Overview of Solid Waste Landfill

PDH: 5.0 Hours

Dr. M. A. Karim, P.E., F.ASCE

PDH Now, LLC.
www.PDH*Now*.com

Overview of Solid Waste Landfill

PDH: 5.0 Hours

Dr. M. A. Karim, P.E., BCEE, F.ASCE

Table of Contents

List of Tables

List of Figures

Overview of Solid Waste Landfill

1. Course Overview

This course introduces an overview of solid waste landfill design, operation, and performance. This course covers the materials related to Site Selection, Site Preparation, Equipment, Operation, Environmental Considerations, Bioreactor Landfill, Landfill Design, Completed Solid Waste Landfills, Solid Waste By-Products, and their beneficial use. This course is suggested for civil engineers, environmental engineers, and solid and hazardous waste landfill managers and operators.

2. Learning Objectives

Upon successful completion of this course, the participants will be able to:

- Describe the requirements for landfill site selection and preparation.
- List the equipment necessary to run a solid waste landfill.
- Explain the operational procedure of solid waste landfill.
- Interpret the environmental considerations for solid waste landfill operation and design.
- Illustrate the types of bioreactor landfills.
- Analyze solid waste landfill components.
- Discuss the beneficial use of solid waste by-products.
- Recognize the software used in solid waste landfill design and operation

3. Introduction

3.1 Definition of Solid Waste Landfill

A solid waste (SW) landfill is defined as a land disposal site employing an engineered method of disposing solid wastes on land in a manner that minimizes **environmental hazards** by spreading the solid waste to the smallest practical volume and applying and compacting cover material at the end of each day.

Why are landfills important?
Landfills contain garbage and serve to prevent contamination between the waste and the surrounding environment, especially groundwater.

What happens to the trash in a landfill?
Landfills are not designed to break down trash, merely to bury it. That is because they contain minimal amounts of oxygen and moisture, which prevents trash from breaking down rapidly. So,

landfills are carefully filled, monitored, and maintained while they are active and for up to 30 years after they are closed.

What is the difference between a dump and a landfill?
A dump is an open hole in the ground where trash is buried and where animals often swarm. Dumps offer no environmental protection and are not regulated (*Figure 1*).

A landfill is a carefully designed and monitored structure that isolates trash from the surrounding environment (e.g., groundwater, air, rain). This isolation is accomplished with the use of a bottom liner and daily covering of soil.

Figure 1: An open dump (Not a landfill)

3.2 Types of Solid Waste Landfill

There are 3 basic types of landfills:

- Sanitary/Municipal Solid Waste (MSW) Landfill
- Construction/Demolition/Debris (CDD) Landfill, and
- Industrial Landfill

Number of landfills appears to be decreasing (*Figure 2* and *Figure 3*) with time as the recycling and recovery of wastes is increasing. As of March 2020, the number of landfills in the USA is about 2627[1] (*Figure 4*).

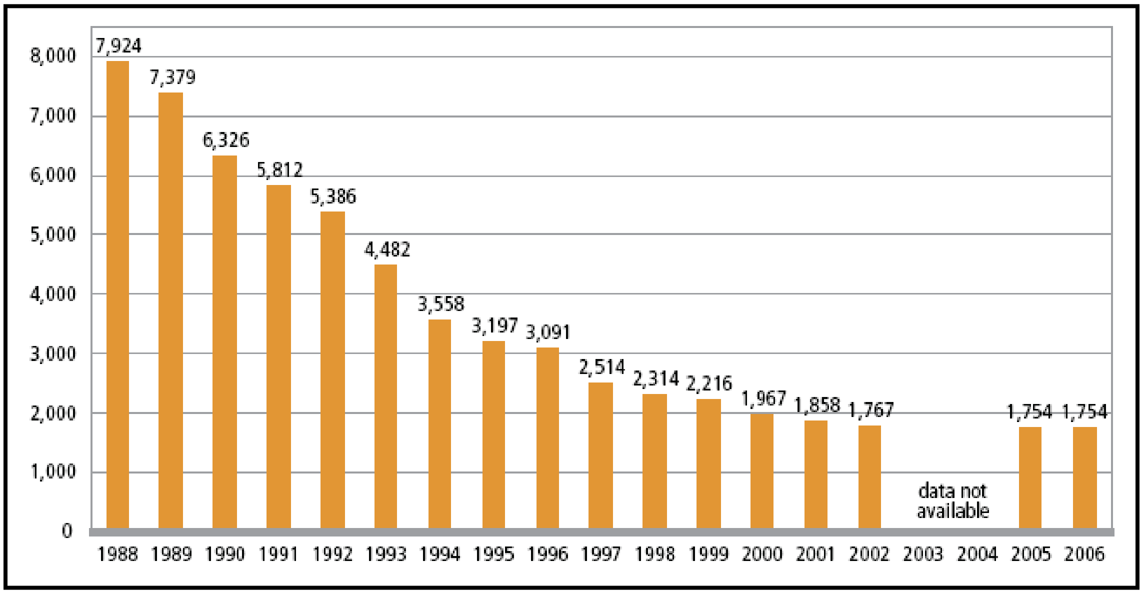


Figure 2: Number of Landfill in the USA from 1988 to 2006

1 https://www.epa.gov/lmop/project-and-landfill-data-state, extracted April 18, 2020.

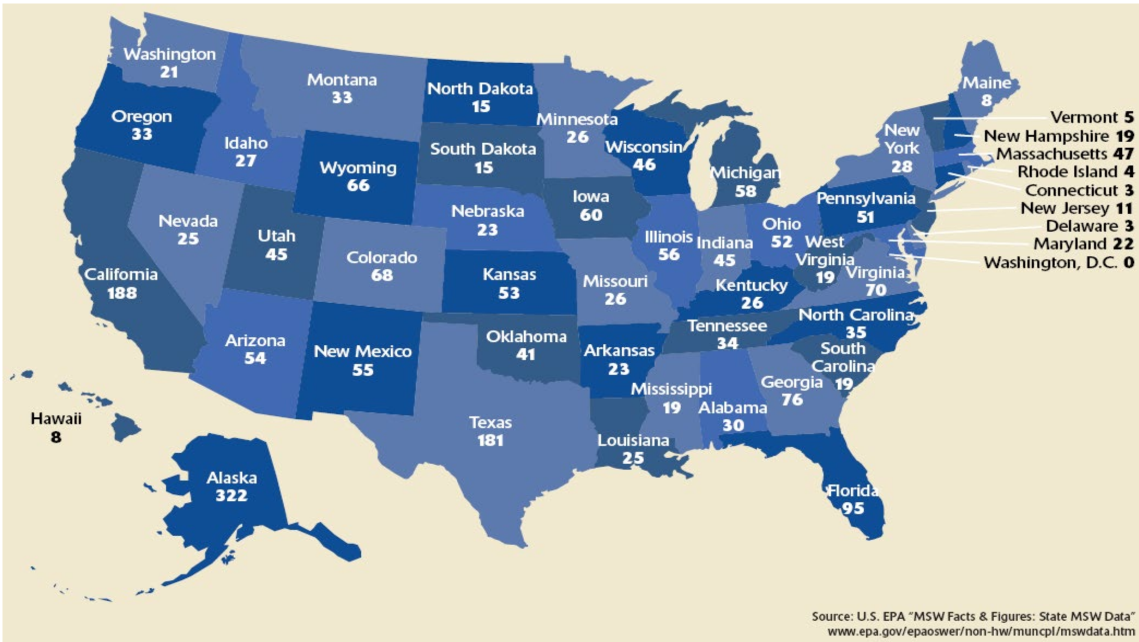


Figure 3: Statewide number of Landfill in the USA, 2005

Landfill Methane Outreach Program (LMOP) tracks key data for landfill gas (LFG) energy projects and municipal solid waste (MSW) landfills in the United States in million metric tons of carbon dioxide equivalents (MMTCO2E). The LMOP Landfill and Landfill Gas Energy Database (LMOP Database) contains information about projects in various stages such as planning, under-construction, operational and shutdown, and is also a data repository for more than 2,600 MSW landfills.

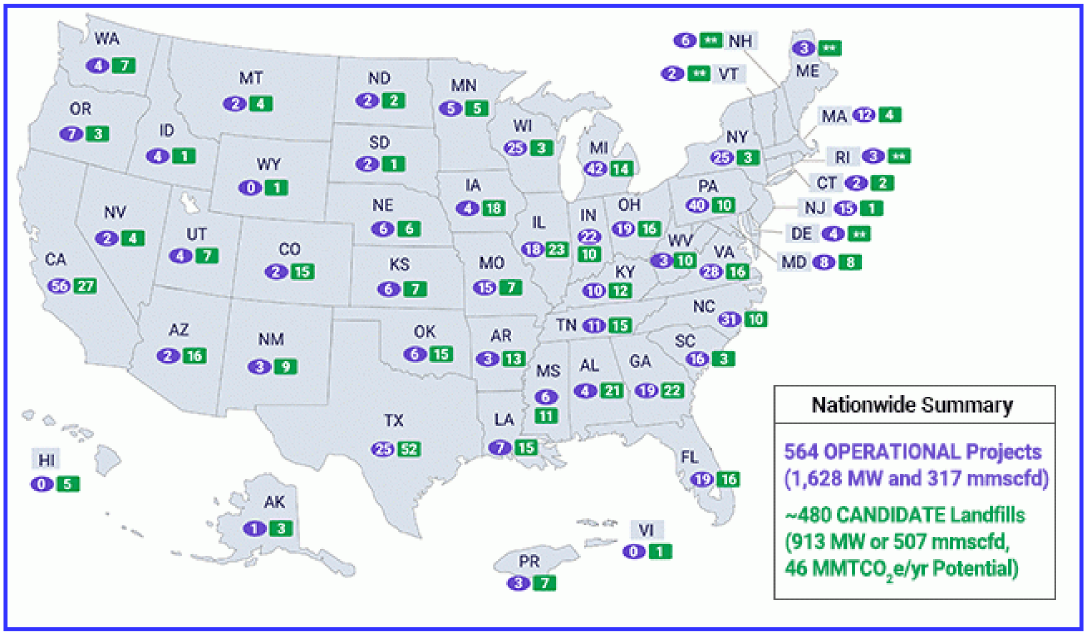


Figure 4: Statewide number of LMOP Landfill in the USA, March 2020

4. Site Selection

Site selection for a solid waste landfill (MSW landfill) is perhaps the most difficult task in the development of a landfill. Opposition by local citizens eliminates many potential sites. In order to select a site, consideration should be given to the following variables:

- Public opposition
- Proximity of major roadways
- Speed limits
- Load limits on access roadways
- Bridge capacities
- Underpass limitations
- Traffic pattern and congestion
- Haul distance (in time)
- Detour
- Hydrology
- Availability of cover material
- Climate (i.e., the site should not be on base flood area)
- Zoning requirements (should be agricultural or industrial)
- Buffer areas around the site
- Historic building, endangered species, wetland, and other similar environmental factors

Under **Subtitle D** of Resource Conservation and Recovery Act (RCRA), a solid waste landfill must comply with the following criteria. It may vary from country to country and region to region based the local needs:

- Certain distance (5 miles) from airport
- Should not be on the flood plain
- Should not be on fault areas
- Should not be on wetlands
- Should not be on seismic impact areas and unstable areas
- Should not be on landslide areas and areas those susceptible to sink holes

Solid waste landfill should be located more than

- 100 ft (30 m) from streams and rivers
- 500 ft (160 m) from drinking water wells
- 200 ft (65 m) from residence, school, nursing homes, parks, etc.
- 10,000 ft (3,000 m) from airport runways.

5. Site Preparation

The plans and specifications of a solid waste landfill (MSW landfill) should require the following steps before operations begins:

- Grading the site area, constructing access roads and fences, and installation of signs, utilities.
- On-site access roads should be all-weather construction and wide enough to permit two-way truck.
- The site should have an office building with electricity, water, and sanitary services for employees and visitors.
- The site should have a building to store hand tools and equipment parts.

6. Equipment

Equipment falls into three functional categories: waste movement and compaction, earth cover transport and compaction, and support functions. *Table 1* shows the needs of equipment based on daily tonnage and population served. Selecting the type, size, quantity, and combination of machines required to move, spread, compact and cover waste depends on:

- Waste amount and type.
- Weather conditions.
- Site and soil conditions: topography, soil moisture and difficulty of excavation.
- The distance the cover material must be transported.
- Amount and type of soil cover.
- Compaction requirements; and
- Supplemental tasks, such as maintaining roads, assisting in vehicle unloading, and moving other materials and equipment around the site

Steel- wheeled compactors feature wheels studded with load concentrators of various designs. They maximize compaction and are suited to medium or large sites, which can support more than one machine (*Figure 5* - *Figure 7*).

Track-type tractors or dozers may handle or compact waste, as well as assist in cover excavation and compaction. They can be used for site preparation, road construction and maintenance. These are versatile units and are preferred for small operations in which one unit must perform a variety of functions.

Earth Movers: Rubber-tired loaders or dozers provide more speed and maneuverability than track-type units, and can haul cover, applying it up to approximately 1,000 feet from the working face. Rubber-tired scrapers are efficient for excavating and transporting cover soil when it is more than 1,000 feet from the working face. Where the soil is hard to excavate (e.g., clay or frozen soil), scrapers can be pushed with a bulldozer.

Draglines are efficient earth-movers but are only able to deposit soil within the area reached by the boom and are not suitable for transporting cover. Backhoes are suited for small, specialized excavation, such as for a leachate collection system. Dump trucks can be used with excavation equipment to move cover material. Motor graders are useful for road construction and maintenance, for berm and drainage construction, and for landscaping.

Maintenance and Backup: Regular equipment maintenance reduces breakdowns and identifies equipment problems early — before more costly and time-consuming repairs are needed. Provisions also must be made for backup equipment, by keeping additional equipment available.

Table 1: Number of equipment need with waste handling in a Landfill

Approximate Population	Daily Wastes Tons	Equipment Number	Equipment Type	Equipment weight, lbs	Accessory[a]
0-20,000	0-50	1	Tractor, crawler	10,000-30,000	Dozer blade, Front-end loader, (1-2 cu/yd), Trash blade
20,000-	50-150	1	Tractor, crawler	30,000-60,000	Dozer blade, Front-end loader, (2-4 cu/yd), Bullclam, Trash blade
		1	Scraper or dragline		
		1	Water truck		
50,000	150-300	1-2	Tractor, crawler	30,000+	Dozer blade, Front-end loader, (2-5 cu/yd), Bullclam, Trash blade
		1	Scraper or dragline[b]		
		1	Water truck		
>100,000	300[c]	1-2	Tractor, crawler	45,000+	Dozer blade, Front-end loader, (2-5 cu/yd), Bullclam, Trash blade
		1	Steel wheel compactor		
		1	Scraper or dragline[b]		
		1	Water truck		
		_[a]	Road grader		

a. Optional, depends on individual needs.
b. The choice between a scraper or dragline will depend on local conditions.
c. For each 500-ton increase add one more of each piece of equipment.
Source: G. Tchobanoglous, Integrated Solid Waste Management: Engineering Principles and Management Issues, 1993

Figure 5: A Typical Compactor

Figure 6: Steel-wheeled compactor

Figure 7: A Steel-wheeled compactor spreading waste in a working face

7. Operation

Over a typical operating day, wastes are placed, compacted, trimmed, and covered with soil. This daily accumulation of wastes is referred to as a cell. There are three general methods of landfills, which are:

1. area method
2. trench method, and
3. ramp or slope method.

1. Area Method

The area method is best suited for flat or gently sloping areas where some land depressions may exist. The wastes are spread, compacted and then covered with material which may need to be hauled in from adjacent areas as shown in Figure 8.

