6 Waste disposal

6.1 Background

Waste management term has been widely accepted as a sum of measures and solutions for waste avoidance, treatment, recovery, reuse and least but not last, final disposal with consideration to ecological and economical aspects.[1] However, waste disposal to controlled landfills should only be a final option, adopted when further treatment of waste is neither economically nor technically possible [Bilitewski et al., 1994]. Unfortunately, uncontrolled waste dumping on the land is the first option for many regions in Asian continent due to very low costs. Over years, this was leading to two main problems: 1) dumped waste has generated liquid and gaseous emissions making the area out of use, and 2) dump sites rapidly became a breeding and hosting place for large amounts of disease-bearing organisms, posing a high threat to humans' health and safety living nearby the respective areas, and as well for the surrounding environment. Nevertheless, carefully managed sanitary landfills should replace the open dumps to significantly reduce the contact between the waste and the environment by concentrating the waste in a well defined and managed area [UNEP, 2005].

Educational objective of the chapter

The present chapter will offer information on construction and managing of landfills such as basic principles, site requirements, as well as technical construction and operation advices.

6.2 Basic principles

6.2.1 Definitions and planning

6.2.1.1 Definitions

An overall definition of a "sanitary landfill" is not simple since this depends a lot on the level of development of the regarded country. Nevertheless, the differences mostly lie on the degree of isolation the respective disposal site offers for the separation of the disposed waste and the surrounding environment. Since this is a very sensitive issue also in many developed countries, not the same requirements are feasible for a developing country.

In order to qualify as a sanitary landfill, a disposal site must meet the following three basic conditions [UNEP, 2005]:

- Disposed waste must be properly compacted;
- The waste has to be properly covered for a good separation from the surroundings;
- High control and prevention of the negative impact given by odours, contaminated waters etc. resulted from the construction and operation of the landfill

The level of accomplishment of these three requirements is different for developing countries compared with developed ones. While the long-term goal must be the filling all three conditions, the last one should be the most important with disregard to the level of development.

<u>Classifications</u>
In addition to the above mentioned criteria, the landfills can be classified by the technical level accomplished, by the type of waste deposited and by processes occurring during the exploitation.

By technical level achieved, in landfill classification system in Germany comprises four levels (see also Table 6.2-1), ordered as following [TETRAWAMA, 2002]:

- Level 1 - Controlled tipping
- Level 2 - Sanitary landfill with a bund and daily cover soil
- Level 3 - Sanitary landfill with leachate circulation
- Level 4 - Sanitary landfill with leachate treatment

[1] Chapter based mostly on two following sources: Bilitewski et al., 1994; UNEP, 2005 – Vol. I + II and TETRAWAMA, 2002

Table 6.2-1 Levels of sanitary landfills [TETRAWAMA, 2002]

Item	Level 1	Level 2	Level 3	Level 4
Soil cover	✓	✓✓	✓✓	✓✓
Embankment	-	✓✓	✓✓	✓✓
Drain facility	-	✓✓	✓✓	✓✓
Gas venting	-	✓✓	✓✓	✓✓
Leachate collection	-	-	✓✓	✓✓
Leachate re-circulation	-	-	✓✓	✓✓
Leachate treatment	-	-	-	✓✓
Liner	-	-	-	✓✓

By the type of deposited waste, the federal waste disposal regulation [BMU, 2002] defines the following landfill classes:

- Class 0 - Inert waste
- Class I - Quite inert municipal waste
- Class II - Municipal waste
- Class III - Hazardous waste
- Class IV - Underground disposal site

By type of processes occurring, the waste decomposition due to biological processes plays a major role in landfills' classification and indicates a different approach for aerobic and anaerobic operating landfills (see also chapter 6.2.1.5). Because the biological content of municipal waste is expected to generally be higher in Asia than in Europe, the biological processes are considered of an extreme importance, suggesting the following types for Asian landfills [TETRAWAMA, 2002]:

- Anaerobic landfill
- Anaerobic landfill with daily cover
- Improved anaerobic sanitary landfill with buried leachate collection pipes
- Semi-anaerobic landfill with natural ventilation and leachate collection
- Aerobic landfill with forced aeration

6.2.1.2 Planning

Planning of a sanitary landfill should always be done starting from the assumption that reduction and recycling of waste designated to be disposed have a higher priority. If further handling of waste is not possible anymore, only then the interested party should start collecting following types of information [UNEP, 2005]:

- Type of waste to be disposed
- Amounts generated
- Waste generation rates
- Characteristics of the waste

Besides the above mentioned information, important criteria have to be evaluated regarding the requirements for the site proposed to host a sanitary landfill (this will be further discussed in the paragraph 6.2.3). The Figure 6.2-1 offers a preliminary overview on the basic aspects of a sanitary landfill layout and its components:

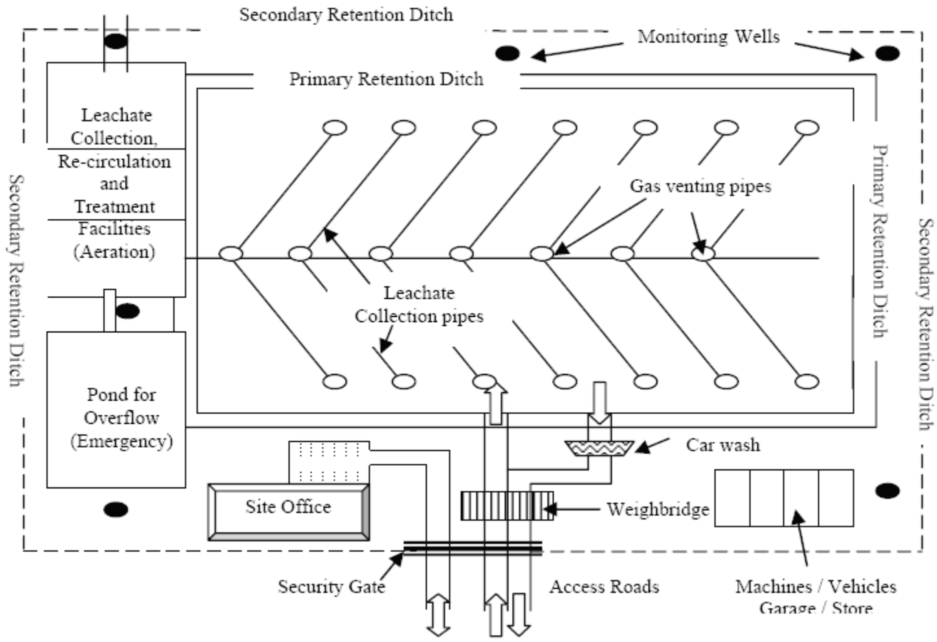

Figure 6.2-1 Schematic diagram of basic aspects of a sanitary landfill layout [TETRAWAMA, 2006]

Processes occurring in a sanitary landfill

When decision to start constructing a sanitary landfill is taken, one has to keep in mind that the waste disposed is not an inert material but it is exposed to a mixture of physical, chemical and biological processes [UNEP, 2005]. Depending on type of waste disposed, amounts and generation rates, and also waste characteristics, the involved processes can largely vary but they can be summarized as follows:

6.2.1.3 Physical processes

Basically, the waste disposed in a sanitary landfill is exposed to a broad form of mechanical-physical processes during the regular operation time of the landfill:

Compaction
The physical compression of the waste has the purpose of reduction the volume of waste deposited, as well as a better stabilisation of landfill slopes (see also chapter 5.6.1.7). This can be achieved with special designed landfill compacting machinery, as seen in Figure 6.2-2:

Figure 6.2-2 Various types of landfill compactors[2]

Dissolution
The amount of water present in the disposed waste represents the key factor for the dissolution of soluble substances and their transport.

Sorption
One important aim of a sanitary landfill is the immobilization of substances that could pose a risk to the environment. This can be achieved also with the aid of sorption processes occurring in the body of the landfill, which is directly dependent on the composition of the disposed waste.

[2] Sources: www.cityofglasgow.org (image left) and www.letsrecycle.com (image right)

6.2.1.4 Chemical processes

Reactions with oxygen

Although limited, oxidation processes still occur in a sanitary landfill, being linked with the presence of trapped oxygen (for more information about oxidation-reduction reactions, see also chapter 5.6.2.4).

Reactions with organic acids and carbon dioxide

This is the second major class of reactions occurring, involving the organic acids and CO_2 resulted from the biological processes.

