [m3/year] (3) | Yearly volume of stabilised waste [m3/year] (4) | Filled volume [m3] (5) | Required area [m2] (6) |
|---|---|---|---|---|---|---|---|---|
| 1 | 50000 | 0.5 | 9,125,000 | 20,278 | 4,056 | 16,591 | 20,646 | 6,452 |
| 2 | 52500 | 0.5 | 9,581,250 | 21,292 | 4,258 | 17,420 | 21,679 | 6,775 |
| 3 | 55125 | 0.5 | 10,060,313 | 22,356 | 4,471 | 18,291 | 22,763 | 7,113 |
| 4 | 57881 | 0.5 | 10,563,328 | 23,474 | 4,695 | 19,206 | 23,901 | 7,469 |
| 5 | 60775 | 0.5 | 11,091,495 | 24,648 | 4,930 | 20,166 | 25,096 | 7,842 |
| 6 | 63814 | 0.5 | 11,646,069 | 25,880 | 5,176 | 21,175 | 26,351 | 8,235 |
| 7 | 67005 | 0.5 | 12,228,373 | 27,174 | 5,435 | 22,233 | 27,668 | 8,646 |
| 8 | 70355 | 0.5 | 12,839,791 | 28,533 | 5,707 | 23,345 | 29,052 | 9,079 |
| 9 | 73873 | 0.5 | 13,481,781 | 29,960 | 5,992 | 24,512 | 30,504 | 9,533 |
| 10 | 77566 | 0.5 | 14,155,870 | 31,457 | 6,291 | 25,738 | 32,029 | 10,009 |
| | | | | | | Total* | 259,689 | 81,153 |

***Figure 25:*** *Size calculation example for a manually operated disposal site*

# Annex 5 - Site selection criteria checklist

The following criteria should be considered when selecting the location of a new site (adapted from Cointreau 1996)); keep in mind, however, that it is almost impossible to fulfil all the criteria. Aim for the best available option and consider implementing mitigation measures for the criteria that are not met.

**Design:**

- [ ] An area sufficient to have a lifetime of at least 10 years (subject to the expected duration of the settlement). See **section 2. 1. 1** for the sizing of a disposal site.
- [ ] Shortest possible distance from where the waste is generated to limit transportation costs.

**Protection of neighbouring living communities:**

- [ ] No residential development within 250 meters from the perimeter. Make this 1 km if the landfill is not well controlled.
- [ ] No visibility of the landfill within 1 km. If residents live within 1 km, landscaping, and other protective measures should be taken (green buffer).

**Protection of surface water and groundwater:**

- [ ] Groundwater table's high level (10 year's high) at least 1.5 meters below the excavation base. If this is not possible, impermeable liners are compulsory to protect the groundwater.
- [ ] A minimum of 1 m of impermeable soil above the groundwater's highest level. Permeability of soil: 10-9 m/s. If these criteria are not met, impermeable clay and/or plastic or bitumen liners should be used to protect the groundwater.
- [ ] Do not locate a site in a groundwater recharge area for existing or pending water supplies.
- [ ] No water supply wells (for drinking, irrigation, or livestock) within 500 meters downgradient of the landfill boundaries.
- [ ] No surface water within 300 m downstream of the landfill.

**Floods:**

- [ ] Do not locate a site in a floodplain subject to 10-year floods. If located within a 10 - 100-year flood area, special measures need to be taken to eliminate the potential of a washout.

**Daily operation:**

- [ ] Availability of cover materials for daily operation, as well as for intermediate and final covers.

**Geology:**

- [ ] No fault lines or significant fractures in the geologic structures within 500 m to avoid unpredictable movements of gas and/or leachate.

**Other important criteria:**

- [ ] No electrical lines or other infrastructure (gas, water or sewers) crossing the landfill, or ensure that no damage can occur or that rerouting is feasible.
- [ ] Do not locate a site within 3 km of an airport to avoid any incident with birds that might be present around the site. It a site is to be located within 8 km from an airport, check with airport authorities for approval.

# Annex 6 - Disposal site operations activities checklist

The following activities are recommended for the operation of a disposal site:

- [ ] Follow and update the long-term disposal site plan if required
- [ ] Plan the short-term disposal of waste (the placement plan)
- [ ] Staff the site for operation
- [ ] Limit the access of unauthorised persons or animals to the site
- [ ] Control and record the waste entering the disposal site
- [ ] Handle the waste daily at the tipping face by:
    - Spreading
    - Compacting
    - Covering
- [ ] Ensure availability of cover material
- [ ] Ensure proper construction of the cells
- [ ] Ensure proper construction of the slopes (outer slopes and base slopes)
- [ ] Clean the site and the surroundings of windblown waste
- [ ] Maintain rainwater peripheral drainage
- [ ] Construct internal rainwater drainage on sealed landfill cells
- [ ] Construct and maintain internal access roads and ramps as the site grows
- [ ] Construct the leachate drainage system as the site grows
- [ ] Maintain the leachate containment or treatment facilities, if existing
- [ ] Construct the gas drainage system as the site grows
- [ ] Monitor groundwater and surface water quality
- [ ] Extinguish fires
- [ ] Maintain and renew equipment when required
- [ ] Ensure proper occupational health conditions for the staff