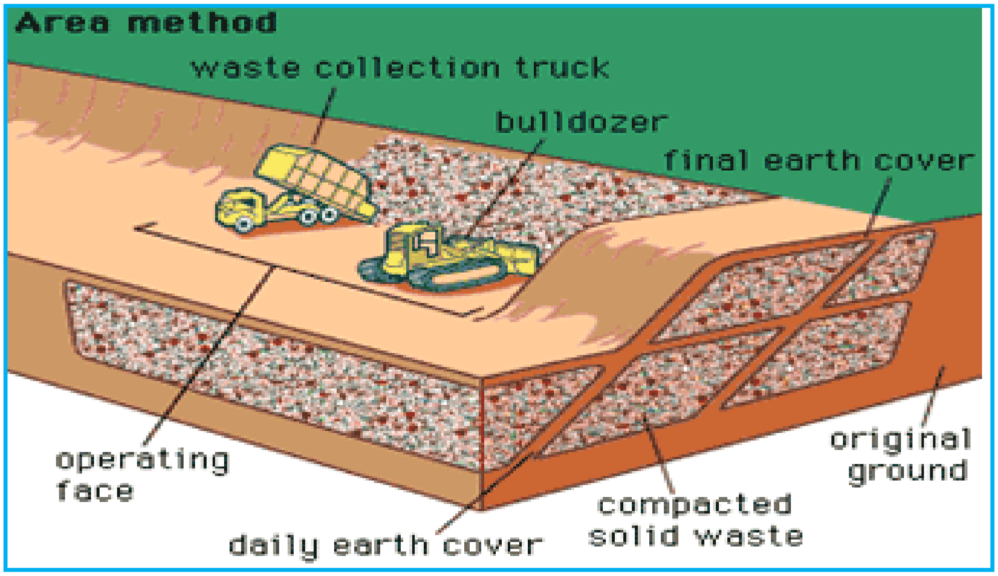


Figure 8: Area fills method of landfill operation

2. Trench Method

The trench method consists of an excavated trench into which the solid wastes are spread, compacted, and covered. The trench method is best suited for nearly level land where the water table is not near the surface. Usually, wastes are placed in one end at the bottom of the trench, compacted, and covered with the soil that was excavated during the landfill construction as shown in *Figure 9*. Currently trench method is not encouraged as it was practiced for unlined and smaller landfills. So, this method is mentioned here for information purpose only.

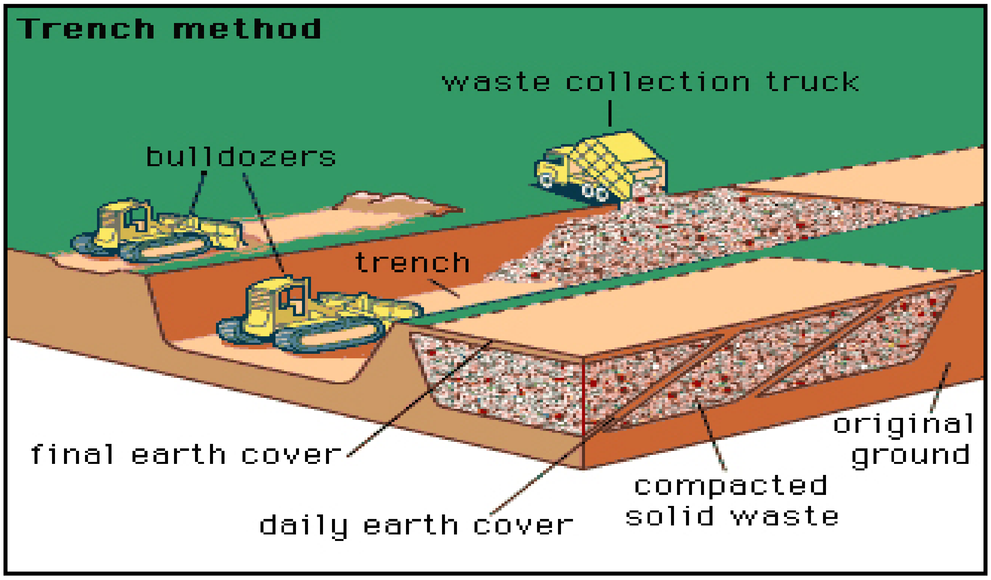


Figure 9: Trench fills method of landfill operation

3. Ramp, or slope method

The slope or ramp is sometimes used in combination with the other two methods. The wastes are spread on an existing slope, compacted, and covered. This variation may be suitable for most areas. The cover materials usually come from just ahead of the working face.

The landfill method can be adapted to suit almost any circumstances, but there is usually one best method for any specific instance.

There is another method called baled method, but it is used rarely in solid waste landfills now a days. However, in one site both area and trench methods can be used simultaneously in two different areas of the landfill. Spread into two-foot layers or less and compacted at the working face. Lift height is not recommended to exceed 10 feet.

7.1 Daily Cover

Daily cover consisting of six inches of compacted soil or other approved material shall be placed upon all exposed solid waste prior to the end of each operating day. **Alternate daily cover (ADC**) can be applied as approved by the regulatory agencies. http://www.impactmovie.com/landfill/

7.2 Intermediate Cover

Intermediate cover of at least six inches of additional compacted soil shall be applied whenever an additional lift of refuse is not to be applied within 30 days.

7.3 Final Cover

Final cover construction will be initiated in accordance with the requirements of Closure Regulations when the following pertain:

- An additional lift of solid waste is not to be applied within one year.
- Any area of a landfill attains final elevation and within 90 days after such elevation is reached. The director may approve alternate timeframes if they are specified in the facility's closure plan.
- An entire landfill's permit is terminated for any reason, and within 90 days of such denial or termination.

7.4 Waste Handling and Placement

Waste movement usually is confined to spreading the waste on the working face with compactors or dozers after loads are deposited by trucks. Movement over long distances is inefficient with this equipment. *Figure 10* shows the uploading, spreading and compaction process of a landfill working face.

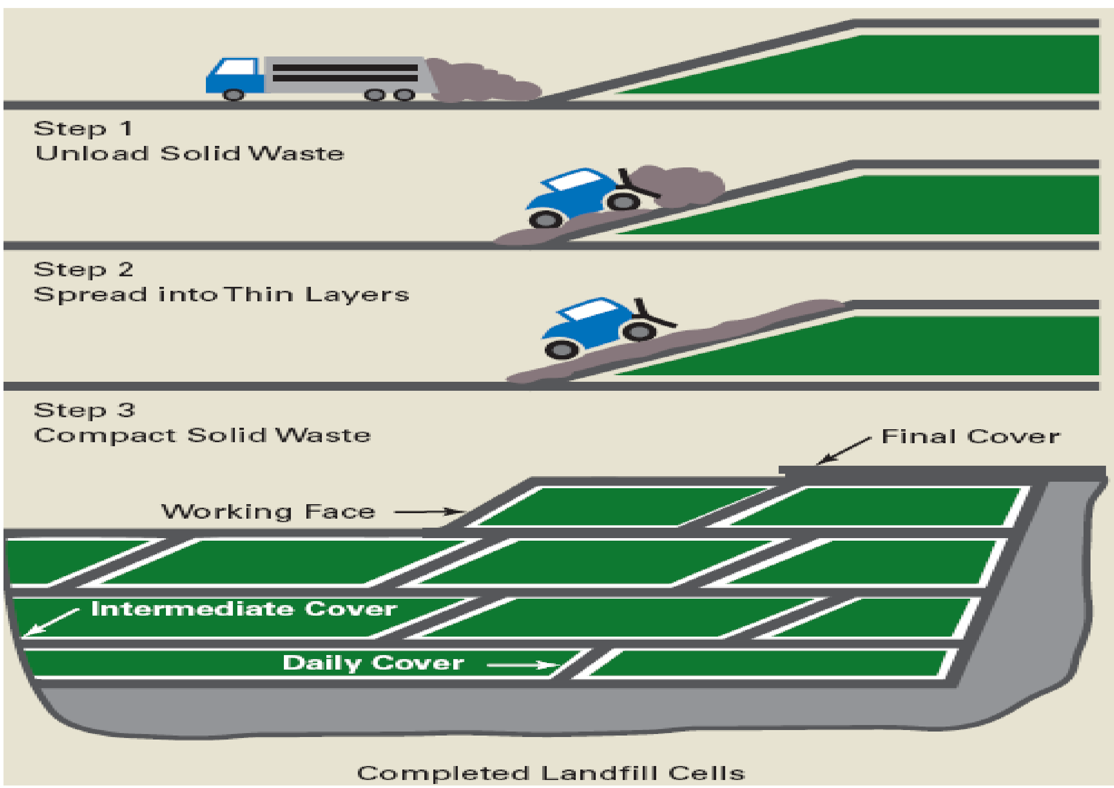


Figure 10: Uploading, spreading, and compaction of solid waste in the landfill working face

7.5 Compaction

Compaction is critical to extending the landfill's life. To achieve high, in-place waste densities, a compactor may be necessary as shown in Figure 7 and Figure 11. A minimum in-place compaction density of 1,000 pounds per cubic yard is recommended. The number of passes that the machine should make to achieve optimum compaction depends on wheel pressure, waste compressibility and compaction layer thickness. Generally, three to five passes are recommended. Although additional passes will compact the waste to a greater extent, the return on the effort diminishes beyond six passes.

Each site will have different compaction results, depending on waste layer thickness. However, there will be a decrease in density above a compacted layer thickness of about one foot to ½ foot. The best compaction results from compacting waste in layers 1- to 2-feet thick.

The working face's slope also affects compaction. As the slope increases, vertical compaction pressure decreases, the lower the slope, the higher the compaction. Nevertheless, the feasibility of a nearly flat working face must be weighed against the larger area over which the waste and cover soil must be spread.

Figure 11: Landfill Compactor being used in working face

7.6 Waste Shredding

Incoming refuse is mechanically processed into small, uniformly sized pieces immediately before landfilling or at a transfer facility prior to transport. Shredding can occur as a sole process or as a combination of the process before disposal or as part of the mechanical separation process that removes recyclable or reusable materials from the waste stream.

Shredded refuse, after compaction, gains greater density than compacted, unprocessed MSW. This helps preserve landfill space and reduce the amount of required cover material. In addition, landfill settlement and stabilization may be more uniform over time due to shredding the waste. These benefits must be compared with the significant capital and operating costs of the shredding equipment, space required to process the waste, and historically significant potential for worker injury and equipment downtime.

7.7 Baling Solid Waste

Baling MSW compacts refuse into high-density blocks that are stacked and covered with other waste or daily cover in a landfill. Bale density can range between 1,000 to 1,900 pounds per cubic yard[2]. Like shredding, in some circumstances, baling waste before final disposal may save landfill space due to increased density and reduced cover material requirements as well as can reduce the amount of blowing litter from the landfill.

7.8 Cover Material Requirements

RCRA Subtitle D standards require landfill that owners or operators have cover solid waste working face with 6-inch of earthen material at the end of each day. Alternative daily cover (ADC) materials of varying thicknesses may be allowed in certain jurisdictions through a review process. Daily and weekly covers prevent waste exposure to birds, insects, and rodents, which can transmit human disease and the flying birds can interfere with the flights, if the landfill is near an airport. Covers also reduce the exposure of combustible materials to ignition sources, reduce odors and control litter.

7.9 Additional Controls

Good housekeeping procedures are necessary. Subtitle C requirements and many state regulations mandate operation controls. A well-planned and maintained landfill provides effective controls for access, aesthetics, wind-blown paper pickup, insects spreading, wildlife and rodents issues, littering airport nuisance by birds, odors and fires, noise due to equipment operations, road dust and tracking, scavenging, gas, leachate, adverse weather, and personal safety[3].

8. Environmental Considerations

- Leachate and gas are the by-products of solid waste landfill operation.
- There is a probability that diseases may be spread by vectors and air and water may be polluted from landfill operations due to the gas emission and leachate disposal.

[2] https://www.waste360.com/mag/waste_landfill_equipment_operating accessed on August 13, 2020

[3] https://www.waste360.com/mag/waste_landfill_equipment_operating accessed on August 13, 2020

- Good compaction of the waste, daily covering of waste with good compaction of the cover, and good housekeeping are musts for control of flies, rodents, and fires.
- Subtitle D standards prohibit routine open burning of waste. Infrequent burning of agricultural and silvicultural waste, diseased trees, or debris from land clearing or emergency cleanup operations is allowed but must meet air pollution control regulations. Burning areas should be far from the landfill to avoid igniting other waste.
- The U.S. Environmental Protection Agency (EPA), Washington, D.C., has established New Source Performance Standards (NSPS) and Emission guidelines. As mandated by the Clean Air Act, these rules require landfills to collect landfill gas and prescribe design standards and performance limits for gas extraction systems.

9. Bioreactor Landfill

Reactor: A containment structure in which reactions are initiated and controlled to optimize a desired outcome.

Bioreactor: A biologically-mediated reactor.

Bioreactor Landfill: A bioreactor where containment structure is a landfill or a portion of a landfill.

9.1 Definition

The Solid Waste Association of North America (SWANA) has defined a bioreactor landfill as "any permitted Subtitle D landfill or landfill cell where liquid or air is injected in a controlled fashion into the waste mass in order to accelerate or enhance biostabilization of the waste."

EPA's Office of Research & Development (ORD) proposed definition: A landfill designed and operated in controlled manner with the express purpose of accelerating the degradation of SW inside a landfill containment system. A pictorial view of bioreactor landfill is shown in Figure *12*.

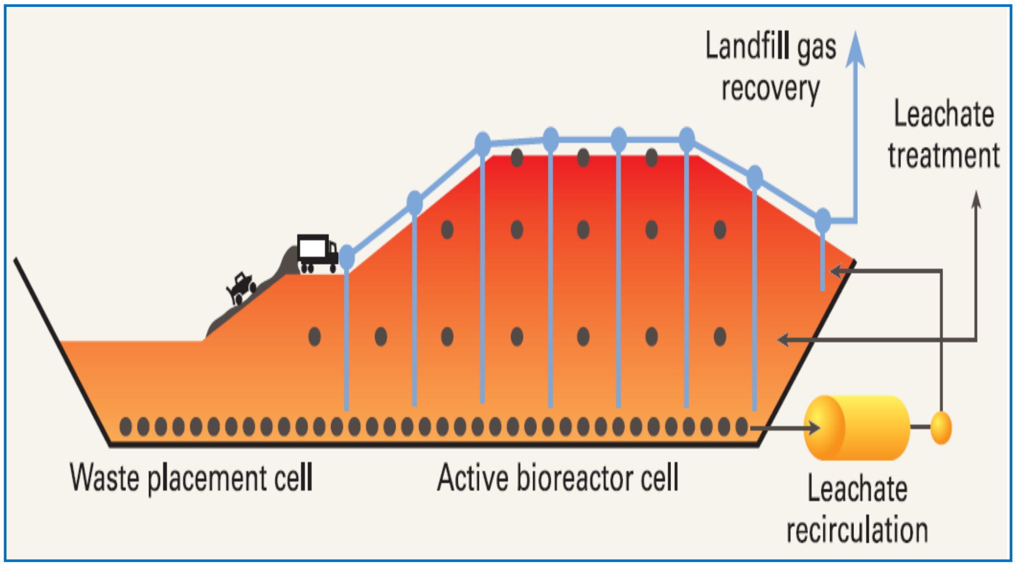


Figure 12: A pictorial view of Bioreactor Landfill

9.2 Types of Bioreactor Landfill – Only for Solid Waste

1. Aerobic
2. Anaerobic, and
3. Hybrid

1. Aerobic

In an aerobic bioreactor landfill, leachate is removed from the bottom layer, piped to liquids storage tanks, and re-circulated into the landfill in a controlled manner. Air is injected into the waste mass, using vertical or horizontal wells, to promote aerobic activity and accelerate waste stabilization (Figure *13*).