6.2.1.5 Biological processes

The biological processes can be regarded as most important processes in a landfill management due to the following reasons [UNEP, 2005]:

- The organic fraction of the deposited waste is biologically rendered inert and thus does not pose further problems;
- Transformation of an important part of the organic fraction into gaseous form with the aid of microorganisms leads to an important reduction in the overall volume occupied by the organic waste.

Another important aspect regarding the biodegradable organic fraction of the deposited waste is the assumption that lies at the base of the landfill management: on the landfill should be brought only waste whose further treatment cannot be economically or technically feasible. Since the organic fraction represents a key issue in the biological treatment of waste, final disposal to the landfill should be chosen only after carefully studying the respective alternatives (see more details on the process of biological treatment of waste see also the chapter 5.5).

☞ Please note:

> Biological processes governing the decomposition of the organic fraction of waste play an important role especially in tropical regions, where they form a high percentage of the dumped waste. Since the activity of most microorganisms improves with the increase of the temperature, it is expected a shorter operational time until the waste in a sanitary landfill become biologically inert, e.g. the landfill becomes “completed”. This conducts to a faster rehabilitation of the site occupied by the landfill and allows the allocation of a further use (recreational, agriculture, construction etc.)

Decomposition of the biodegradable organic fraction in a landfill can be done either aerobic or anaerobic, depending on the oxygen trapped inside the landfill and the time the microorganisms need to break down the organic compounds by using this ready available oxygen.

Aerobic decomposition

This decomposition occurs very fast, mostly at the beginning of the landfill operation and has a relatively short duration, until all the trapped oxygen has been consumed by the demanding microorganisms. The effect of the aerobic decomposition on the overall environmental impact is minimal since most of the ultimate end products resulted is carbon dioxide and water.

Anaerobic decomposition

When all available oxygen has been depleted, the decomposition turns to an anaerobic breakdown. On a general scale, this is most important biological process because if left uncontrolled, it leads to important negative impacts to the environment. This are expressed as end products of reaction and can be found mostly in the form of volatile organic acids. In reaction with other substances, the organic acids can form more dangerous compounds, serving also as substrate for the methane producing microbes [UNEP, 2005]. The resulting gases are methane (CH_4) and CO_2, but also traces of hydrogen sulphide (H_2S), hydrogen (H_2) and nitrogen (N_2). The management of the landfill gases will be presented more in detail in chapter 6.3.1.9).

6.2.2 Waste characterization

6.2.2.1 Waste type

The type of waste accepted to the landfill should be decided by the landfill operator together to the regional or national environmental institutions and it should be based on surveys regarding the large waste generators in the respective area [UNEP, 2005]. Usually, sanitary landfills should accept for disposal waste from residential, commercial and industrial sources. Among them, the municipal solid waste will probably count for the highest percentage, while liquid waste or waste with high water content should be treated prior to disposal to a landfill (for solidification technologies, see chapter 5.6.2.3). Nevertheless, many types of industrial waste should be classified as “not acceptable” for sanitary landfills and should be disposed to special designed landfills [UNEP, 2005].

☞ Please note:

Among “not acceptable” waste, a special concern should be paid for hazardous waste (see chapter 4.6) or waste coming from hospitals and medical units (the so called “special waste”), both of them having to be specially handled.

6.2.2.2 Waste quantity and composition

For a good planning of a sanitary landfill, representative statistical data on waste quantity generated and its composition are needed. These design parameters are linked with the level of development of the local community, with the demographic predictions and also with climatic and geographic factors. Unfortunately, for most situations this is a difficult aim since the waste generation and composition varies significantly from country to country and from one area to another, thus it is not always possible to use much of the available data. Detailed and expensive studies have to be performed for a proper characterization of waste properties (see chapter 3 for more details).

6.2.3 Site requirements for landfills

Several factors linked to the selection of the “best site” have to be carefully analysed when building a sanitary landfill in order to assure a minimisation of the negative impact to the environment, especially to groundwater and surface water resources, and human life and habitation. These factors will be described on the following paragraphs.

6.2.3.1 Site selection

The selection of the best suitable site for building a sanitary landfill is a difficult matter since this will have many implications over years on the regional development of the respective area. Prognosis of various kinds have to be made, such as for demographic growth, growth of inhabited areas over time or waste generation rates and compositions. For the densely populated areas it may intervene also the problem of the ownership of the land and impacts on the surrounding environment.

One of the first calculations that have to be done when selecting the site is the duration in years of landfill operation. In general it is recommended to consider a life span of ten years [UNEP, 2005] but the decision has to take in consideration that the capital investment has to be recovered. Therefore, the useful life span of the area has to be calculated according to the local conditions and based on parameters like depth of fill, quantity of waste to be disposed, the delivery rate and it composition [UNEP, 2005]. Also the adjacent works related to the landfill have to be included, like access roads, buildings and others.

Empirical equations are available for calculation of the useful life of a sanitary landfill based on the volume of the selected site, on the quantity of waste disposed and on quantity of cover material (see UNEP, 2005, page 333). Various diagrams can further help on estimating the necessary surface area for the built land as function of the population served by the landfill and the degree of waste compaction (Figure 6.2-3) or the landfill volume required as function of waste bulk density and amounts delivered (Figure 6.2-4):

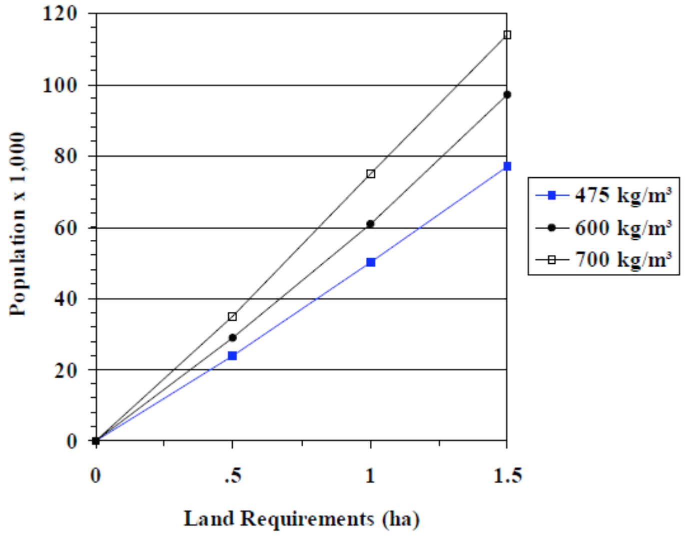

Figure 6.2-3 Land requirements for a landfill as function of compaction [UNEP, 2005]

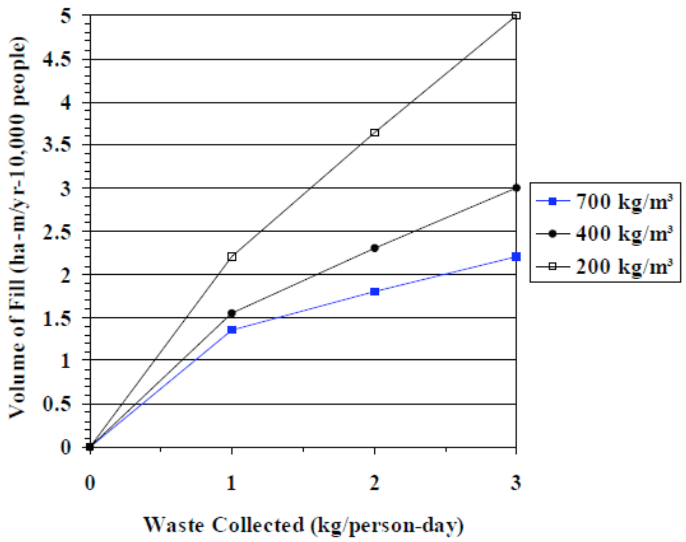

Figure 6.2-4 Relationship between bulk density of waste and landfill volume required [UNEP, 2005]

6.2.3.2 Topography

Information on topography of the selected area is extremely important in regard to the water flows to the landfill (e.g. from precipitations) and from the landfill (e.g. runoff from the waste). A completely flat area is exposed to accumulations of water during raining seasons and a very steep slope can be easily eroded. Therefore, a full set of information that is connected to the topographic maps must include the risks of flood, trajectory of surface waters, distance to nearby households, occurrence and eventual use of groundwater in the vicinity of the landfill, and the monitoring and drainage works [UNEP, 2005].