# Annex 7 - Equipment and materials for manual landfilling operations

For manual operation of a landfill to function well, the following equipment and materials are recommended:

- ☐ Metal gratings or wood planks for internal access roads
- ☐ Mobile fence to capture windblown waste
  - ○ Spreading the waste: ☐ pick ☐ shovel ☐ fork ☐ rake
  - ○ Compacting: ☐ hand tamper ☐ manual roller compactor
  - ○ Covering: ☐ shovel ☐ wheelbarrow ☐ iron bar ☐ pickaxe
- ☐ Stones for the construction of drains and gas vents having diameters of 5 cm to 15 cm.
- ☐ Metal or plastic drums to construct the gas vents (>50 cm diameter)
- ☐ Cover material to cover the waste
- ☐ Used tires (to be used for support ramps or slope construction)
- ☐ Personal protective equipment
  - ○ Thick and long clothing
  - ○ Impermeable and resistant gloves
  - ○ Steel-toed and/or steel mid-sole impermeable boots
  - ○ Goggles
  - ○ Particle face masks (for full protection consider masks with filters for gas and vapours)
  - ○ Hard hat
- ☐ Soap for sanitary facilities and washing stations
- ☐ Running water and electricity
- ☐ If leachate is recirculated, tools for maintenance and pump replacement parts
- ☐ ____________________________________________
- ☐ ____________________________________________
- ☐ ____________________________________________
- ☐ ____________________________________________

This is a non-exhaustive list of materials and equipment for a manual disposal site with a basic level of control. There might be other items useful to manually operate the site. With experience, the site manager will be able to identify if additional items would help in the operation of a site.

# Annex 8 - Landfilling processes

There are three types of sanitary landfilling processes: anaerobic, aerobic, and semi-aerobic (see **Table 6**). These processes mostly influence the generation of leachate and the production of methane gas at landfills. Semi-aerobic landfills are often recommended when limited resources are available, as they do not require complex construction or management. Anaerobic landfills aim to maximise gas production to use it for energy generation. Because managing gas is a very complex task and requires a fully engineered landfill, it is recommended to try to limit the generation of gas at simple disposal sites. Aerobic landfilling requires a lot of energy because air must be continuously pumped into the landfill through a piped network. These guidelines recommend a semi-aerobic process and to limit organic waste into the disposal site if possible, and promote natural ventilation and aeration of the waste through the gas vents and leachate drainage system to limit methane generation.

***Table 6:*** *Landfilling processes and description*

| Landfilling process | Disposal site characteristics |
|---|---|
| **Anaerobic** | **Pro:** this method maximises biogas generation from the decomposition of organic waste. Gas is collected and used for energy production or flaring. This is the most common method.<br><br>**Con:** unfortunately, methane gas is rarely flared or collected, contributing to greenhouse gas emissions and climate change when it escapes landfills that do not have proper gas management. |
| **Aerobic** | **Pro:** this method limits the anaerobic conditions by continuously introducing air into the landfilled waste to promote aerobic conditions. Organic waste degrades as a result and there is a low production of methane.<br><br>**Con:** this method is energy and cost intensive and requires equipment and a piping system to pump air into the landfill. |
| **Semi-aerobic** | **Pro:** this method passively aerates the waste to promote aerobic conditions and limit methane generation. Aeration is done through the drainage and venting systems. Large diameter drainage pipes allow for both leachate and air to circulate. The drainage systems for leachate and gas are connected to permit the better circulation of air flows.<br><br>**Con:** anaerobic conditions still occur and methane is produced, which is often not properly managed. |

# ACKNOWLEDGEMENTS

## Authorship

These guidelines have been developed by the Swiss Federal Institute of Aquatic Science and Technology (Eawag) in collaboration with the Geneva Technical Hub, embedded in UNHCR's Technical Support Section.

**Authors:** Dorian Tosi Robinson, Sara Ubbiali, Adeline Mertenat, Christian Zurbrügg (Eawag)

**Contributors:** Philippe Reymond, Emmett Kearney, Fidelis Folifac, Manuel Krähenbühl (UNHCR)

## Proofreading

Paul Donahue

## Technical drawings

The figures presented in these guidelines are adapted from Jaramillo (2013), unless otherwise stated.
The adaptation has been made by Sandra Ilie

## Layout

Nur Alam Shanto

## Funding

The Geneva Technical Hub and the backstopping mandate by Eawag are funded by the Swiss Agency for Cooperation and Development (SDC).



## CONTACTS

**Christian Zurbrügg**, Group leader Solid Waste Management at Eawag-Sandec:
info@sandec.ch

**Contact at UNHCR DRS TSS**:
hqsl00@unhcr.org


## LINKS

- UNHCR WASH
- Geneva Technical Hub


Cover Picture by Dorian Tosi Robinson, Eawag

**First edition, March 2024.**




GENEVA TECHNICAL HUB

Co-convened by

UNHCR The UN Refugee Agency

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

eawag aquatic research