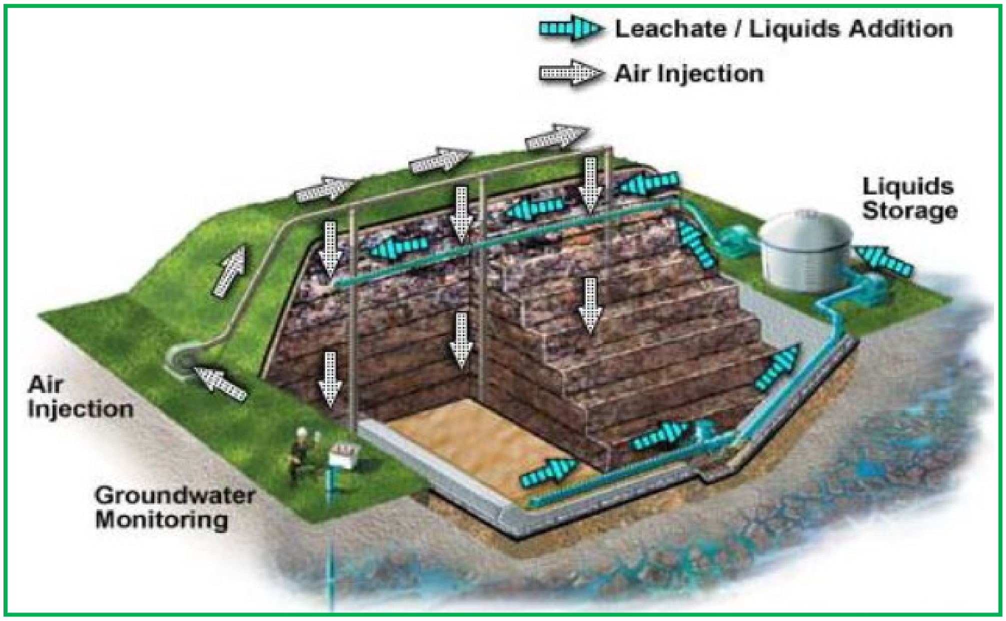


Figure 13: A typical Bioreactor Landfill – Aerobic

2. Anaerobic

In an anaerobic bioreactor landfill, moisture is added to the waste mass in the form of re-circulated leachate and other sources to obtain optimal moisture levels. Biodegradation occurs in the absence of oxygen (**anaerobically**) and produces landfill gas. Landfill gas, primarily methane, can be captured to minimize greenhouse gas emissions and for energy projects (Figure *14*).

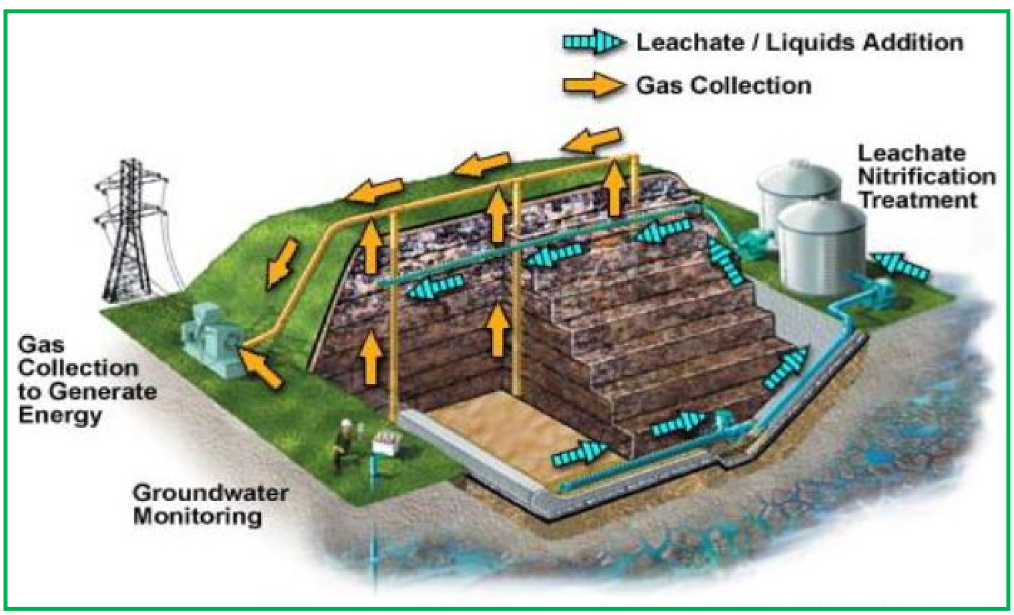


Figure 14: A typical Bioreactor Landfill – Anaerobic

3. Hybrid (Aerobic-Anaerobic)

The hybrid bioreactor landfill accelerates waste degradation by employing a sequential aerobic-anaerobic treatment to rapidly degrade organics in the upper sections of the landfill and collect gas from lower sections. Operation as a hybrid results in the earlier onset of methanogenesis compared to aerobic landfills. The uppermost lift or layer of waste is aerated, while the lift immediately below it receives liquids. Landfill gas is extracted from each lift below the lift receiving liquids. Horizontal wells that are installed in each lift during construction are used to transport air, liquids, and landfill gas (Figure *15*).

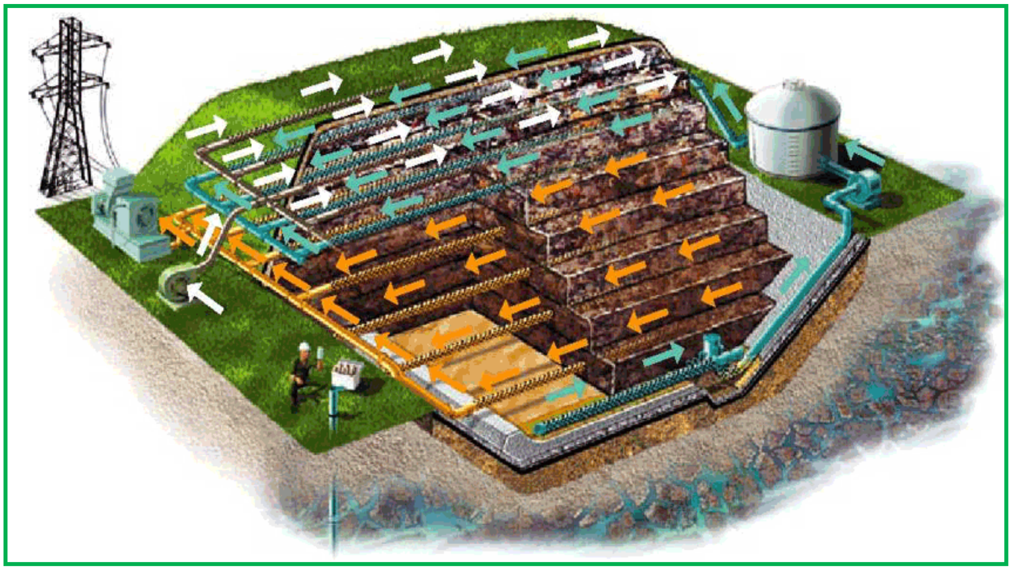


Figure 15: A typical Bioreactor Landfill – Hybrid (Aerobic-Anaerobic)

9.3 Features Unique to Bioreactor Landfill

- The bioreactor accelerates the decomposition and stabilization of waste.
- At a minimum, leachate is injected into the bioreactor to stimulate the natural biodegradation process.
- Bioreactors often need other liquids such as stormwater, wastewater, and wastewater treatment plant sludges to supplement leachate to enhance the microbiological process by purposeful control of the moisture content and differs from a landfill that simple recirculates leachate for liquids management. Landfills that simply recirculate leachate may not necessarily operate as optimized bioreactors.
- Moisture content is the single most important factor that promotes the accelerated decomposition.

- The bioreactor technology relies on maintaining optimal moisture content near field capacity **(approximately 35 to 65%)** and adds liquids when it is necessary to maintain that percentage. The moisture content combined with the biological action of naturally occurring microbes decomposes the waste. The microbes can be either aerobic or anaerobic.
- A side effect of the bioreactor is that it produces landfill gas (LFG) such as methane in an anaerobic unit at an earlier stage in the landfill's life and at an overall much higher rate of generation than traditional landfills.

Bioreactor Landfill - Advantages

- Accelerate waste degradation
- Reduced long-term risks
- Extend landfill life
- Reduced need for new landfills
- More efficient landfill gas (LFG) collection and energy recovery
- More economical leachate treatment and disposal

Bioreactor Landfill - Disadvantage and Risks:

- Potential increased gas emissions
- Additional cost
- Odor problem if gas is not managed properly
- Leachate seeps
- Side slope instability
- Potential for fires
- Water logging

Bioreactor Landfill – Concepts - Figure *16*

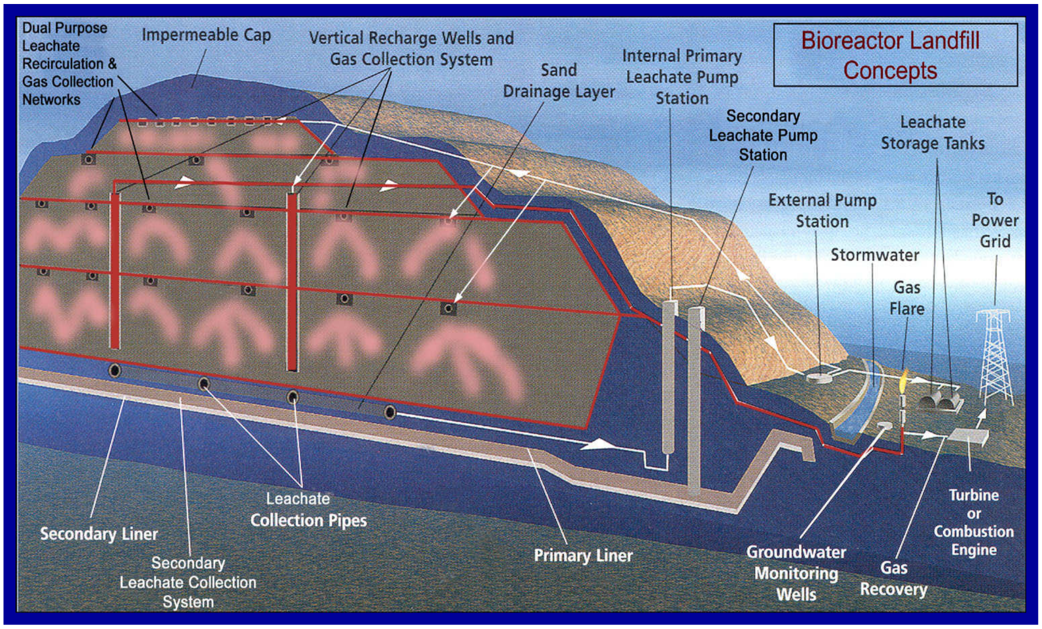


Figure 16: Conceptual representation of Bioreactor Landfill

9.4 Leachate Recirculation and/or Liquid Addition Methods

1. Ponding
2. Spraying
3. Vertical Wells
4. Horizontal Wells
5. Leach Fields

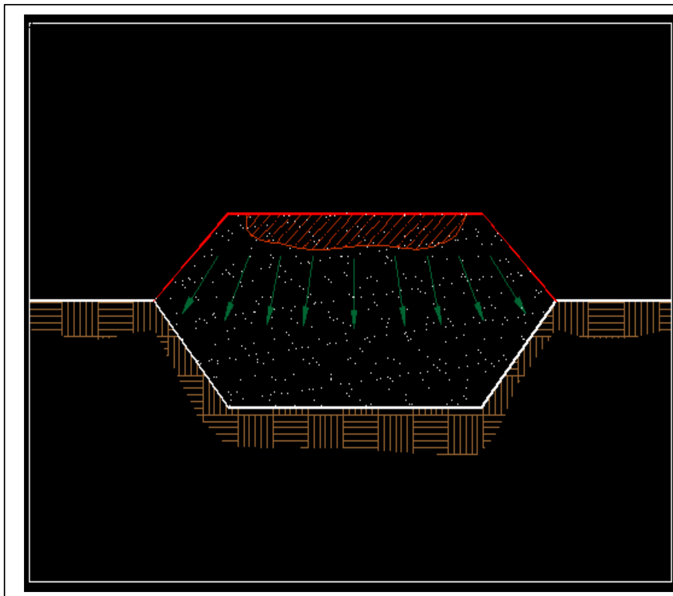


Figure 17: Concept of Ponding

1. **Ponding -** Figure *17* and Figure *18*

- **Advantages**
  - ✓ Low cost
  - ✓ Immediate implementation
  - ✓ Simple

- **Disadvantages**
  - ✓ Potential odors
  - ✓ Potential short-circuiting of liquids
  - ✓ Aesthetics

Figure 18: Ponding Used in Landfill

2. **Spraying -** Figure *19*
   - Advantages
     - ✓ Low cost
     - ✓ Immediate implementation
     - ✓ Simple
     - ✓ Good distribution of moisture if done consistently

   - **Disadvantages**
     - ✓ Potential odors
     - ✓ Can only be used while landfill is operating

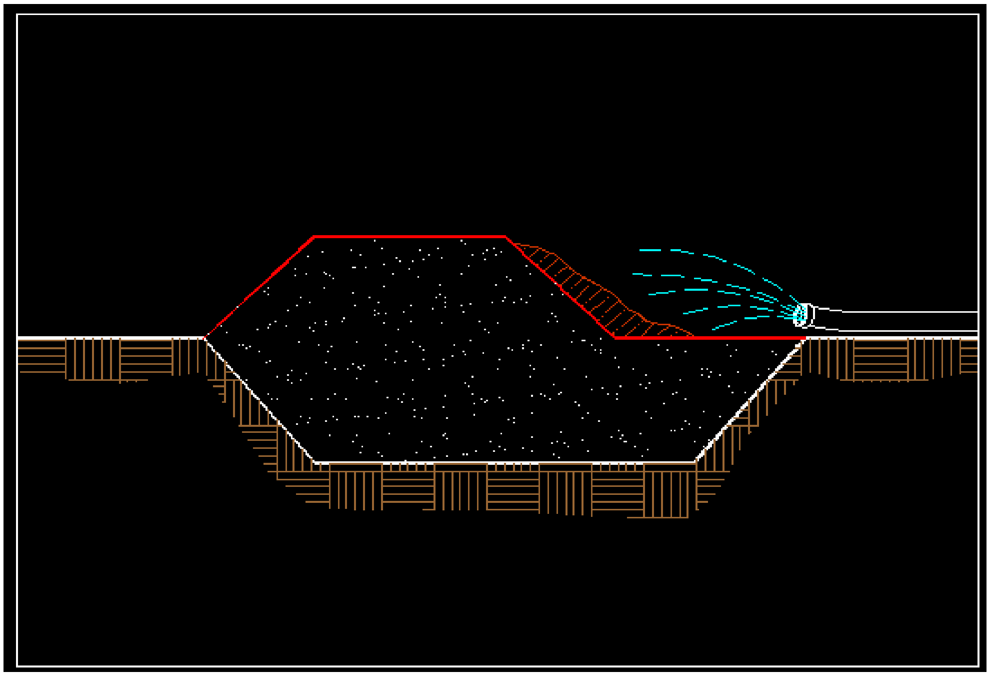


Figure 19: Concept of Spraying

3. **Vertical Wells -** Figure *20*
   - **Advantages**
     - ✓ Moderate cost
     - ✓ Wells can be implemented relatively quickly
     - ✓ Can be implemented and used after landfill cell is completed (closed)
   - **Disadvantages**
     - ✓ Potential flooding of LFG wells
     - ✓ Limited distribution

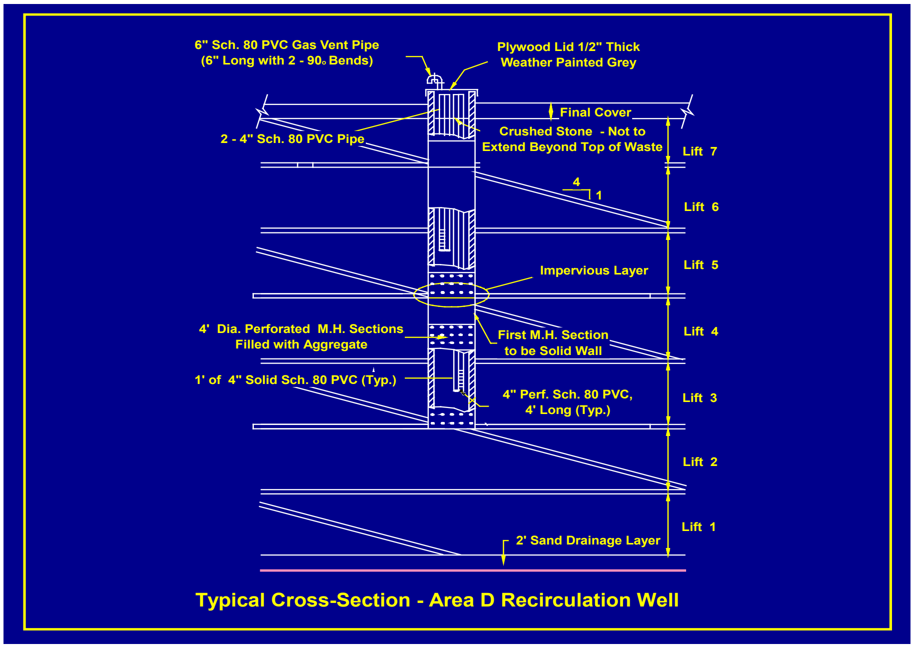


Figure 20: Concept of Vertical Wells

4. **Horizontal Wells -** Figure *21*
   - **Advantages**
     - ✓ Ability to recirculate significant quantities of leachate
     - ✓ Can be implemented and used after landfill cell is completed (closed)
   - **Disadvantages**
     - ✓ Expensive
     - ✓ Complicated