6.2.3.3 Soil

Economical and managerial reasons suggest that overall costs of the investment could be much reduced if the soil required for the bottom liners or top layers is already available on site and does not have to be imported. If the respective soil is not available, sufficient storage place has to be planned. The migration of contaminants in the subsurface can eventually be reduced or controlled if the soil characteristics are taken into consideration for the site selection.

☞ Please note:

See the UNEP report (2005), Volume I, page 335 for an overview on different soil classes and some important soil parameters.

6.2.3.4 Geology

Certain information on geology is important for proper planning of a landfill, like distance to bedrock or bedrock characteristics, especially in those cases when the bedrock is very close to the surface and it will be part of the foundation base [UNEP, 2005]. Discontinuities in the bedrock can affect the overall stability of the landfill and its facilities, and also offer convenient pathways for migration of contaminants.

6.2.3.5 Hydrogeology

Vadose zone

The vadose zone is defined as the zone between the top soil level and the groundwater table (Figure 6.2-5). Its characteristics are linked to the vertical mobility of contaminants toward the water table, and could play an important role in their attenuation or degradation. Therefore, the characterization of the site selected for building of a sanitary landfill should also include the following information about the vadose properties: mineralogy, porosity, organic matter content, particle size distribution, soils structure, as well as some information about its cation exchange capacity, temperature, soil pH value and the availability of microorganisms [UNEP, 2005].

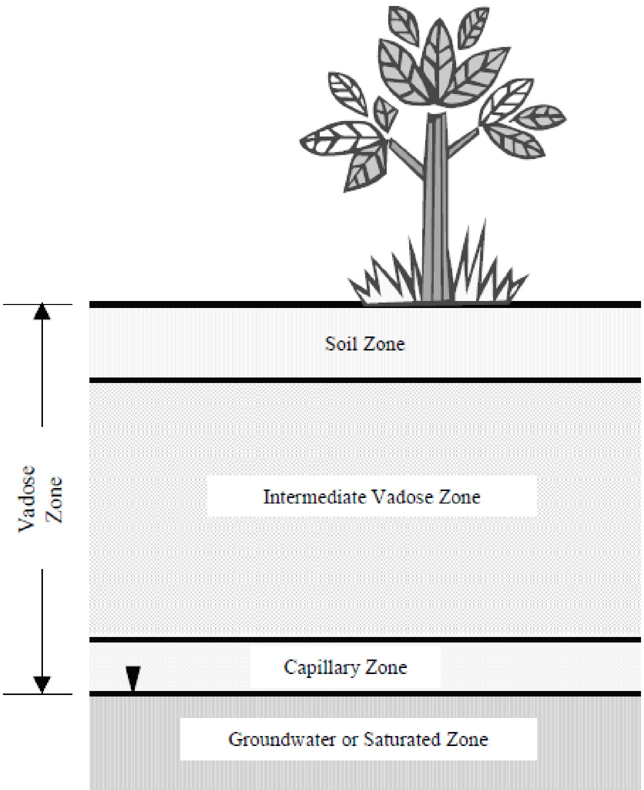

Figure 6.2-5 Schematic representation of vadose and groundwater zones [UNEP, 2005]

Groundwater

Considerations should be paid for areas with high groundwater recharge, which should normally be avoided [UNEP, 2005]. This would be the case of topographically high areas, where groundwater table would be relatively deep and any contaminant infiltration would lead to very long migrations along the aquifer. In opposite, the groundwater table is expected to be found very near to the surface in groundwater discharge areas, which may also pose a problem due to the pressure on the landfill bottom liner.

Monitoring of the groundwater quality should be performed especially for the uppermost aquifers since they are the first ones exposed to the risk of contamination by pollutants originating from the landfill runoff. The risk of contamination decreases if they or the respective vadose zone contain sorptive materials able to stop the spreading of contaminants (see also Figure 6.2-6) and could be limited by a combination of the following factors [UNEP, 2005]:

- the distance between groundwater table and the ground surface is more than 30 m;
- the net recharge rate is less than 5 cm/year;
- there are no major paths for contaminant migration;
- the topographic gradient is steeper than 18%
- the vadose zone is comprised of impervious soil (e.g. clay);
- the hydraulic conductivity of the aquifer is less than about 0.4 m^3/day/m^2.

In opposite, the risk of contamination rises dramatically if the following conditions are met [UNEP, 2005]:

- the distance between groundwater table and the ground surface is less than 3 m;
- the groundwater recharge rate is more than 25 cm/year;
- the vadose and/or the aquifer composition is made of fractured rocks;
- the topographic gradient is less than 2%;
- the hydraulic conductivity is higher than 80 m^3/day/m^2.

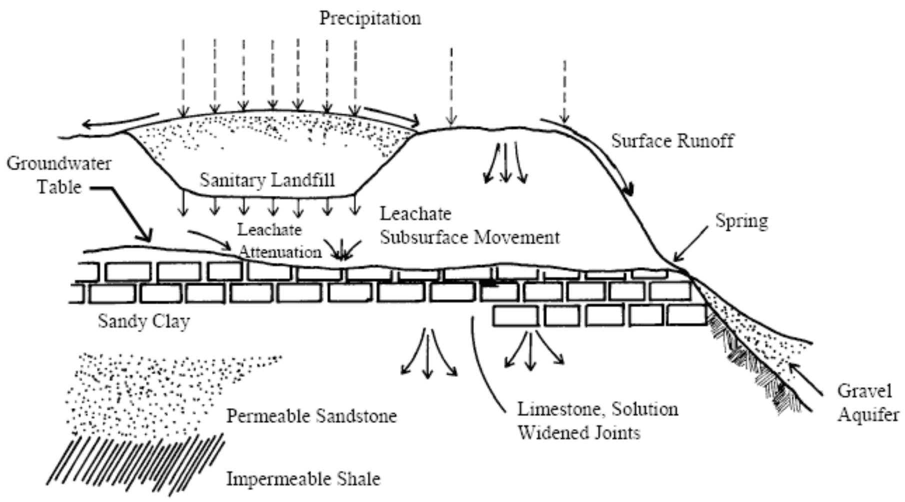

Figure 6.2-6 Interrelation between climatic, topographic, hydrologic, and geologic factors in terms of leachate travel and groundwater contamination [UNEP, 2005]

6.2.3.6 Vegetation

For a sanitary landfill, vegetation has the role of ensuring long-term stability and performance of the final landfill cover [UNEP, 2005]. Small trees, grasses and bushes can be planted to help against the erosions of the slopes and to behave like natural barriers against native climatic factors.

6.2.3.7 Access and transport

From economical perspective, the location of the landfill site should be chosen in such a way that it can allow minimum transportation times of the waste collected and this would mean the centre of the inhabited area. But as expected, this criterion gets in conflict with other socio-economical considerations and therefore a location outside of settlement has to be chosen. The access roads to the site should be in good condition, since a bad road can delay the waste delivery and deteriorate the transport vehicles, increasing the investment and maintenance costs significantly.

6.2.3.8 Economic considerations

Since most of the technical challenges expressed above can be solved by good site documentation and planning work, the decision about building a sanitary landfill faces actually the willingness of local communities to pay for their waste being properly disposed (which will implicitly improve the surrounding environment and life quality). Different economical aspects have to be well balanced in order to find the best compromise able to satisfy most of the stringent requirements. Among them, the costs for the cover materials and the costs of transportation to the site are weighting heavily in the overall balance. While the costs for the materials can be reduced by the availability of the materials on site, the transportation costs can be the main obstacle against building the landfill. On the other hand, a location far outside the settlement can offer low costs for land acquisition, which can be very important especially in densely inhabited regions, where free land is scarce and difficult to find at a convenient price. Moreover, a far off location may offer a lower adverse impact on the public health and the environment, so the final decision must be based on the evaluation of all factors involved, but in the same time not minimizing the importance of the full recovery of investment costs.