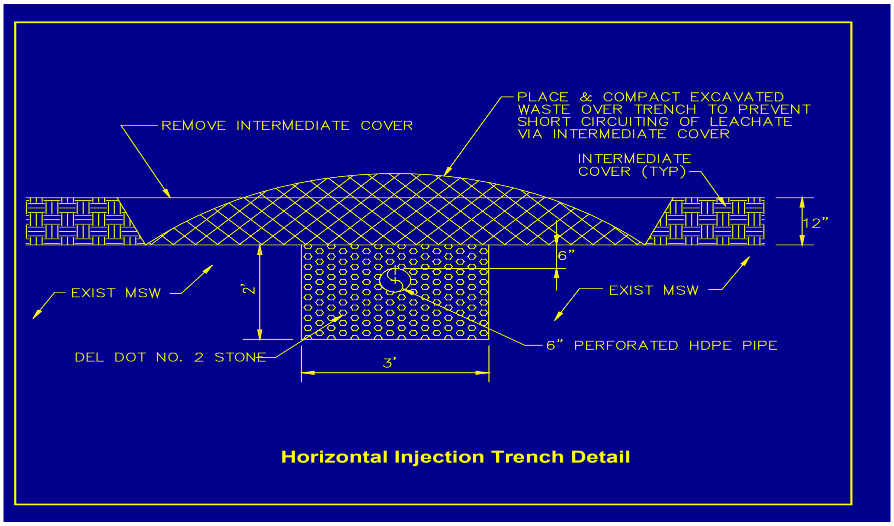


Figure 21: Concept of Horizontal Wells

5. **Leach Field -** Figure *22*
   - **Advantages**
     - ✓ Can be implemented and used after landfill cell is completed (closed)
   - **Disadvantages**
     - ✓ Need to wait until landfill cell is completed (closed)

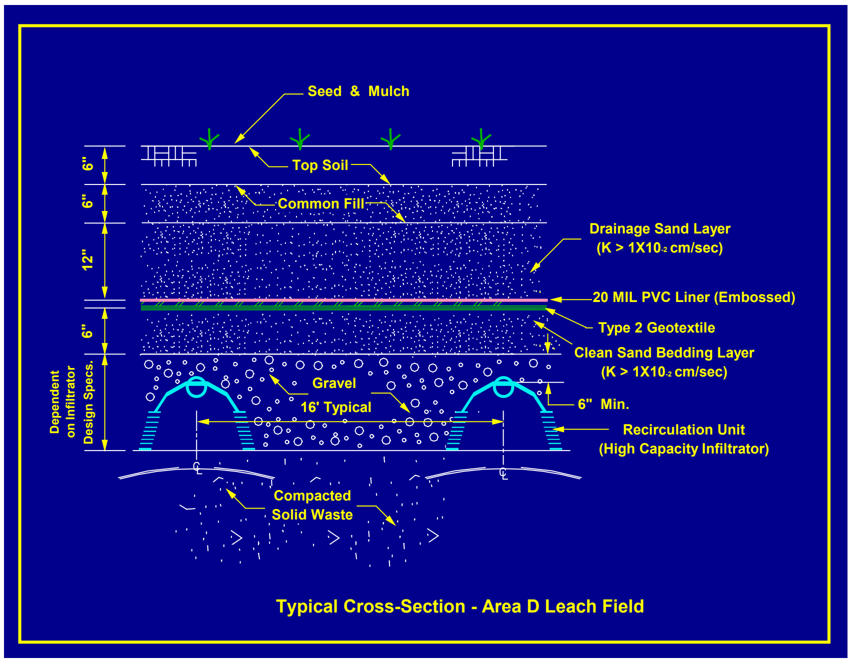


Figure 22: Concept of Leach Field

10. Landfill Design

The design of the landfill (schematics - Figure *23* and Figure *24*) has many components including:

- site preparation
- buildings
- groundwater monitoring wells
- size
- liners
- leachate collection system
- final cover system
- gas monitoring, collection, and control system
- run-on and run-off control system.

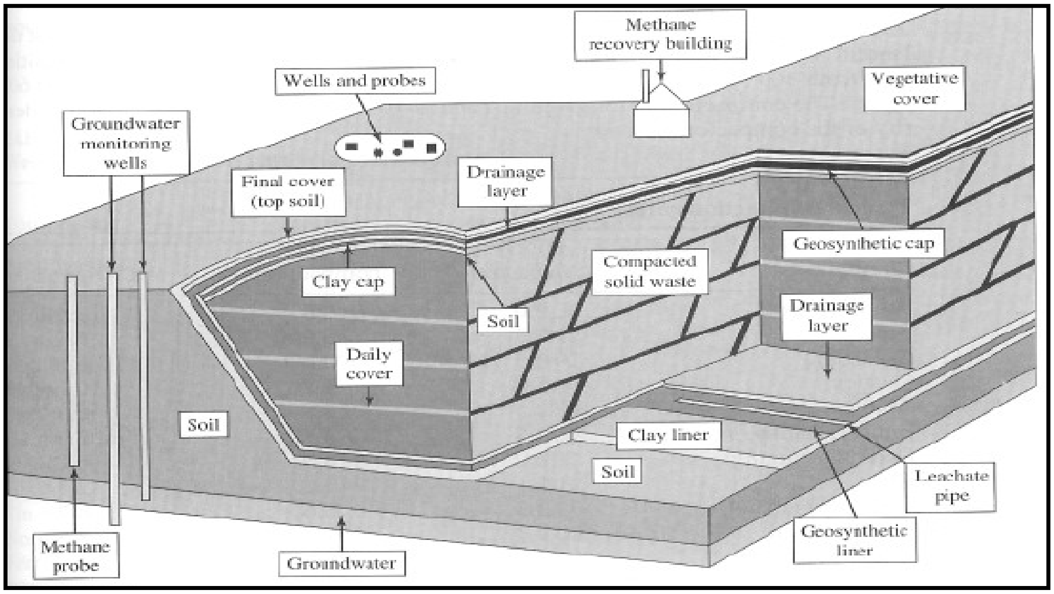


Figure 23: A schematic of LF section

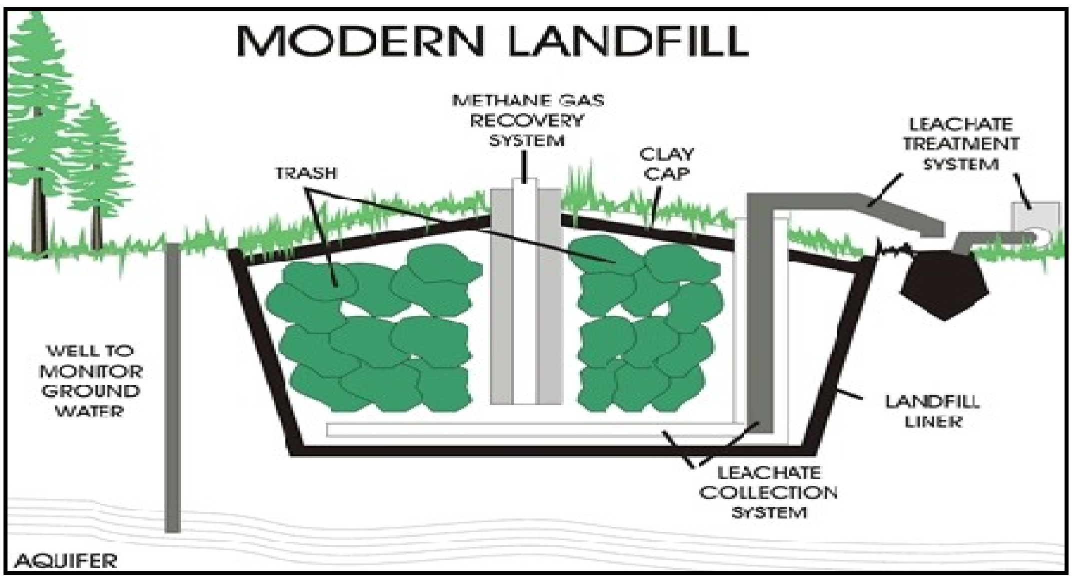


Figure 24: A schematic of LF section with groundwater monitoring wells, leachate, and gas collection systems

10.1 Landfill Groundwater Monitoring

- Groundwater monitoring for landfills is mandatory by the solid waste regulations.
- Regulations require that at least one upgradient and three downgradient monitoring wells shall be required within a compliance network.

- The designer may produce a greater number of upgradient and downgradient wells depending on the hydrogeology of the site.
- Regulations require that the owners or operators of sanitary landfills must perform quarterly ground water monitoring.

10.2 Landfill Capacity/Size and Life

The landfill capacity/size is also designated as air space or volume or service life.

- To estimate the size of a landfill, generation rate of waste, population estimate, and number of years of operation are necessary.
- In other words, if the landfill area is known, the volume between the base grade and final elevation can be estimated by using computer software that are commercially available.
- If the volume of the landfill and the density of waste are known, based on the daily throughput of waste (volume//day of ton/day), the landfill life can be estimated.

Example 1: Calculate how much daily cover will be needed and how much total volume (air space) will be used by the daily cover during the life of the hazardous waste landfill. How much longer the landfill can be used if daily cover were not employed. The landfill is 500 m by 300 m in an average plan and 15 m high. Daily fitting rates are 15 m by 10 m by 2 m and daily cover is 0.3 m.

Solutions:

Given, landfill length, L =	500	m	Width, w =	300	m	depth/height,	15	m
Daily filling rates are =	15	m by	10	m by	2	m daily cover	0.3	m
The total landfill airspace, $\forall_1$	500 m x 300 m x 15 m =		2,250,000	m^3				
Each daily layer (lift) has a volume of $\forall_2$ = 15 m x 10 m x 2 m =				300	m^3			
Daily cover has a volume of $\forall_3$ =		15 m x 10 m x 0.3 m =		45	m^3 **ANS.**			
The volume of airspace used by daily cover (in %), $\forall_r$ $\forall_3/\forall_1$ =				(45 / 300) x 100 =		15%	**ANS.**	
The life of he landfill with daily cover, $t_1 = \forall_1/(\forall_2 + \forall_3)$ = 2250000/(300 + 45) =						6522	days	
					=	17.87	years	
The life of he landfill without daily cover, $\forall_1/\forall_2$ =			2250000/300 =		7,500	days		
				=	20.55	years		
Therefore, life of the landfill will extended by, $t_3 = t_2 - t_1$ =				7500 - 6522 =		978	days	
					=	2.68	years **ANS.**	

10.3 Landfill Liner System

A landfill's major purpose and one of its biggest challenges is to contain the trash so that the trash does not cause problems in the environment. The **bottom liner prevents the trash from coming in contact with the outside soil, particularly the groundwater**. In MSW landfills, the liner is usually some type of durable, puncture-resistant synthetic plastic (polyethylene, linear low-density polyethylene, polyvinylchloride - **LLDPE**, high-density polyethylene, polyvinylchloride - HDPE). It is usually 30-100 mils thick. The plastic liner may also be combined with compacted clay soils as an additional liner. The plastic liner may also be surrounded on either side by a fabric mat (**geotextile mat**) that will help to keep the plastic liner from tearing or puncturing from the nearby rock and gravel layers. **RCRA Subtitle D** requires that solid waste landfills must have a bottom composite liner system that consists of (from top to down) - Figure *25* to Figure *30*:

- A leachate drainage layer (12-18-inch-thick drainage materials with $k \geq 1.0x10^{-3}$ cm/sec)
- A flexible membrane liner (FML), at least 30-mil thick if LLDPE is used or at least 60-mil thick if HDPE is used
- A minimum 24-inch-thick compacted clay layer with a permeability of $k \leq 1.0x10^{-7}$ cm/sec.
- A prepared sub-base to protect the liner by preventing liner failure through subsidence or structural failure of the liner system .

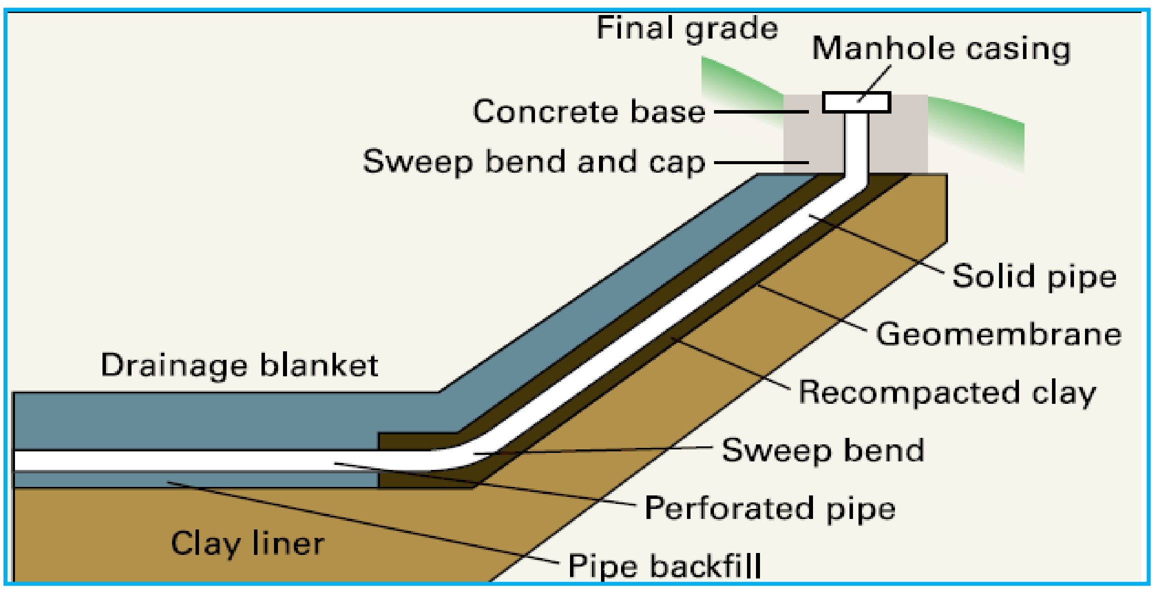


Figure 25: A typical bottom liner system

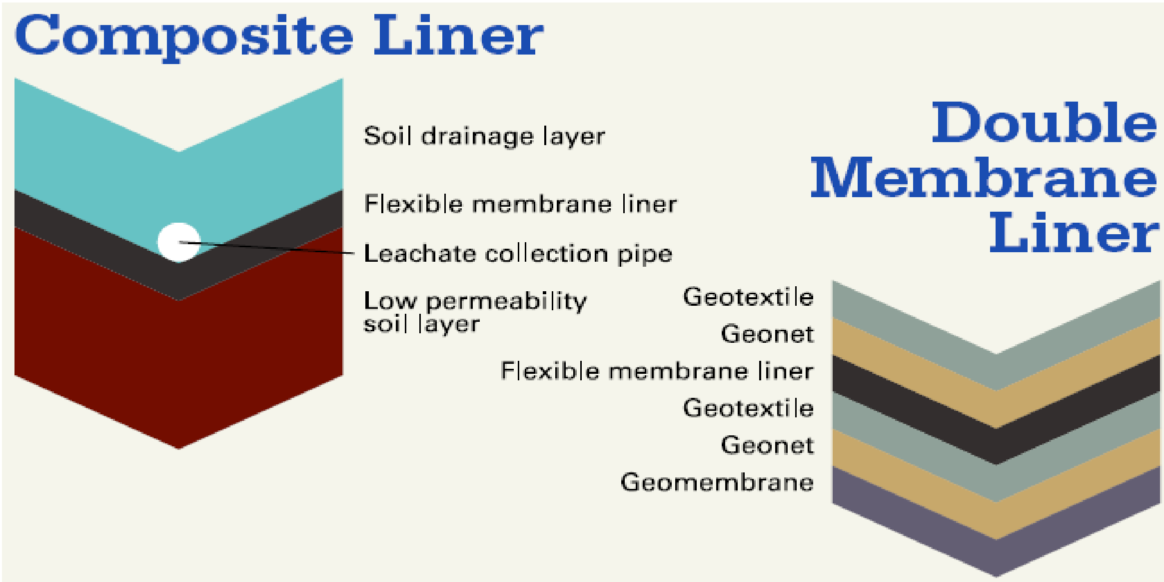


Figure 26: Typical liner systems with composite and double liner. Subtitle D (solid waste landfill) landfill does not require double liners. Only Subtitle C (hazardous waste landfill) landfill requires double liners