6.2.3.9 Decision-making

The decision making process for in a developing country should follow the next logical scheme in three steps [UNEP, 2005]:

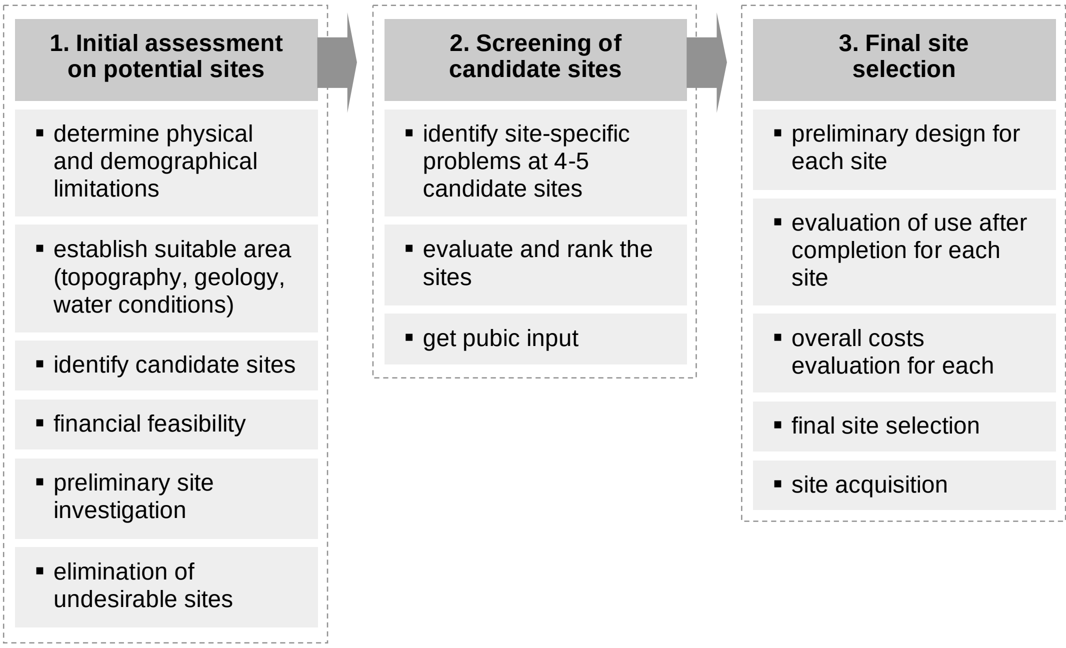

Figure 6.2-7 Decision making process for the selection of a landfill site

6.3 Landfill construction, operation and management

6.3.1 Landfill construction

According to the German waste disposal regulation [BMU, 2002], a landfill construction implies *“measures designed to create the requirements for commissioning of a landfill site, including in particular upgrading the geological barrier, landfill base sealing system, leachate and landfill gas disposal, landfill site areas, ventilation, and loading equipment”.* The following chapters will present the construction of landfill’s components, general landfill operation guidelines and management.

6.3.1.1 Landfill components

In order to ensure the environmental performance desired, a sanitary landfill must contain a few standard elements that are meant to reduce or even completely eliminate the negative impact to the environment and human health. The landfill components listed in Figure 6.3-1 have the main role of separation between the waste deposited in the landfill and the outside surroundings. The main problems posed by a landfill is the management of water and gases originating from the decomposition of the waste’s organic fraction but also the groundwater, surface water and rainwater than might get in contact to the deposited waste.

Liner system	▪ positioned at the base and on the sides of the landfill ▪ can include clay, geotextiles for liquid leaching prevention ▪ compacted clay liner + synthetic liner
Leachate collection	▪ positioned at the top of the liner ▪ it collects the leachate and the water that passes through waste ▪ brings the leachate to the treatment unit
Cap system	▪ positioned at the top of the landfill ▪ compacted clay and synthetic material + vegetation ▪ prevents the precipitation from infiltration into the landfill
Gas collection system	▪ vertical wells + horizontal pipes installed in the landfill ▪ prevents gases escaping from the landfill (especially methane) ▪ extracts gases and pumps them to the destruction unit
Surface water control	▪ drainage channels installed on and around the landfill ▪ controls erosion of the cap and contamination of adjacent waters ▪ collects the precipitations and brings them to a retention pond
Monitoring system	▪ installed around the landfill ▪ it checks that liner and gas collection system operate properly ▪ ensures that health and environment are protected

Figure 6.3-1 Typical municipal solid waste landfill components

The systems for control and prevention (see also Figure 6.3-2) are mostly located at the landfill's boundaries (e.g. the liner system, the leachate collection system and the cap system) but also inside and around the landfill (the gas collection system, the surface water system or the monitoring system). They will be detailed in the following chapters, together with some information about the technologies used for the construction of a sanitary landfill.

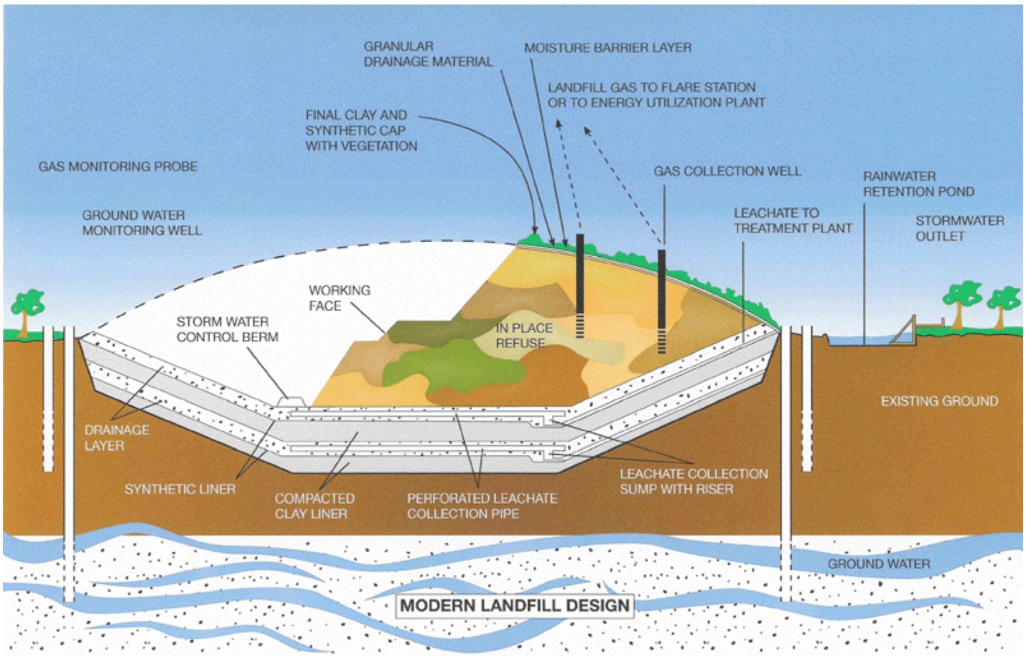

Figure 6.3-2 Landfill cross-section [www.runcoenv.com]

6.3.1.2 Cell design

A typical landfill structure is based on "cells", which are created by spreading and compacting the deposited waste within a delimited area. At the end of each day it is recommended to cover the compacted waste with a thin layer of soil, which also has to be also compacted. The characteristics of each cell like height, length, width of the working face, slope and thickness of the cover layer) depend on the specific conditions of each particular case.

☞ Please note:

The minimum width of the cell depends upon the equipment used and the maximum number of vehicles working simultaneous at the site. A recommended width is about 2 to 2.5 times the width of the blade building the cell [UNEP, 2005].

The maximum recommended slope of the cell should be 1 to 3. A slope less than 1 to 6 implies very large areas for working face [UNEP, 2005].

6.3.1.3 Slope stability

The slope stability is an important element in the landfill design. Improperly calculated, it can lead to massive landslides of waste, destroying surrounding properties or causing serious injuries of landfill working personnel. Beside incorrect calculations, the slope's stability depends directly on the following factors [UNEP, 2005]:

- properties of the waste deposited on the landfill
- properties and type of materials used to separate the landfill waste from the environment
- amount of moisture in the waste
- natural causes like earthquakes or heavy rains

6.3.1.4 Sealing layers

The major role of a landfill sealing layers is to act as a barrier between waste and the environment and to not allow exchanges between them. As mentioned before, they can surround the landfill (e.g. the base seal) or lay on the top of waste layers (e.g. as final cover component). The depth of the base and surface sealing layers, together with their *k* values, are presented in Table 6.2-1 and Table 6.3-1, according to landfill class:

Table 6.3-1: Standard structure of the geological barrier and the base sealing system [BMU, 2002]

System component	Landfill class 0	Landfill class I	Landfill class II	Landfill class III
Geological barrier	$k \leq 1 \cdot 10^{-7}$ m/s $d \geq 1.0$ m	$k \leq 1 \cdot 10^{-9}$ m/s $d \geq 1.0$ m	$k \leq 1 \cdot 10^{-9}$ m/s $d \geq 1.0$ m	$k \leq 1 \cdot 10^{-9}$ m/s $d \geq 5.0$ m
Mineral sealing layer (at least two layers)	not required	not required	$k \leq 5 \cdot 10^{-10}$ m/s $d \geq 0.5$ m	$k \leq 5 \cdot 10^{-10}$ m/s $d \geq 0.5$ m
Plastic sealing liner ($d \geq 2.5$ mm)	not required	not required	required	required
Protection layer	not required	required	required	required
Mineral drainage layer	$d \geq 0.3$ m $k \geq 1 \cdot 10^{-3}$ m/s	$d \geq 0.5$ m $k \geq 1 \cdot 10^{-3}$ m/s	$d \geq 0.5$ m $k \geq 1 \cdot 10^{-3}$ m/s	$d \geq 0.5$ m $k \geq 1 \cdot 10^{-3}$ m/s

Table 6.3-2: Standard structure of the surface sealing system [BMU, 2002]

System component	Landfill class 0	Landfill class I	Landfill class II	Landfill class III
Compensatory layer	not required	$d \geq 0.5$ m	$d \geq 0.5$ m	$d \geq 0.5$ m
Gas drainage layer	not required	not required	required in some cases	required in some cases
Mineral seal	not required	$d \geq 0.5$ m $k \leq 5 \cdot 10^{-9}$ m/s	$d \geq 0.5$ m $k \leq 1 \cdot 10^{-9}$ m/s	$d \geq 0.5$ m $k \leq 1 \cdot 10^{-3}$ m/s
Plastic sealing liner	not required	not required	$d \geq 2.5$ mm	$d \geq 2.5$ mm
Protective layer	not required	not required	required	required
Drainage layer	not required	$d \geq 0.3$ m $k \geq 1 \cdot 10^{-3}$ m/s	$d \geq 0.3$ m $k \geq 1 \cdot 10^{-3}$ m/s	$d \geq 0.3$ m $k \geq 1 \cdot 10^{-3}$ m/s
Recultivation layer ($d \geq 1.0$ m)	required	required	required	required
Vegetation	required	required	required	required

6.3.1.5 Landfill operation and management

6.3.1.6 Specific operational procedures

Depending of how the waste is deposited on the landfill site, one can differentiate two major filling methods: area method (Figure 6.3-3) and trench method (Figure 6.3-4). In the area method, the waste is deposited on a large open area (most common method), while in the second method, the waste is deposited in an excavated trench. Additionally, waste can also be deposited on the existing slopes of a site.

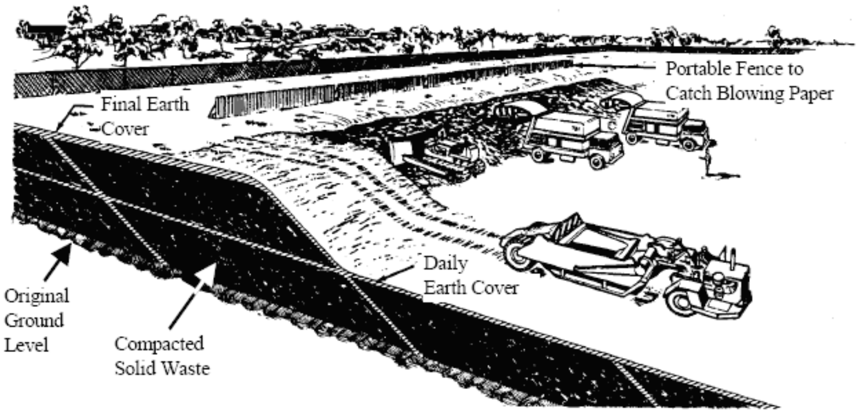

Figure 6.3-3 Area method and trench method of sanitary landfilling [UNEP, 2005]

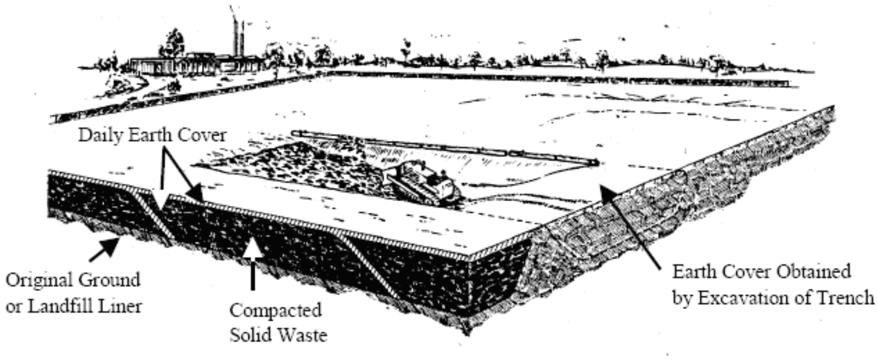

Figure 6.3-4 Trench method of sanitary landfilling [UNEP, 2005]

According to the filling method, some specific operational procedures have been summarized in Figure 6.3-5 and Figure 6.3-6. These procedures have grouped in the following basic categories:

- site preparation
- traffic flow and unloading
- compaction
- cover layers

<u>Area method</u>

In opposite to trench method, area method implies spreading and compaction of the waste on a flat area, usually a valley, an old mine or quarry, canyons etc. The key issues regarding the specific operational procedures are presented on short in Figure 6.3-5 (compiled from UNEP, 2005):

	AREA METHOD
Site preparation	▪ minimum disturbance of soil and vegetation from selected site ▪ eventual excavations should be effective, without stockpiling (double work avoided)
Traffic flow and unloading	▪ good compaction required if collection vehicles drive over the already deposited waste ▪ unloading should be performed at the bottom of the working face, to allow an easier compaction later
Compacting	▪ increases the landfill capacity ▪ its efficiency depends upon waste layer thickness, waste characteristics, number of passes, type of compactor
Daily, intermediate and final cover	▪ daily cover: control against odour, water infiltration, vectors ▪ intermediate cover: same function as daily cover; remains longer exposed and serves also for traffic on landfill ▪ final cover: closes the landfill and allows area rehabilitation

Figure 6.3-5 Specific operational procedures for area method

Trench method
The trench method implies placing the waste into an excavated trench, compaction, and using the excavated soil as cover material. The width and length of trenches can very according to the specific site conditions. The specific operation procedures are summarized in Figure 6.3-6:

	TRENCH METHOD
Site preparation	▪ phased fill and covering approach: soil from trench excavations should be used as cover layer either for the same trench or for the adjacent trench
Traffic flow and unloading	▪ unloading over the edge (attention at sidewall stability) or from within the trench (preferred) ▪ traffic procedures similar to area method
Compacting and cover	▪ the same like in area method

Figure 6.3-6 Specific operational procedures for trench method

Ramp method
The ramp method is very similar to area method, being mostly used for landfills built on existing slopes. The difference is represented by the cover layer, whose material is excavated right from the front of the working face. This creates a small depression for depositing the next load to waste, making the method very effective.

6.3.1.7 Water management

The contaminated water originating from the landfill is the main factor of negative impact to the environment, therefore a strict control is required for the water quantities entering and leaving the landfill. The two major water sources that have to be protected from the negative impact of a landfill are the surface waters and the groundwater.

Surface water
The contamination of the surface water flowing in the vicinity of the landfill has to be protected against the runoff from the landfill site. This can be done by constructing a series of small channels and drains around the landfill able to take over the runoff waters. It is assumed that the degree of water contamination increases with the retention time of the precipitations on the landfill, therefore grading the landfill cover could help for an efficient runoff of rainfall [UNEP, 2005].

Groundwater
The contamination of groundwater has the main origin in the passage of precipitations through the solid waste in a landfill. The rainfall can get together with the existent mixture (water from the waste decomposition) and then get in contact with the groundwater layers if the bottom liner is not able to

realise a good isolation. The solution to avoid the groundwater contamination is the realisation of a system for the collection and further treatment of the landfill leachate (see chapter 6.3.1.8).

<u>Water balance</u>

The components of the water balance in a landfill are presented in Figure 6.3-7 and can be expressed using the following equation [UNEP, 2005]:

$$MC = W_{SW} + W_C + W_P - W_{RO} - W_{lfg} - W_V - W_{evap} + W_{leach}$$

where:

- MC = the variation of the moisture quantity stored in the landfill (kg/m^3);
- W_{SW} = quantity of water in the upcoming waste (kg/m^3);
- W_C = quantity of water in the cover material (kg/m^3);
- W_P = quantity of water from precipitations (kg/m^3);
- W_{RO} = quantity of water from precipitations diverted as runoff (kg/m^3);
- W_{lfg} = quantity of water used in the formation of landfill gas (kg/m^3 of gas);
- W_V = quantity of water lost as saturated vapours with landfill gas (kg/m^3 of gas);
- W_{evap} = quantity of water lost due to evapotranspiration (kg/m^3);
- W_{leach} = quantity of water leaving the landfill as leachate (kg/m^3).