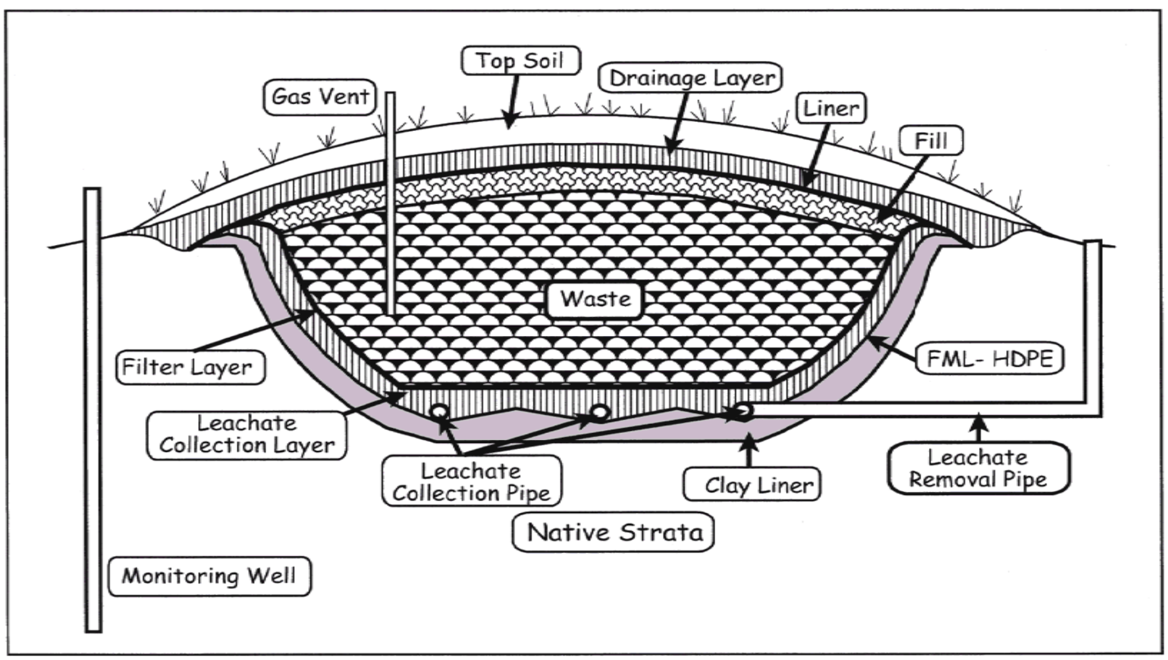


Figure 27: A typical liner system with different components

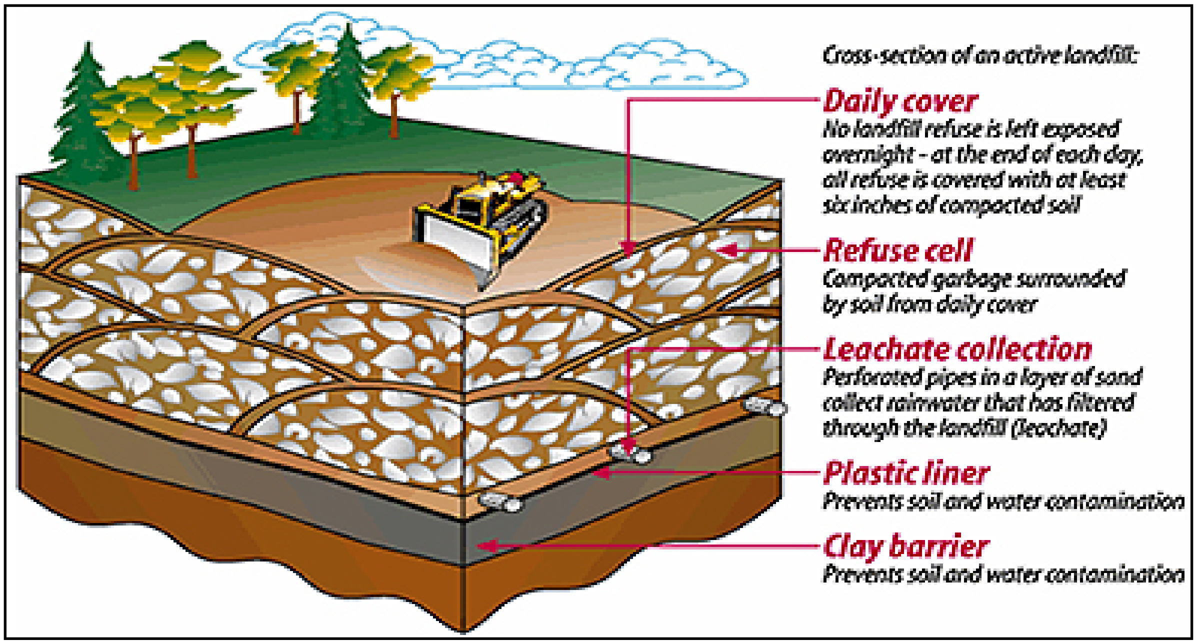


Figure 28: A typical landfill cross-section with different layers

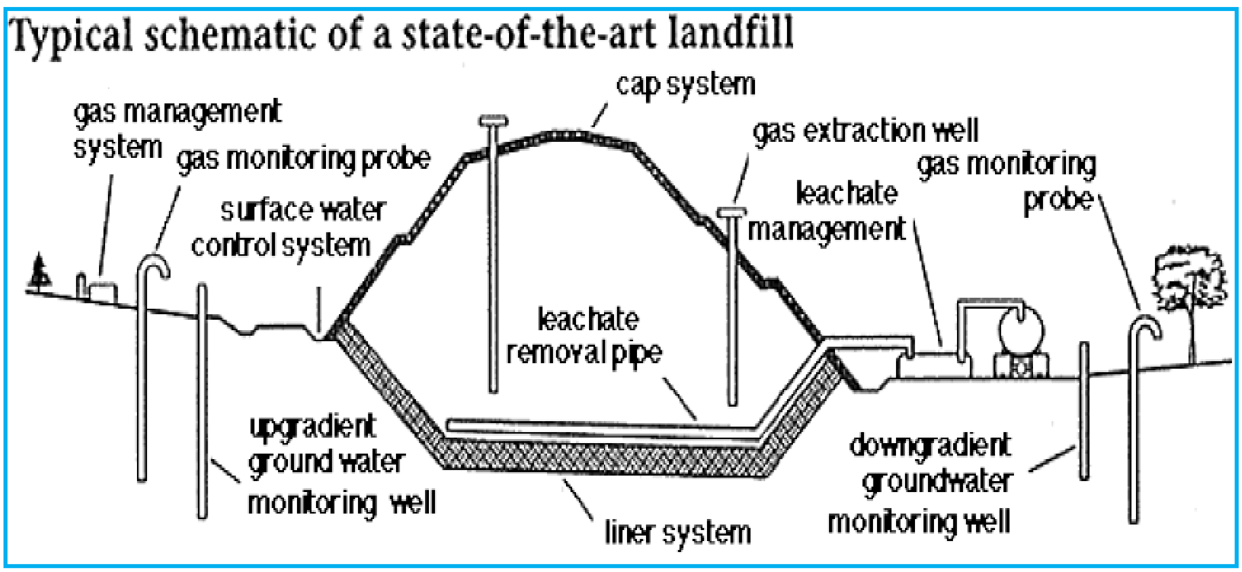


Figure 29: A typical landfill cross-section with gas and groundwater monitoring systems

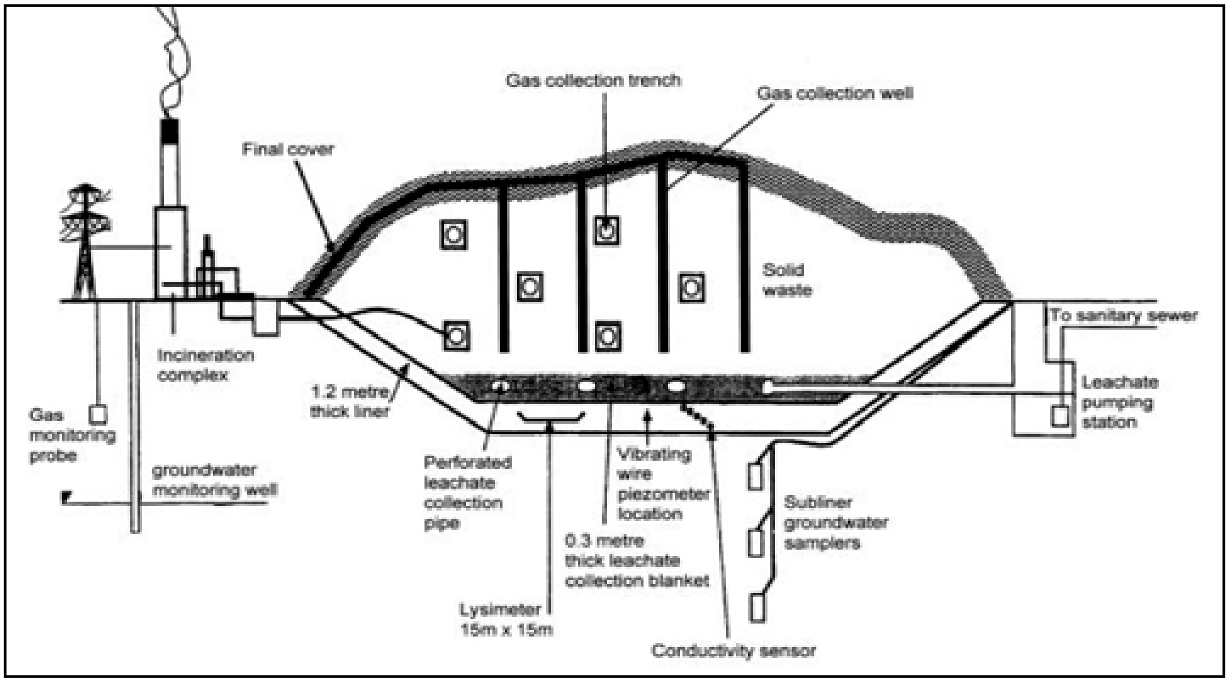


Figure 30: A typical landfill cross-section with gas flaring system

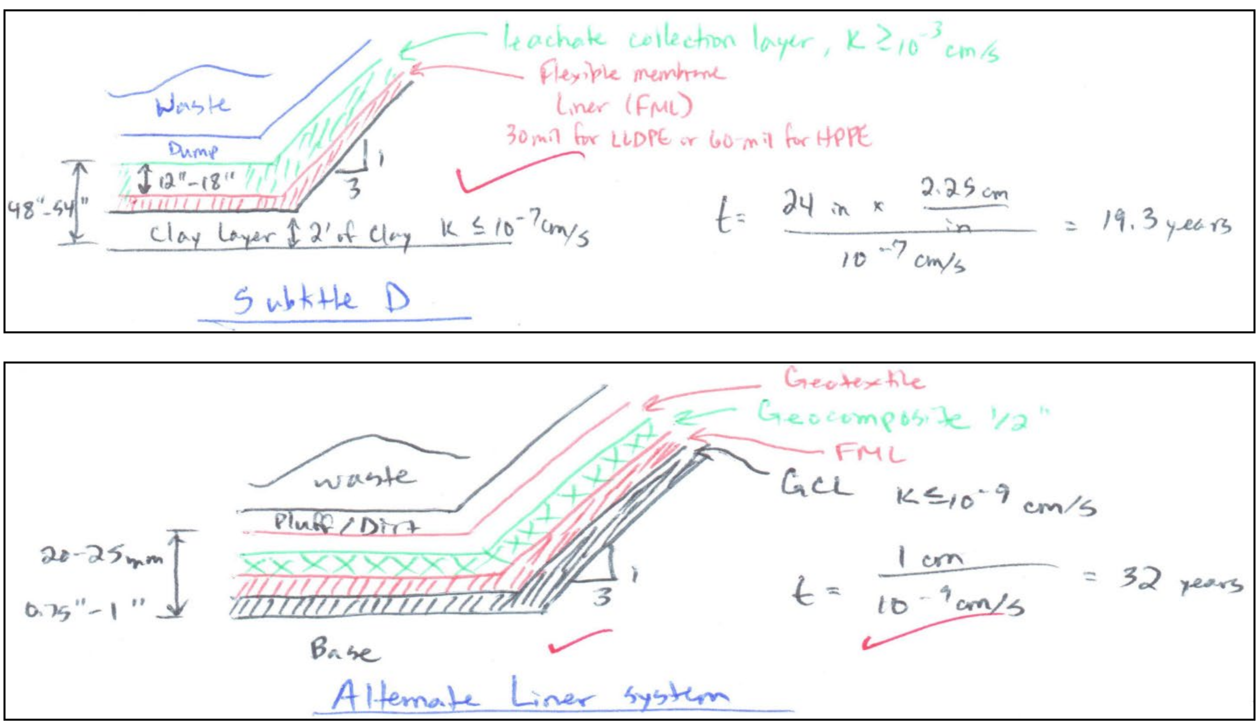


Figure 31: Cross-sectional views for typical Subtitle D and Alternate Liner Systems

- HELP model is run for both Subtitle D and Alternate liner systems (Figure *31*) and the percolations through the 24-inch clay liner and Geosynthetic Clay Liner (GCL) are calculated.
- If the percolation through GCL for alternate liner is less than or equal to (≤) the percolation through the 24-inch clay liner for Subtitle D liner, the alternate liner is considered to be equivalent to Subtitle D liner and it is acceptable.

Example 2: Estimate the volumetric flowrate through a compacted clay liner at a landfill measuring 3.0 ha. The liner thickness is 1 m (3 ft) and the saturated hydraulic conductivity is $1.0\text{x}10^{-7}$ cm/s. Assume 0.33 m (1 ft) water ponded on the liner.

Solutions:

Given, *A* =	3	ha =	30000	m^2
k =	1.00E-07	cm/s	1E-09	m/s
Liner thickness, ***T*** =	1	m =	3.281	ft
Water/Leachate depth on liner, ***H*** =	0.33	m =	1.08	ft
Using Darcy's flow equation,	$Q = kAi$			
Where, ***i*** =	$\frac{H + T}{T}$	=	$\frac{0.33 + 1}{1}$	
		=	**1.3300**	
Q =	0.000000001 m/s x 30000 m^2 x 1.33			
=	3.99E-05	m^3/s		
=	**3.45**	**m^3/day ANS.**		

10.4 Landfill Leachate Collection System

The leachate collection system shall be designed and placed:

- To prevent causing failure of the liner.
- To filter and prevent migration of fines to the drainage layer from above; and
- So that no more than one-foot head of leachate may accumulate over the liner at its lowest point excluding manifold trenches and sumps.

The tanks or impoundments used for storage of leachate shall have a flow equalization and surge capacity at least equal to the maximum expected production of leachate from **HELP Model** run for any **seven-day** period for the life of the facility. The storage tanks and impoundments shall be aerated as necessary to prevent and control odors. Leachate storage impoundments (Figure *32*) shall be equipped with a liner system that shall provide equal or greater protection of human health and the environment than that provided by the liner of the cells producing the leachate. At a minimum, a synthetic component will be required.

Figure 32: A leachate collection pond is designed to catch the contaminants that can get into water that goes through the trash in a landfill

Example 3: Determine the spacing between pipes in a leachate collection system by using granular drainage material and the following properties. Assume that most conservative design all storm water from 24-hr, 25-year storms enter the leachate collection system.

Design storm (24-hr, 25-year) = 8.2 inch = 0.00024 cm/s
Hydraulic conductivity of the granular material = 10^{-2} cm/s
Drainage slope = 1.5%
Maximum leachate depth on liner = 14.2 cm

Solutions:

Using Richardson and Zhao equation, $Y_{max} = \frac{p}{2} \times \frac{q}{K}\left[\frac{K\tan^2\alpha}{q} + 1 - \frac{K\tan\alpha}{q}\left(\tan^2\alpha + \frac{q}{K}\right)^{\frac{1}{2}}\right]$

where, Y_{max} = maximum leachate head on the liner (cm) =	14.20	cm			
L = the horizontan drainage distance (cm) =					
tanα = the inclination of liner in horizontal (deg) =	1.50%	=	0.0150		
q = the vertical inflow (infiltration), defined in this equation as from a 24-hr, 25-year storm (cm/day) =	0.00024	cm/s =	20.74	cm/day	
K = hydraulic conductivity of the drainage layer (cm/day) =	0.01	cm/s =	864	cm/day	
p = the distance between collection pipes (cm) =	???				

Rearranging the equation we get,

$$p = \frac{2Y_{max}}{\left(\frac{q}{K}\right)\left[\frac{K\tan^2\alpha}{q} + 1 - \frac{K\tan\alpha}{q}\left(\tan^2\alpha + \frac{q}{K}\right)^{\frac{1}{2}}\right]}$$

Denominator = $\frac{20.736}{864}$ $\frac{864\ (0.015)\text{^}2}{20.736}$ + 1 - $\frac{864 \times 0.015}{20.736}$ (0.015^2+(20.736/864)^1/2)

= 0.0219

∴ p = $\frac{2 \times 14.2}{0.0219}$ = **1297** **cm =** **12.97** **m ANS.**

10.5 Landfill Final Cover System

Owner or operator of all sanitary landfills shall install a final cover system that is designed to achieve the performance requirements of the regulations. The final cover system shall be designed and constructed to (from bottom to to). Typical final cover systems are shown in Figure *33*:

- Have an **18 to 24-inch** (45 to 61-cm) infiltration layer with a hydraulic conductivity less than or equal to the hydraulic conductivity of any bottom liner system or natural subsoils present, or a hydraulic conductivity no greater than **$1.0\text{x}10^{-5}$ cm/sec**, whichever is less; and
- Minimize infiltration through the closed disposal unit by the use of an infiltration layer that is constructed of earthen material; and
- Minimize erosion of the final cover by the use of an erosion layer that contains a minimum of **6-inch** (15-cm)of earthen material that is capable of sustaining native plant growth and provide for protection of the infiltration layer from the effects of erosion, frost, and wind.

Alternate arrangement (Figure *33*b) could be acceptable after meeting the minimum requirements mentioned above. Finished side slopes shall be stable and be configured to adequately control erosion and runoff. Slopes of 33% (3H : 1V) will be allowed provided that adequate runoff controls are established. Steeper slopes may be considered if supported by necessary stability calculations and appropriate erosion and runoff control features.

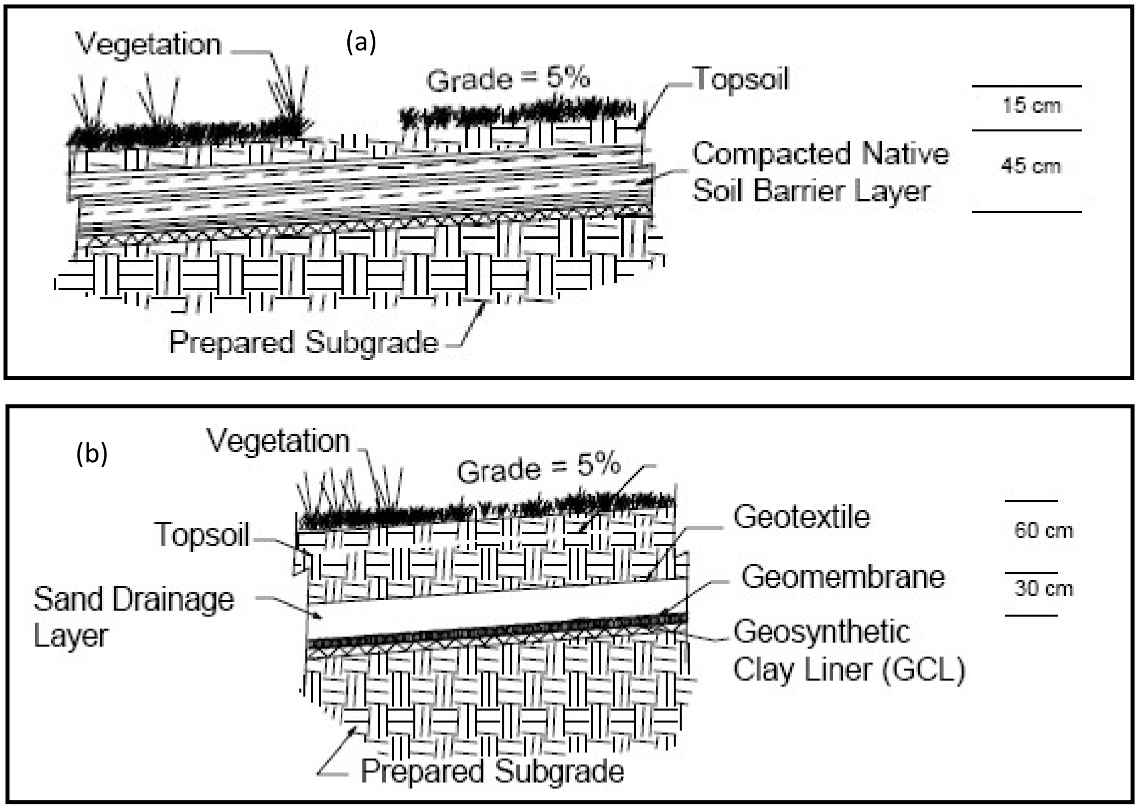


Figure 33: Typical final cover systems

Example 4: Determine the ratio of waste to cover materials (soil – volume basis) as a function of initial compacted specific weight for a solid waste stream of 70 tons per day to be placed in 10 ft lifts with a cell width of 15 ft. The slope of the working face is 3:1. Assume the waste is compacted initially to an average specific weight of 600 lb/yd^3. Daily cover thickness is 6-inch.

Solutions:

Given, Waste stream	70	ton/day	
Lift height, h =	10	ft.	
Cell width, b =	15	ft.	
working face slope, z =	3	: 1	
Initial avg specific weigh	600	lb/yd^3	
daily cover thickness, t =	6	inch	

Determine the daily volume of the deposited waste ($\forall_d$)

$\forall_d$ = 70 ton/day x 2000 lb/ton x (1 yd^3 /600 lb)

= 233.33 yd^3

(2) Determine the length of the cell (L)

$$L = \frac{\forall_d \times 27\ ft^3/yd^3}{h \times b}$$

$$= \frac{233.33\ yd^3 \times 27\ ft^3 / yd^3)}{10\ ft \times 15\ ft}$$

= 42 ft

(3) Determine Cell surface area, SA

(a) for the top of the cell

SA_T = L x b

= 42 ft x 15 ft

= 630 ft^2

(b) for the face of the cell

SA_F = L x SQRT$[h^2 + (z \times h)^2]$

= 42 ft x SQRT[10^2 + (3 x 10)^2]

= 1328.2 ft^2

(c) for the side of the cell

SA_S = b x SQRT$[h^2 + (z \times h)^2]$

= 15 ft x SQRT[10^2 + (3 x 10)^2]

= 474.34 ft^2

(4) Determine the volume for daily cover ($\forall_c$)

$$\forall_c = t \text{ inch} \times (1 \text{ ft}/12 \text{ inch}) \times (SA_T + SA_F + SA_S) \text{ ft}^2$$

$$= 6 \text{ inch} \times (1 \text{ ft}/12 \text{ inch}) \times (630 + 1328.16 + 474.34) \text{ ft}^2$$

$$= 1216.25 \text{ ft}^3$$

(5) Determine the ratio of waste to cover soil

$$R_{W:C} = \frac{\forall_d \times 27 \text{ ft}^3/\text{yd}^3}{\forall_c}$$

$$= \frac{233.33 \text{ yd}^3 \times 27 \text{ ft}^3/\text{yd}^3}{1216.25 \text{ ft}^3}$$

$$= 5.18 : 1$$ **ANS.**

10.6 Landfill Gas Monitoring, Collection, and Control Systems

Landfill Gas Monitoring System

- Owners or operators shall implement a gas management plan to protect the facility cap, and to prevent migration into structures or beyond the facility boundary.
- The concentration of methane gas generated by the facility does not exceed 25 percent of the lower explosive limit (**LEL = 5% methane in air**) for methane in facility structures (excluding gas control or recovery system components); and
- The concentration of methane gas does not exceed the lower explosive limit for methane at the facility boundary.
- Monitoring wells (gas probes - Figure *34*) shall be located at or near the facility boundary.
- the lateral spacing between adjacent monitoring wells (probes) should not exceed 250 feet.
- Normally, the number and depths of monitoring probes within the well bore should be installed in accordance with the following criteria:
  - ✓ A shallow probe installed 5 to 10 feet below the surface.
  - ✓ An intermediate probe installed at or near half the depth of the well bore; and
  - ✓ A deep probe at or near the depth of the well bore.

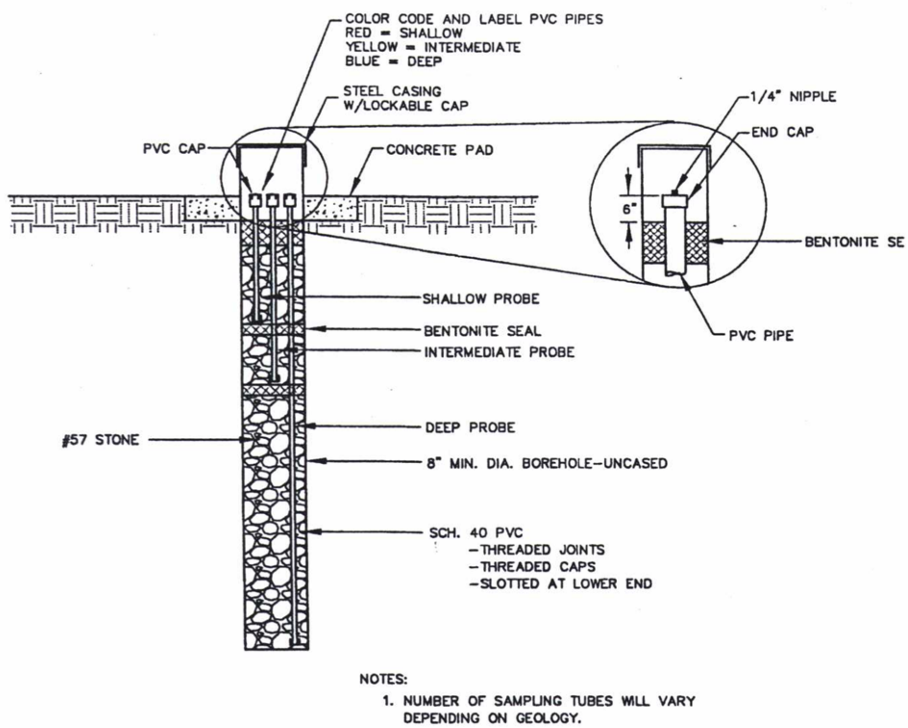


Figure 34: A typical Monitoring wells (gas probes)

Gas Collection and Control Systems

- A gas control system shall be designed to:
  - ✓ Prevent methane accumulation in on-site structures.
  - ✓ Reduce methane concentrations at monitored property boundaries to below compliance levels in the timeframes specified in the gas remediation plan.
  - ✓ Provide for the collection and treatment and/or disposal of decomposition gas condensate produced at the surface.
  - ✓ Condensate collected in condensate traps and drained by gravity into the waste mass will not be considered recirculation.
  - ✓ Typical control systems are:
    - a. Passive vents - recommended one vent per acre.
    - b. Interception trench.
    - c. Active extraction system

a. Landfill Gas - Passive vents (Figure *35*)

- ✓ Depth = 50 - 90% of the depth of waste (80% recommended)
- ✓ 2 - 3 ft. diameter borehole
- ✓ 4 - 6 in. diameter slotted pipe surrounded by a granular material to facilitate collection of gases.

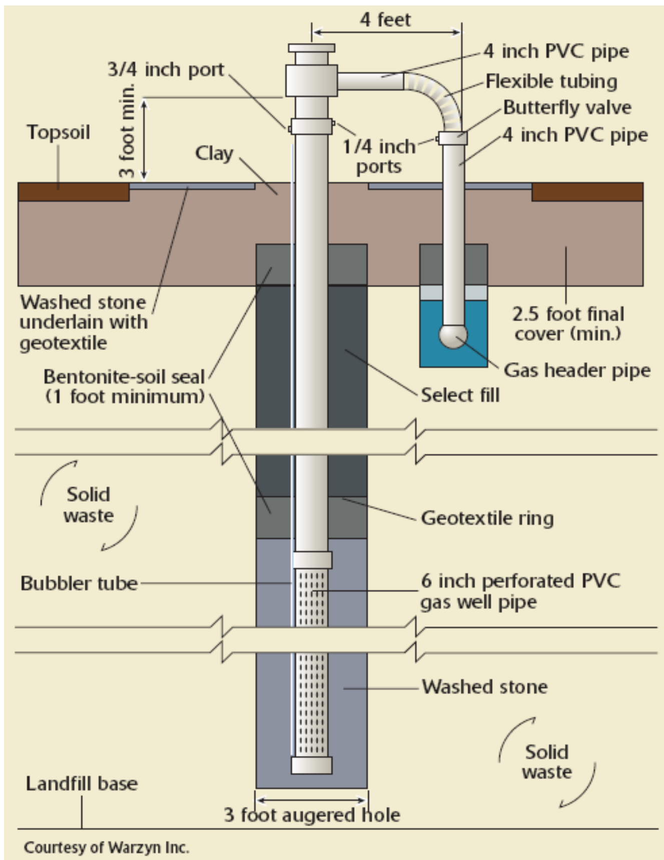


Figure 35: A typical passive vent

b. Landfill Gas - Interception Trench (Figure *36*)

- ✓ Width = 2 - 3 ft.
- ✓ 4-6 in. diameter vents
- ✓ Depth = Up to Water Table/Bedrock
- ✓ Backfilled with (VDOT # 57 or appropriate) stone/tire chips
- ✓ Plastic migration barrier to outerside & top

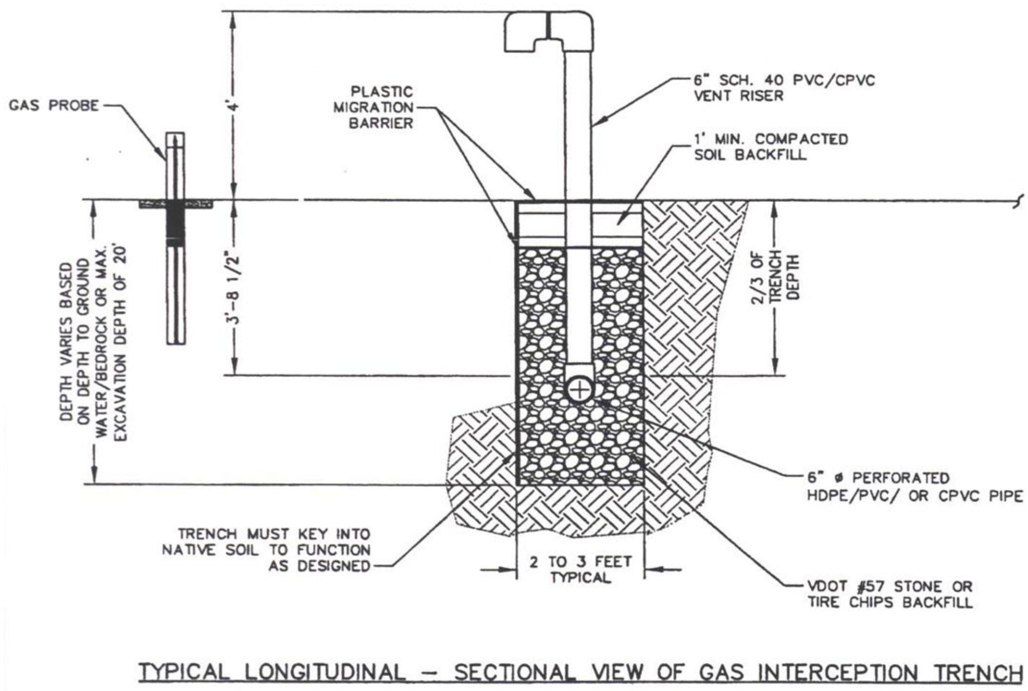


Figure 36: A typical longitudinal - sectional view of gas interception trench

c. Landfill Gas - Active Extraction System

a. The well spacing should be determined through pump tests conducted in accordance with industry standards and placed as shown in Figure *37*.