☞ **Please note:**

For landfills in developing countries, the following values can be used for calculations [UNEP, 2005]:

- moisture content of waste 30 to 60%
- water used in the formation of landfill gas ~ 0.2 kg/m^3 of gas
- water lost as saturated vapours with the landfill gas ~ 0.04 kg/m^3 of gas

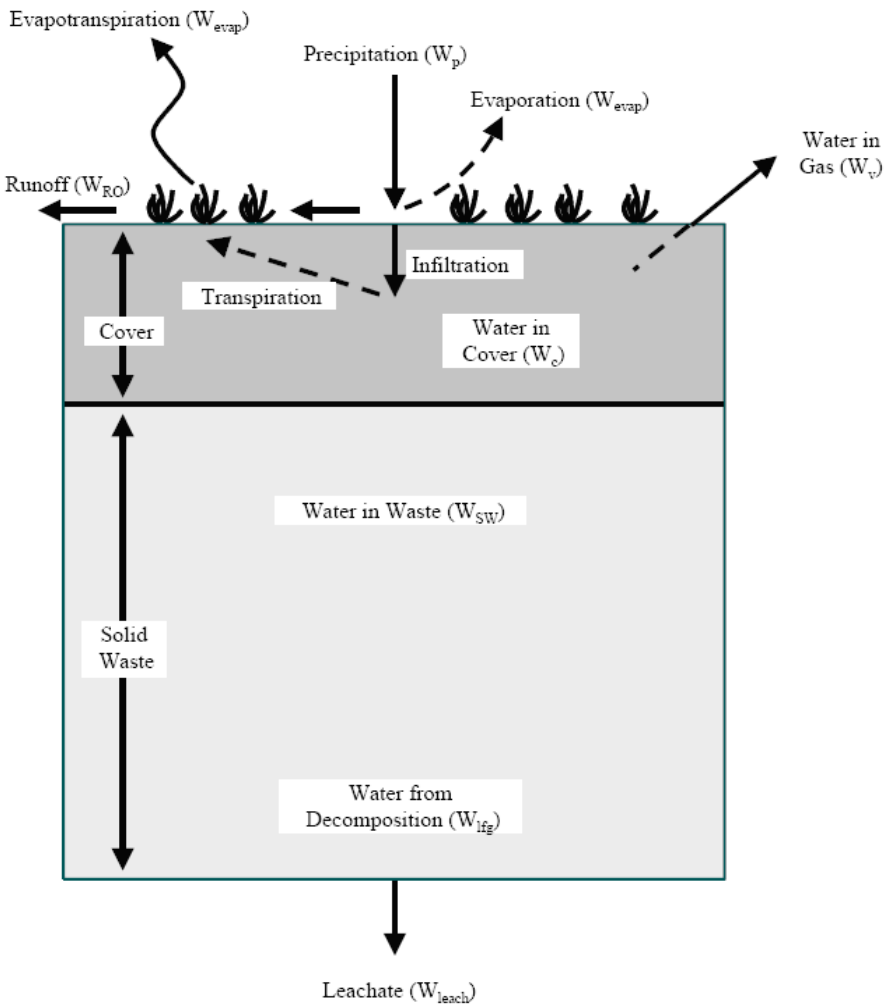

Figure 6.3-7 Components of a water balance [UNEP, 2005]

Conducting a preliminary water balance in a landfill is an important step for the correct design of a leachate collection and treatment system. The water balance should be calculated regularly and on a long time basis, as many of its components could dramatically change their values over time. Among them, the quantity of water leaving the landfill as leachate is of major importance and it will be detailed in the following chapter.

6.3.1.8 Leachate collection and treatment

The formation of leachate in a sanitary landfill is mainly caused by the percolation of water from precipitations through the waste mass. In contact with the decomposing waste, it becomes loaded with various substances and degradation products (see Table 6.3-3) and moves slowly to the base of the landfill with 10^{-2} to 10^{-4} cm/s [UNEP, 2005].

Table 6.3-3: Characteristics of leachate from decomposition of municipal solid waste [UNEP, 2005]

Parameter	Range of values (mg/l)
pH	4.5 to 9
Alkalinity ($CaCO_3$)	300 to 11,500
BOD (5-day)	20 to 40,000
Calcium	10 to 2,50
COD	500 to 60,000
Copper	4 to 1,400
Chloride (Cl^-)	100 to 5,000
Hardness ($CaCO_3$)	0 to 22,800
Iron – total	3 to 2,100
Lead	8 to 1,020
Magnesium	40 to 1,150

Parameter	Range of values (mg/l)
Manganese	0.03 to 65
Ammonia-NH_3	30 to 3,000
Organic N	10 to 4,250
Nitrogen – NO_2	0 to 25
Nitrogen – NO_3	0.1 to 50
Nitrogen – total	50 to 5,000
Potassium	10 to 2,500
Sodium	50 to 4,000
Sulphate (SO_4^-)	20 to 1,750
Total dissolved solids	0 to 42,300
Total suspended solids	6 to 2,700
Total phosphate	0.1 to 30
Zinc	0.03 to 120

The leachate composition can widely vary, consisting of organic and inorganic compounds that can be either dissolved or suspended. During the decomposition process, the temperature of the waste mass rises and the pH value decreases, making possible that certain metals ions, insoluble in normal conditions, to become soluble and thus dissolved in the leachate. The high amount of dissolved gases (e.g. methane, hydrogen, sulphur) and nutrients make the water resources contaminated by leachate become very quickly depleted in dissolved oxygen. Apart the contamination with heavy metals and other harmful substances, this will strongly affect the life in the respective water body making it improper for its original use.

In order to protect the respective water bodies, the landfill must be equipped with a leachate collection system consisting of a drainage layer, leachate cleanout and maintenance ports, a collection pump and a leachate storage tank [Bilitewski et al., 1994]. The extraction of leachate can be done by pipes and/or drainage layers and it has to consider all the processes occurring in a landfill. For a good review on best available techniques for landfill leachate extraction and pumping see Last et al., 2004.

Once collected, the leachate has to be discharged and, according to regulations, further managed. For this, one of the following methods can be applied:

<u>Recirculation</u>

In this method, the leachate released by a landfill is collected at the base of the landfill and reintroduced trough the landfill waste many times. This method provides a simple solution for the leachate disposal and it enhances the landfill stabilization (because the leachate helps in the production of more landfill gas by increasing the waste moisture and thus decreasing the overall waste volume). However, the recirculation does not solve the problem posed by the contaminants contained since they are only concentrated, not removed. Moreover, some landfills operators reintroduce the leachate by spraying it at the surface of the landfill, which actually increases the risk of surrounding waters contamination through stormwater runoff from the landfill area [Jones-Lee and Lee, 2000].

<u>Discharge to sewage</u>

This method might offer an alternative to recirculation but it is restricted by the local or national regulations on wastewater quality. Usually, the strength of landfill leachate is tens to thousands times higher than the accepted wastewater in a sewerage system, therefore a discharge of such high-concentrated is not indicated.

<u>Treatment</u>

In most developed countries, leachate generated by a municipal solid waste landfill has to be treated. Normally, any wastewater treatment methods available can be used for treating landfill waste and Table 6.3-4 provides an overview on these methods, together with their applicability and restrictions:

Table 6.3-4: Overview of leachate treatment processes [Bilitewski et al., 1994]

Method	Comments	Problems
Physical methods		
Sedimentation	Low cost	Only suitable for insoluble compounds
Evaporation	Preconcentrating constituents	Costly, corrosive, only a partial solution, COD is removed but not destroyed
Physical/Chemical methods		
Activated carbon adsorption	Suitable for hydrophobic compounds in wastewater	Only provides partial treatment, regeneration of carbon necessary
Resin adsorption	Suitable for chlorinated hydrocarbons, other hydrocarbons, aromatics	Only partial treatment, costly
Membrane Process / Reverse osmosis	Reverse osmosis, good retention	Concentrated solids may acquire additional treatment, membrane fouling possible
Ion exchange	Only specialized ions suitable	Organic solids and colloids are disruptive to process
Flocculation and precipitation	Often used, partial COD elimination, not necessarily state-of-the-art anymore	Treatment/disposal of sludges and high quantities of salts required (35 kg/m^3 leachate!)
Chemical methods		
Wet oxidation with H_2O_2	No concentrating, elimination of residual COD	No always appropriate for direct treatment, high energy demand
Wet oxidation with O_3/UV	No concentrating, elimination of residual COD	No always appropriate for direct treatment, high energy demand
Biochemical methods		
Anaerobic treatment	No energy needs for oxygenation, no surplus sludge	Retaining the biomass, sensitivity, not a total treatment
Aerobic treatment (aerated lagoons)	Most common, most cost effective method	Not effective for non-biodegradable materials, regulatory limits difficult to achieve

☞ Please note:

To some extend, the leachate can be used after treatment in agriculture, for irrigation and as fertilizer, due to its high content of nutrients (e.g. for plants suitable for biofuels production). See also www.leachate-irrigation.com.