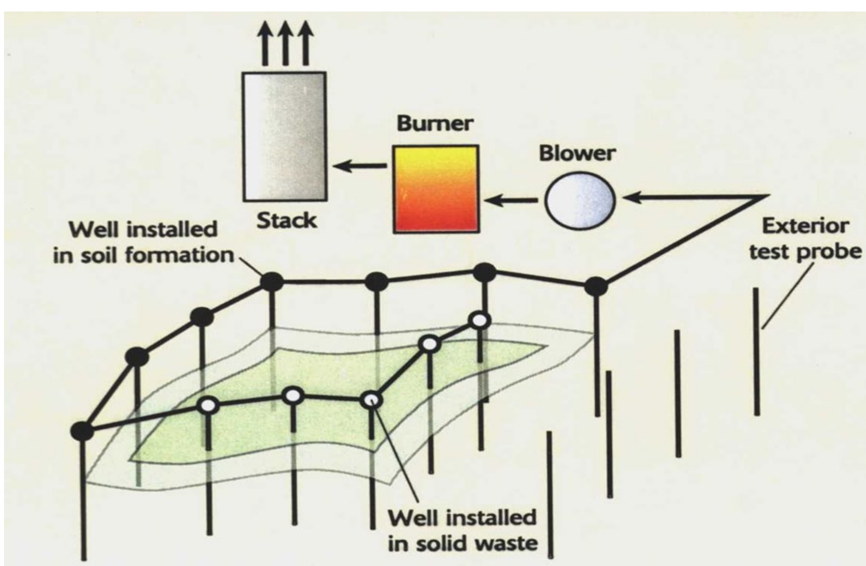


Figure 37: A layout of Landfill Gas Active Extraction System

Based on the estimate, if enough methane is generated, electricity can be generated by combustion of methane with micro-turbine. Methane can also be fed to several capacity gas combustion micro-turbines as it will depend on the amount methane generation (Figure *38*). Combustion micro-turbine will be procured from open source and tried to see the electricity generation density. Landfill gas create a huge pressure in the final cover and break it (Figure *39*).

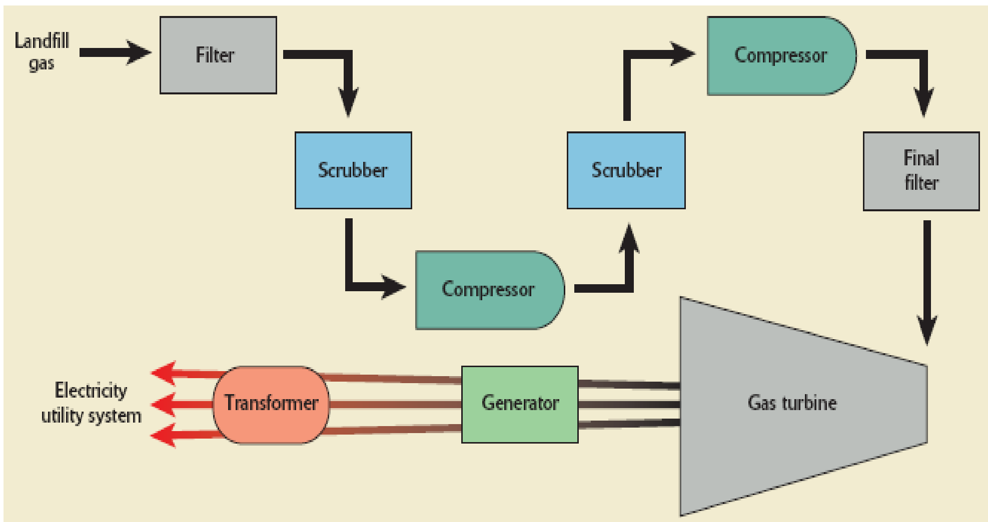


Figure 38: A typical electricity generation flowchart from LFG

Figure 39: Effect of landfill gas pressure on final cover

10.7 Landfill Run-on and Run-off Control System

Run-on Control System: As much water as possible should be diverted off the landfill to minimize operational problems and leachate formation. A run-on control system (Figure *40* and Figure *41*) should prevent liquid from flowing onto the active portion of the landfill during the peak discharge from a 25-year storm event. The run-on system also should collect and redirect surface waters entering the landfill boundaries.

Run-off Control System: A run-off control system (Figure *40*) must be able to manage at least the volume of water that results from a **24-hour, 25-year** storm over the active portion of the landfill. The run-off system should collect and control any water that may have contacted any waste materials and must comply with Clean Water Act (CWA) point and nonpoint source requirements.

Figure 40: This storm drainage pipe empties into a drainage ditch. Controls both run-on and run-off

Figure 41: Drainage ditches run along the base of a landfill. The black pipe carries landfill gas to a pumping station. Controls both run-on and run-off

10.8 Landfill Construction Quality Assurance (CQA) and Quality Control (QC)

A construction quality assurance and quality control program is required for all landfill units mentioned above. The program shall ensure that the constructed unit meets or exceeds all design criteria and specifications in the permit. The program shall be developed and implemented under the direction of a CQA officer who is a registered professional engineer. The CQA program shall address the following physical components, where applicable:

(a) Foundations.
(b) Low-hydraulic conductivity soil liners.
(c) Synthetic membrane liners.
(d) Leachate collection and removal systems.
(e) Gas management components; and
(f) Final cover systems.

10.9 Software Used in Landfill Design

Several software is used when a landfill is designed, and these are:

1. **HELP Model** – to estimate the leachate amount, head on the liner system, and the percolation of leachate through the liner system.

2. **PCSTABL and/or GEOSLOPE** – used to make sure that the side slopes the cells and/or the final covers are stable under normal and seismic conditions.

3. **MultiMed Model** – used to estimate the concentration of pollutants from the landfill percolation to a nearby monitoring well. This is required to meet the regulatory requirements.

4. **LandGEM** – used to estimate the amount of gas generated from the solid waste decomposition process.

11.Completed Solid Waste Landfills

Completed landfills generally require maintenance for **30 years** (called post-closure care period) because of uneven settlement, final cover maintenance, groundwater monitoring, and leachate and gas management. Completed landfills have been used for recreational purposes such as parks, play-grounds, or golf courses. Parking and storage areas or botanical gardens are other final uses (Figure *42*).

Figure 42: Grass and other plants cover at the completed municipal solid waste landfill

12.Solid Waste By-Products

There are two solid waste by-products, and these are:

- Leachate
- gas

Leachate is defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials from it.

Gases found in the landfills include air, ammonia, carbon dioxide, carbon monoxide, hydrogen, hydrogen sulfide, methane, nitrogen, and oxygen.

USEPA **HELP** (**Hydrologic Evaluation of Landfill Performance**) model is used to estimate the amount of leachate generated in a landfill. The estimate helps in designing the leachate storage facility as well as hauling and treatment facility.

USEPA **LandGEM** (**Landfill Gas Emission Model**) is used to estimate the amount of gas generated in a landfill. The estimate helps in designing the power generation facility as well as collection system, flare, and blower capacity.

12.1 Leachate Characteristics

- The major parameters that are used to characterize leachate include BOD_5, *COD*, *TOC*, *pH*, and *Total Alkalinity*.
- Parameters are evaluated by tracking concentration versus time and comparing to drinking water standards.

12.2 Leachate Estimate

Other than HELP model, hypothetical water balance can be used to estimate the amount of leachate a landfill will generate:

The equation is $L = P - R_{on} + U - E - R_{off}$

where, L = leachate amount, P = precipitation, R_{on} = run-on surface water, U = underflow of groundwater into the landfill cell, E = evapotranspiration, and R_{off} = run-off surface water.

- If the landfill (LF) is designed and operate properly, then there should not be any run-on into the LF that is $R_{on} = 0$.
- Additionally, most of the time a landfill is constructed above the groundwater table and possessing an impermeable liner will give $U = 0$.
- Therefore, the equation can be simplified as $L = P - E - R_{off}$

Example 5: Estimate the annual volume of leachate generated per hectare (or acre) for a landfill in the USA. The climate is temperate, annual average rainfall is 1.07 m/year (42 inch/year) and evapotranspiration is estimated to be at 55%. The waste is covered with soil and run-off from the site is 10%. There is no run-on of surface water, similarly there is no underflow groundwater into the cell.

Solutions: For these calculations, it is necessary to convert depth of rainfall (precipitation) into volume.

P = 1.07 m /year = 1.07 ha m /year / ha

$\therefore$ **L = P – E – R_{off}** = 1.07 ha m – (0.55 x 1.07 ha m) – (0.1 x 1.07 ha m)

= 0.3745 ha m x (10,000 m^2/ ha)

= 3,745 m^3 x (1000 L/ 1 m^3) = 3.745 x 10^6 L

= **989,432 gal**. **ANS.**

Leachate Estimation by EPA HELP Model:

Hydrologic
Evaluation of
Landfill
Performance
→ HELP

What does the model do?

- Estimate the amount of leachate generated by a landfill to assist in the evaluation of liner, leachate collection system, storage capacity and cap designs.
- Estimate the percolation through the liner that is used to MultiMED Model as an input to assess the groundwater contamination for alternate liner design.
- The model is basically a device to estimate the water balance for a landfill.

What does not the model do:

- HELP model is not a tool for estimating the amount of stormwater runoff from a landfill.

Data input:

Weather Data	**soil/waste layer characteristics**	**Landfill parameters**
✓ Evaporation ✓ Precipitation ✓ Temperature ✓ Solar radiation	✓ Porosity ✓ Field capacity ✓ Wilting point ✓ Saturated hydraulic conductivity ✓ Soil Conservation Service (SCS) runoff curve number for antecedent moisture condition II.	✓ landfill design (liners, leachate collection & removal systems [LCRS], waste, cap) ✓ vegetation and shading ✓ leachate recirculation

Wilting point: *When soil-water content becomes so low that the surface tension of soil-water interface exceeds the osmotic pressure of the roots, water will no longer enter the roots.*

Note: leachate amount is calculated usually on the basis of 1-acre area

Model uses input to account for:

- ✓ surface storage of water
- ✓ snowmelt
- ✓ runoff, infiltration
- ✓ evapotranspiration, vegetative growth
- ✓ soil/waste moisture storage
- ✓ lateral drainage, leachate recirculation
- ✓ unsaturated vertical drainage.

Data output from HELP Model:

- ✓ leakage through the liners
- ✓ head on the liner
- ✓ volume of leachate generated.

Uses of HELP model data:

- ✓ evaluate effectiveness of LCRS **(<12" head**) - pipe spacing; hydraulic conductivity of drainage material; slope of the liner
- ✓ develop design capacity of leachate storage units (7 days)
- ✓ evaluate performance of alternate caps
- ✓ used (w/Multimed) to evaluate alternate liners

Input data - climatology:

- certain data are needed to perform the water balance evaporative zone depth, leaf area index.
- these parameters act with other variables (precipitation, temperature, solar radiation) to determine evapotranspiration

Input data – precipitation:

- default data in model is for 5-year period only
- other option is synthetic data generation
- data for synthetic record are provided in the model for certain areas of USA.
- consider stations in adjoining states – e.g., Greensboro, Knoxville, Washington DC, etc.
- synthetic data generation allows for periods greater than **5** years
- synthetic data may be used from cities in model, or other data may be input; monthly averages for other cities may be entered, NOAA data can be imported, etc.
- synthetic data generation statistically manipulates mean monthly precipitation data for a period of record to produce a realistic rainfall record (dry years and wet years)
- run synthetic data for at least **20** years

- select monthly output = results will be provided for monthly precipitation rates each year, annual averages, average for all years, peak day
- for a bottom liner, assume **0%** runoff, for a cap assume **100%** runoff

Input data – temperature:

- location and duration selected should match precipitation data
- data can be manually entered

Input data - solar radiation:

- location and duration should match precipitation data

Input data – Liner layers:

- vertical percolation layer
- lateral drainage layer
- barrier soil layer
- geomembrane liner

Vertical percolation layer:

- vertical drainage patterns - downward due to gravity; upward due to evapotranspiration
- downward movement depends on the characteristics of the material, number/type of waste layers
- vegetative support layers, protective cover soils and waste are examples
- to run model, consider the thickness of the layer, characteristics of the material
- to evaluate a bottom liner, use one lift of appropriate waste material (120 inches) - assume well compacted MSW for sanitary landfill (SLF); MSW with channeling for construction demolition debris (CDD); appropriate type of industrial waste for industrial landfill (ILF).

Lateral drainage layer:

- layer directly above a liner/barrier soil to promote flow into the leachate collection system (LCS)
- for model, consider thickness of the layer and characteristics of the material
- material may be sand/aggregate or geosynthetic
- for bottom liners, usually use **18-inch** of sand or gravel
- must input slope and slope length (maximum flow distance to LCS)

Barrier soil layer:

- functions to restrict vertical drainage
- hydraulic conductivity (*k*) significantly less than vertical percolation layer or lateral drainage layer

- assume that soil is saturated when installed
- flow is assumed to be only vertical
- driving force is head on the layer
- must input the thickness of the layer, type of material
- model menu has $\mathbf{1.0x10^{-7}}$ cm/sec soil or it can be changed manually.

Geomembrane (GM):

- virtually impermeable synthetic membrane
- percolation/drainage due to flaws in manufacturing and installation
- model considers flaws in manufacturing and installation, quality of installation
- ‘reasonable’ values generally assumed to be one manufacturing hole/acre; five installation holes/acre; good quality installation

QUESTION - are these assumption conservatives? They are industry practices. Individual can assume different numbers with justifications.

Model software is user friendly:

- Prompts user when additional information is needed.
- Contains menus with values normally used.
- Allows input of additional data.
- Has good “Help” function
- Carefully review any data other than default values in menus in model

Modeling a composite liner system:

- Layer 1 = waste = vertical percolation layer (assume 10 feet or 120 inches)
- Layer 2 = LCS drainage layer = lateral drainage layer (input slope on the liner, greatest flow distance)
- Layer 3 = geosynthetic liner = geomembrane layer (select thickness[in inches], type of material)
- Layer 4 = compacted clay or amended soil = barrier soil layer (assign thickness, in inches)
- Evaluation performed for one acre
- Assume bare soil, no leaf cover, no runoff

HELP Model results that affect landfill design:

- head on the liner
- leakage through the liner
- leachate collected from the lateral drainage layer

Head on the liner:

- model result used to assess the effectiveness of the LCS design = spacing of pipes, permeability of the drainage material
- maximum buildup of head < 12 inches
- model provides the maximum head for 1 day for the period, also the location of the greatest buildup

Leakage through the liner:

- results are used to assess the performance of the liner system for alternate liner design or the performance of an alternate cap design
- results are influenced by the materials, QA/QC during installation of geomembrane (GM), head on the liner
- for bottom liners, the data are used to evaluate effects on groundwater and liner performance
- for caps, data are used to demonstrate equivalency of alternate cap design to regulatory cap
- look at average annual data, also maximum year data

Print out from Computer HELP Model Run

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**             HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**               HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                 **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                       **
**                USAE WATERWAYS EXPERIMENT STATION                         **
**          FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                 **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\HELP3\PRECIP.D4
TEMPERATURE DATA FILE:       C:\HELP3\TEMP.D7
SOLAR RADIATION DATA FILE:   C:\HELP3\SOLAR.D13
EVAPOTRANSPIRATION DATA:     C:\HELP3\EVAPO.D11
SOIL AND DESIGN DATA FILE:   C:\HELP3\ATLANTA.D10
OUTPUT DATA FILE:            C:\HELP3\ATLANTA.OUT

TIME:  39:18     DATE:  11/11/2017
```

```
******************************************************************************

    TITLE:  A Landfill in Atlanta, Georgia

******************************************************************************

    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
           COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.