6.3.1.9 Management of landfill gas (LFG)

<u>Gas origin and composition</u>

During the initial period after disposal, the waste still contains certain amounts of oxygen that is the base for the aerobic degradation processes. This phase is usually short (from few days to several weeks) and the resulted gas contains mostly CO_2 and water vapour. Soon afterwards, due to waste compaction and application of daily and intermediate cover layers, the oxygen is getting depleted and the system becomes anaerobic (phase two). This is followed by the apparition of gas emissions containing methane (CH_4) in rising concentrations (phase 3), followed by the last phase defined by constant production of methane and other gases having the following composition: 40% – 60% methane, 40% – 50% carbon dioxide, 3% - 20% nitrogen and 1% oxygen [UNEP, 2005].

<u>Gas generation</u>

The production of methane containing gas in a landfill is directly influenced by the waste moisture and pH value and does not depend much on the compaction level, age or density of waste deposited [UNEP, 2005]. However, due to different waste composition reported, the gas production can vary in developed countries from values of 2.33 m^3/ton*year in Denmark to 5.09 m^3/ton*year and more in countries like Portugal (see Table 6.3-5).

Table 6.3-5: Data on worldwide gas production from landfills [Willumsen, 2003]

Country	**Number of plants**	**Size of plants** (MW)	**Waste amount** (Mio. ton)	**Landfill gas** (m^3/h)	**Landfill gas** (m^3/ton*year)
USA	354	2,208	2,850	958,400	2.95
Canada	16	88	100	72,00	6.31
Australia	18	76	101	43,657	3.79
South Africa	4	4	4	1,600	3.50
Brazil	7	11	12	4,000	2.92
Austria	15	22	28	8,820	2.80
Czech Republic	6	7	8	2,700	2.96
Denmark	20	22	20	5,913	2.59
France	20	30	35	12,400	3.10
Finland	14	12	20	6,500	2.85
Germany	180	270	380	78,500	1.81
Greece	1	13	20	7,400	3.24
Netherlands	47	62	100	26,575	2.33
Italy	135	362	240	115,150	4.20
Norway	30	28	13	5,790	3.99
Switzerland	6	7	8	2,988	3.27
Spain	13	36	51	20,700	3.56
Portugal	1	2	2	900	5.09
Sweden	61	55	35	12,950	3.24
Poland	19	18	15	5,000	2.92
UK	150	320	400	180,000	3.94
Hong Kong	8	32	28	14,620	4.64
China	4	4	4	2,160	4.73
Taiwan	4	20	20	10,972	4.81
South Korea	3	16	14	7,000	4.54

In developing countries, although the organic matter content of the deposited waste is very high, the landfill cover is usually not adequately applied and this leads to free escape of the landfill gas.

<u>Gas collection and utilisation</u>

The first step in gas collection is providing a proper landfill sealing, with special focus on the top layers. The collection itself is done by installing a set of perforated pipes on high permeable areas and using a venting principle to pump the gas out of the landfill (Figure 6.3-10). The number and characteristics of venting pipes and their arrangement in the landfill should be designed according to the local conditions and requirements (Figure 6.3-8 shows some areal methods of connecting gas wells to the gas collection system). The collected gas can be then utilised as low heat fuel or further treated and used as a high-heat fuel. For using the landfill gas in cooking, the hydrogen sulphide (H_2S) has to be removed [UNEP, 2005].

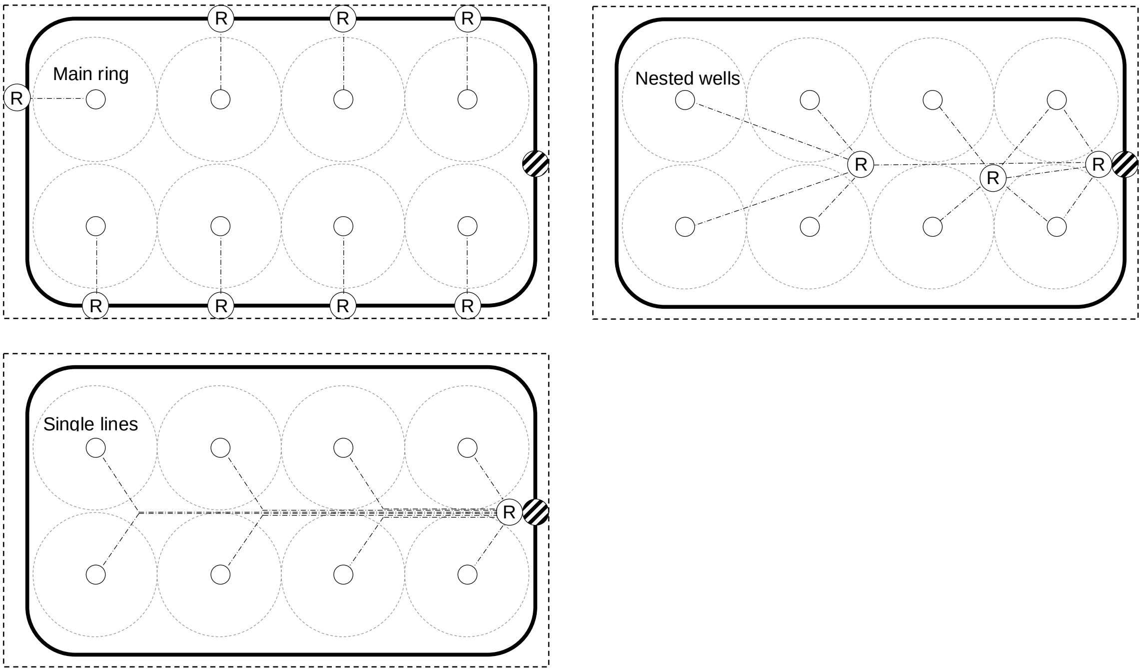

Figure 6.3-8 Methods of connecting wells to the gas collection system [Bilitewski et al., 1994]

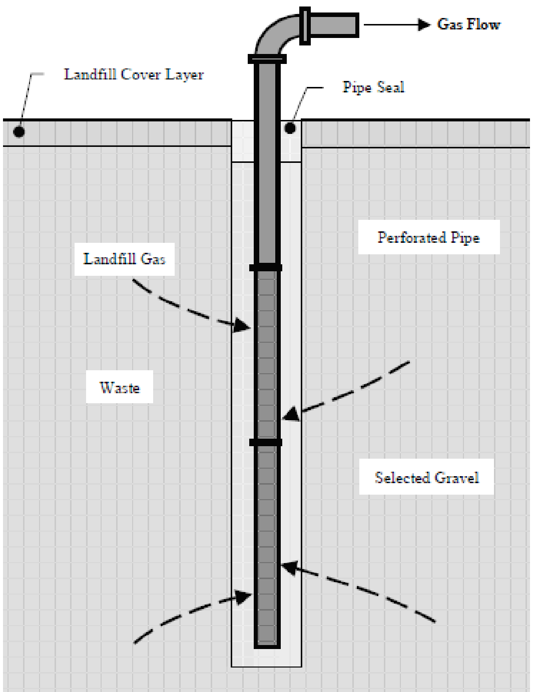

Figure 6.3-9 Schematic diagram of a gas well [UNEP, 2005]

The problem of odours from landfill sites may have important consequences on health of operating personnel, as well as important negative impacts on the socio-economical development of the area surrounding the landfill site. Taking into consideration that gas production at a landfill may take even up to several years after the applying the final cover, a careful design is required for the gas collection system. However, the reduction of odours can be realized by taking a couple of additional measures too, such as installing an onsite weather station and field monitoring or by spraying odour neutralizing chemicals along the landfill border. The Figure 6.3-10 shows an overview on different methods to reduce the odours at a landfill:

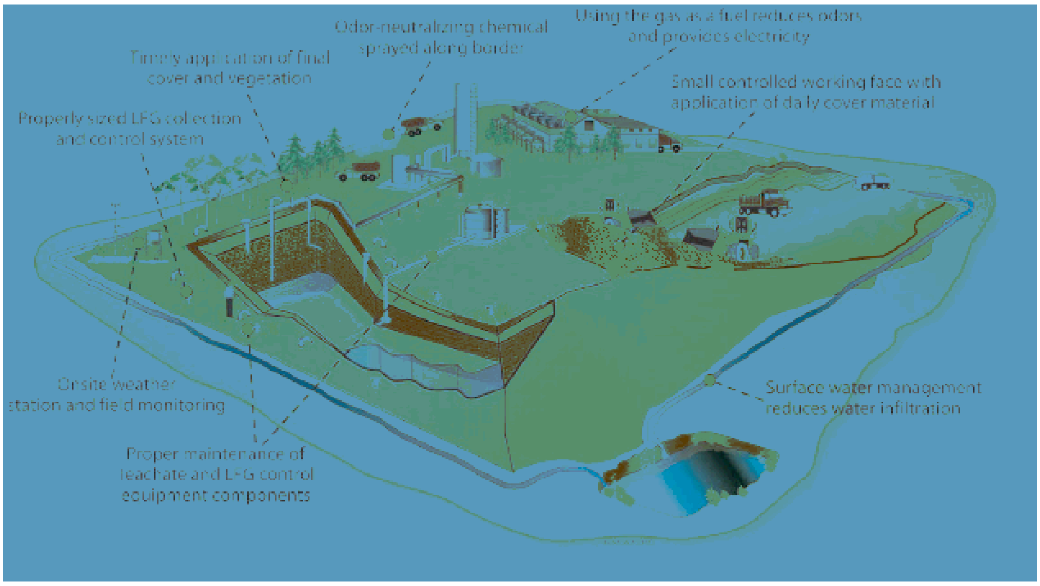

Figure 6.3-10 Methods to control odours at landfills [NAWMA, 2008]

6.3.2 Environmental monitoring

The monitoring of environmental impact of a landfill is strictly required and it has to be done by comparing the characteristics of the environmental components before building the landfill and after completion. The monitoring of the landfill vicinity should run over a long period of time and it should contain also a plan for remediation in case necessity.

6.3.2.1 Groundwater

The potential impact of a landfill on groundwater quality can be generally evaluated by a detailed analysis of the leachate composition and generation rate. This allows the identification of contaminants posing a threat to groundwater and the intensity of a potential contamination [UNEP, 2008].

Nevertheless, the groundwater quality has to be check before reaching the vicinity of the landfill and after the area potentially affected. The following parameters will offer indication of contamination by landfill leachate and should constitute the basis for an environmental monitoring program:

- pH
- specific conductance
- alkalinity
- biological oxygen demand
- chemical oxygen demand
- nitrate/nitrite nitrogen
- chloride
- iron
- sodium
- magnesium
- sulphate

The collection of water samples for the detection of the above parameters can be done using classical monitoring wells, like in Figure 6.3-11:

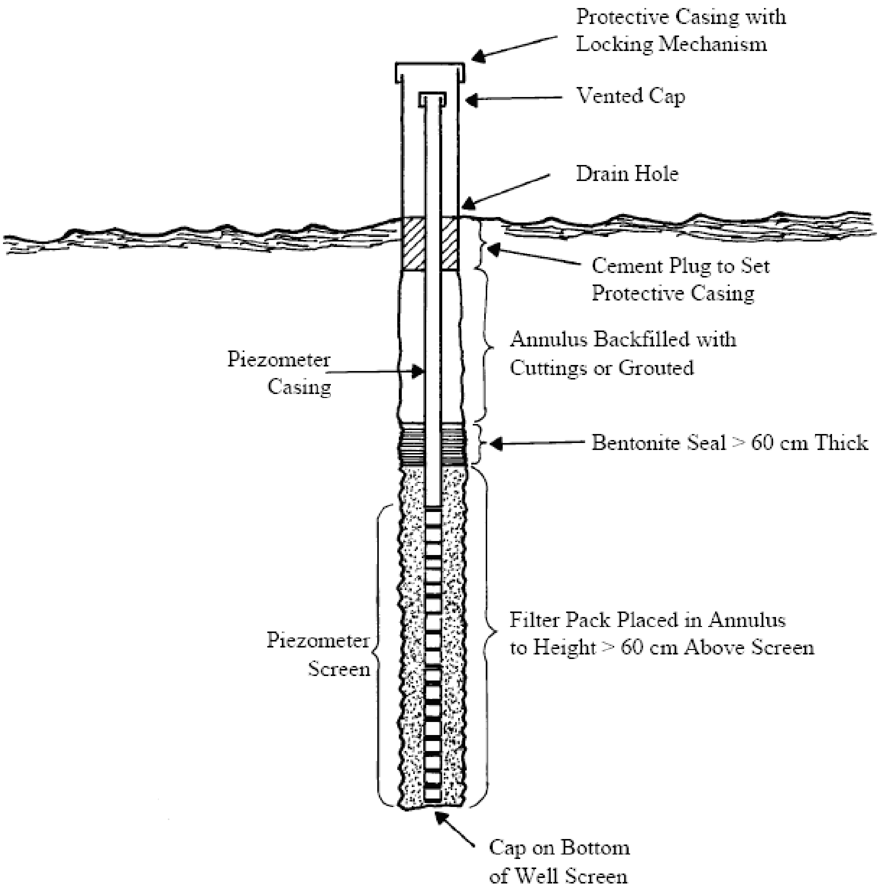

Figure 6.3-11 Groundwater monitoring well [UNEP, 2005]

6.3.2.2 Surface water

The negative impact depends mostly on the distance and also on the drainage patters between the landfill and the adjacent surface waters. A landfill situated very close to a lake or a river which is not adequately isolated can lead to massive impacts to the respective water source, as seen in Figure 6.3-12. The general approach for surface waters should be similar those adopted for the groundwater, with water samples taken upstream and downstream of the landfill and analysed for quality parameters.

Figure 6.3-12 Dumping site in the proximity of surface water in India

6.3.2.3 Landfill gas

The landfill gas escaping the landfills without a system for collecting it can also be regarded possible factor of environmental contamination. Moreover, the chemical composition of the gas (see chapter 6.3.1.9) make the gas very dangerous for the people working at the landfill and within its surroundings. If the landfill is properly top closed, the gas will find its ways out by lateral sides. This can be detected by installing sampling devices and monitoring the concentration of methane in the air samples.

6.4 Completed landfills and rehabilitation

Landfill closure starts when the planned landfill capacity is reached but the closure can also be done progressively, while still adding waste to new cells. However, a completed landfill is not going to become an abandoned place. The management of landfill gas, leachate, as well as environmental monitoring will continue for long periods of time (even 20-30 years or more) and this should be well considered at the planning stage because the costs for these activities will not be incurred on a revenue basis.

The rehabilitation of a landfill means using the site for a variety of functions, among them being:

- Residential development (houses and annexes, green spaces)
- Commercial development (storage areas, parking lots, etc)
- Active recreation areas (sport)
- Passive recreation areas and open space (parks, green areas)

The final use of a completed landfill can be decided according to criteria established by the local regulatory agencies and according to the needs the local communities. This can be influenced by the following aspects: low bearing capacity, differential settlement of the landfill site, methane which might eventually escape in the atmosphere, general public acceptance.

Figure 6.4-1 Closing works of a sanitary landfill in Germany

☑ Self-assessment

1. What are the criteria a disposal site has to meet in order to be considered a sanitary landfill?
2. Classify the landfills according to the type of waste disposed and to technical level accomplished
3. What are the processes occurring in a landfill? Which ones are the most important and why?
4. Describe the site requirements for the construction of a new landfill.
5. Enumerate the minimum necessary steps to be followed when deciding about constructing a new landfill.
6. What are the typical landfill components?
7. What are the main methods of depositing the waste to a landfill?
8. What is a water balance and what are its components?
9. What are the advantages and disadvantages between different methods for the management of landfill leachate?
10. What is the composition of the landfill gas?
11. What measures can be taken to reduce the negative environmental impact posed by a landfill?

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