                                  LAYER  1
                                  --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER   9
          THICKNESS                  =     30.00    INCHES
          POROSITY                   =      0.5010 VOL/VOL
          FIELD CAPACITY             =      0.2840 VOL/VOL
          WILTING POINT              =      0.1350 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.3363 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.190000006000E-03 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  3.00
               FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.

                                  LAYER  2
                                  --------

                    TYPE 2 - LATERAL DRAINAGE LAYER
                      MATERIAL TEXTURE NUMBER   1
          THICKNESS                  =     12.00    INCHES
          POROSITY                   =      0.4170 VOL/VOL
          FIELD CAPACITY             =      0.0450 VOL/VOL
          WILTING POINT              =      0.0180 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.2227 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.999999978000E-02 CM/SEC
          SLOPE                      =      4.00    PERCENT
          DRAINAGE LENGTH            =    200.0     FEET

                                  LAYER  3
                                  --------

                    TYPE 4 - FLEXIBLE MEMBRANE LINER
                      MATERIAL TEXTURE NUMBER  36
          THICKNESS                  =      0.04    INCHES
          POROSITY                   =      0.0000 VOL/VOL
          FIELD CAPACITY             =      0.0000 VOL/VOL
          WILTING POINT              =      0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT =      0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.399999993000E-12 CM/SEC
          FML PINHOLE DENSITY        =      1.00    HOLES/ACRE
          FML INSTALLATION DEFECTS   =     10.00    HOLES/ACRE
          FML PLACEMENT QUALITY      =  4 - POOR
```

```
                         LAYER  4
                         --------

              TYPE 3 - BARRIER SOIL LINER
              MATERIAL TEXTURE NUMBER  28
  THICKNESS                     =     36.00    INCHES
  POROSITY                      =      0.4520 VOL/VOL
  FIELD CAPACITY                =      0.4110 VOL/VOL
  WILTING POINT                 =      0.3110 VOL/VOL
  INITIAL SOIL WATER CONTENT    =      0.4520 VOL/VOL
  EFFECTIVE SAT. HYD. COND.     =  0.120000004000E-05 CM/SEC


                         LAYER  5
                         --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER  18


  THICKNESS                     =    300.00    INCHES
  POROSITY                      =      0.6710 VOL/VOL
  FIELD CAPACITY                =      0.2920 VOL/VOL
  WILTING POINT                 =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT    =      0.2920 VOL/VOL
  EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC
                         LAYER  6
                         --------

          TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   5
  THICKNESS                     =     12.00    INCHES
  POROSITY                      =      0.4570 VOL/VOL
  FIELD CAPACITY                =      0.1310 VOL/VOL
  WILTING POINT                 =      0.0580 VOL/VOL
  INITIAL SOIL WATER CONTENT    =      0.1377 VOL/VOL
  EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC
                         LAYER  7
                         --------

          TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER  20
  THICKNESS                     =      0.20    INCHES
  POROSITY                      =      0.8500 VOL/VOL
  FIELD CAPACITY                =      0.0100 VOL/VOL
  WILTING POINT                 =      0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT    =      0.0100 VOL/VOL
  EFFECTIVE SAT. HYD. COND.     =  10.0000000000      CM/SEC
  SLOPE                         =      3.00    PERCENT
  DRAINAGE LENGTH               =    100.0     FEET

                         LAYER  8
                         --------

          TYPE 4 - FLEXIBLE MEMBRANE LINER
              MATERIAL TEXTURE NUMBER  35
  THICKNESS                     =      0.06    INCHES
  POROSITY                      =      0.0000 VOL/VOL
  FIELD CAPACITY                =      0.0000 VOL/VOL
  WILTING POINT                 =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT    =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.     =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY           =      1.00    HOLES/ACRE
  FML INSTALLATION DEFECTS      =     10.00    HOLES/ACRE
  FML PLACEMENT QUALITY         =  3 - GOOD
```

```
                        LAYER  9
                        --------

              TYPE 2 - LATERAL DRAINAGE LAYER
                MATERIAL TEXTURE NUMBER  21
 THICKNESS                    =     12.00    INCHES
 POROSITY                     =      0.3970 VOL/VOL
 FIELD CAPACITY               =      0.0320 VOL/VOL
 WILTING POINT                =      0.0130 VOL/VOL
 INITIAL SOIL WATER CONTENT   =      0.0320 VOL/VOL
 EFFECTIVE SAT. HYD. COND.    =  0.300000012000      CM/SEC
 SLOPE                        =      3.00    PERCENT
 DRAINAGE LENGTH              =    100.0     FEET

                        LAYER 10
                        --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
                MATERIAL TEXTURE NUMBER  35
 THICKNESS                    =      0.06    INCHES
 POROSITY                     =      0.0000 VOL/VOL
 FIELD CAPACITY               =      0.0000 VOL/VOL
 WILTING POINT                =      0.0000 VOL/VOL
 INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
 EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
 FML PINHOLE DENSITY          =      1.00    HOLES/ACRE
 FML INSTALLATION DEFECTS     =     10.00    HOLES/ACRE
 FML PLACEMENT QUALITY        =  3 - GOOD

                        LAYER 11
                        --------
                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER  16
 THICKNESS                    =     36.00    INCHES
 POROSITY                     =      0.4270 VOL/VOL
 FIELD CAPACITY               =      0.4180 VOL/VOL
 WILTING POINT                =      0.3670 VOL/VOL
 INITIAL SOIL WATER CONTENT   =      0.4270 VOL/VOL
 EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC


           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------
 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 9 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF  3.%
          AND A SLOPE LENGTH OF  200. FEET.

SCS RUNOFF CURVE NUMBER            =     82.20
FRACTION OF AREA ALLOWING RUNOFF   =    100.0     PERCENT

AREA PROJECTED ON HORIZONTAL PLANE  =     15.000  ACRES
EVAPORATIVE ZONE DEPTH              =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      7.103  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =     11.022  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      2.970  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =    134.042  INCHES
TOTAL INITIAL WATER                 =    134.042  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR
```

```
            EVAPOTRANSPIRATION AND WEATHER DATA
            ----------------------------------
NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
         ATLANTA              GEORGIA

    STATION LATITUDE                          = 33.65 DEGREES
    MAXIMUM LEAF AREA INDEX                   =  2.00
    START OF GROWING SEASON (JULIAN DATE)     =    77
    END OF GROWING SEASON (JULIAN DATE)       =   316
    EVAPORATIVE ZONE DEPTH                    = 22.0  INCHES
    AVERAGE ANNUAL WIND SPEED                 =  9.10 MPH
    AVERAGE 1ST QUARTER RELATIVE HUMIDITY     = 65.00 %
    AVERAGE 2ND QUARTER RELATIVE HUMIDITY     = 67.00 %
    AVERAGE 3RD QUARTER RELATIVE HUMIDITY     = 76.00 %
    AVERAGE 4TH QUARTER RELATIVE HUMIDITY     = 69.00 %

      NOTE:  PRECIPITATION DATA FOR     ATLANTA            GEORGIA
               WAS ENTERED FROM THE DEFAULT DATA FILE.


      NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR    ATLANTA            GEORGIA

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   41.90       44.90       52.50       61.80       69.30       75.80
   78.60       78.20       73.00       62.20       52.00       44.50


      NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR    ATLANTA            GEORGIA
                 AND STATION LATITUDE  =  33.65 DEGREES


HEAD  #1:  AVERAGE HEAD ON TOP OF LAYER  3
DRAIN #1:  LATERAL DRAINAGE FROM LAYER  2 (RECIRCULATION AND COLLECTION)
LEAK  #1:  PERCOLATION OR LEAKAGE THROUGH LAYER  4
HEAD  #2:  AVERAGE HEAD ON TOP OF LAYER  8

DRAIN #2:  LATERAL DRAINAGE FROM LAYER  7 (RECIRCULATION AND COLLECTION)
LEAK  #2:  PERCOLATION OR LEAKAGE THROUGH LAYER  8
HEAD  #3:  AVERAGE HEAD ON TOP OF LAYER 10
DRAIN #3:  LATERAL DRAINAGE FROM LAYER  9 (RECIRCULATION AND COLLECTION)
LEAK  #3:  PERCOLATION OR LEAKAGE THROUGH LAYER 11
```

```
******************************************************************************
    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1974 THROUGH 1978
------------------------------------------------------------------------------
                               INCHES           CU. FEET      PERCENT
                          -------------------  -------------  ---------
 PRECIPITATION             49.46     (  9.546)   2692879.2     100.00

 RUNOFF                     1.923    ( 1.0744)    104698.95      3.888

 EVAPOTRANSPIRATION        33.885    ( 3.9139)   1845017.00     68.515

 LATERAL DRAINAGE COLLECTED 13.91821 ( 5.53853)   757846.562   28.14261
   FROM LAYER  2

 PERCOLATION/LEAKAGE THROUGH 0.25439 ( 0.15459)   13851.688     0.51438
   LAYER  4

 AVERAGE HEAD ON TOP        4.050 (    2.684)
   OF LAYER  3

 LATERAL DRAINAGE COLLECTED  0.10555 ( 0.05559)     5746.932    0.21341
   FROM LAYER  7

 PERCOLATION/LEAKAGE THROUGH 0.12973 ( 0.04085)     7063.736    0.26231
   LAYER  8

 AVERAGE HEAD ON TOP        0.000 (    0.000)
   OF LAYER  8

 LATERAL DRAINAGE COLLECTED  0.12970 ( 0.04084)     7062.171    0.26225
   FROM LAYER  9

 PERCOLATION/LEAKAGE THROUGH 0.00001 ( 0.00000)        0.279    0.00001
   LAYER 11

 AVERAGE HEAD ON TOP        0.001 (    0.000)
   OF LAYER 10


CHANGE IN WATER STORAGE       -0.505    (  0.6192)     -27493.03      -1.021
******************************************************************************
```

```
******************************************************************************

            PEAK DAILY VALUES FOR YEARS 1974 THROUGH 1978
------------------------------------------------------------------------
                                              (INCHES)      (CU. FT.)
                                             ----------    -------------
  PRECIPITATION                                 3.43        186763.500

  RUNOFF                                        1.108        60306.1055

  DRAINAGE COLLECTED FROM LAYER  2              0.14651       7977.65381

  PERCOLATION/LEAKAGE THROUGH LAYER  4          0.005136       279.64716

  AVERAGE HEAD ON TOP OF LAYER  3              32.487

  MAXIMUM HEAD ON TOP OF LAYER  3              40.341

  LOCATION OF MAXIMUM HEAD IN LAYER  2
        (DISTANCE FROM DRAIN)                  80.4 FEET

  DRAINAGE COLLECTED FROM LAYER  7              0.00150         81.44305

  PERCOLATION/LEAKAGE THROUGH LAYER  8          0.001122        61.09970

  AVERAGE HEAD ON TOP OF LAYER  8               0.000

  MAXIMUM HEAD ON TOP OF LAYER  8               0.000

  LOCATION OF MAXIMUM HEAD IN LAYER  7
        (DISTANCE FROM DRAIN)                   0.0 FEET

  DRAINAGE COLLECTED FROM LAYER  9              0.00112         61.09426

  PERCOLATION/LEAKAGE THROUGH LAYER 11          0.000000         0.00171

  AVERAGE HEAD ON TOP OF LAYER 10               0.002

  MAXIMUM HEAD ON TOP OF LAYER 10               0.006

  LOCATION OF MAXIMUM HEAD IN LAYER  9
        (DISTANCE FROM DRAIN)                   0.0 FEET

  SNOW WATER                                    2.47        134721.9840


  MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.4242

  MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1350
```

```
     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.
******************************************************************************

******************************************************************************
```

FINAL WATER STORAGE AT END OF YEAR 1978

LAYER	(INCHES)	(VOL/VOL)
1	9.0801	0.3027
2	1.0598	0.0883
3	0.0000	0.0000
4	16.2720	0.4520
5	87.6000	0.2920
6	1.7477	0.1456
7	0.0020	0.0100
8	0.0000	0.0000
9	0.3841	0.0320
10	0.0000	0.0000
11	15.3720	0.4270
SNOW WATER	0.000	

****

12.3 Beneficial Use of Leachate

- Leachate can be recycled to the waste mass in order to increase the moisture content in the waste that will augment the biomass activities to degrade the organic wastes.
- After recycling the leachate couple of times, the quality of the leachate improves a lot, which may allow the leachate to be discharged into the surface water stream sometime even without further treatment.
- Recycling the leachate reduces the storage, treatment, and disposal costs.

12.4 Surface Water, Groundwater, and Soil Contamination by Leachate

If the side slopes of the landfill are not compacted and maintained properly, leachate may leak through the wastes and finds its way to go to the nearby surface streams. That is how the surface water will be contaminated by leachate. If the bottom liners of the landfill are not designed and constructed properly, the leachate may leak through the liners and finds its way to go to the groundwater and the soil (Figure *43*). The dissolved contaminants will be in groundwater and the suspended and ionized contaminants will be stuck with soil by adsorption and ion exchange mechanisms.

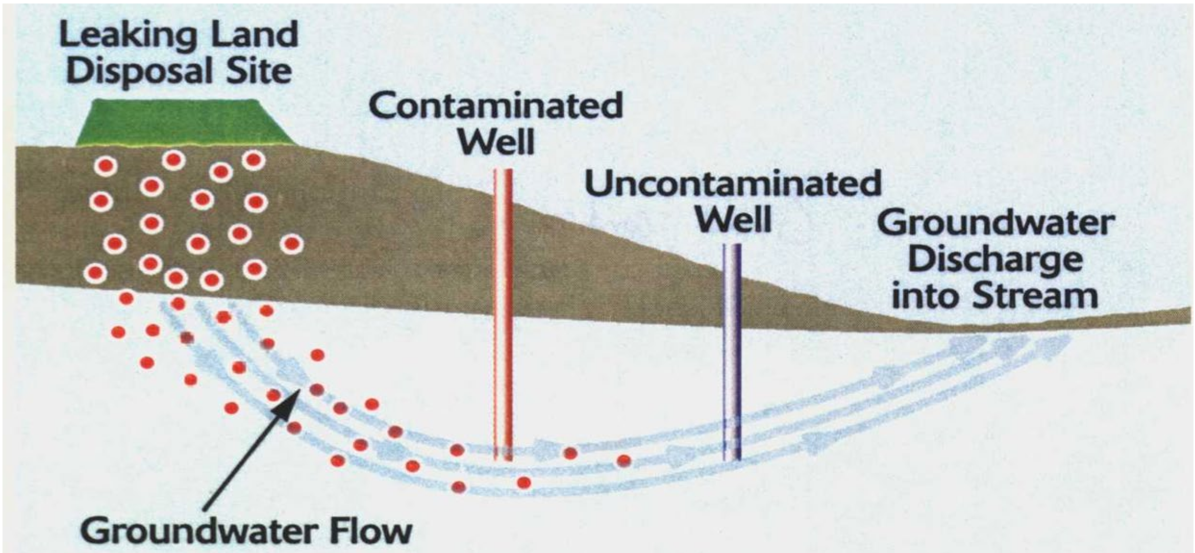


Figure 43: Soil and groundwater contamination by leachate

12.5 Landfill Gas Characteristics

Landfill gas (LFG) is generated through the degradation of municipal solid waste (MSW) and other biodegradable waste, by microorganisms. Aerobic conditions, presence of oxygen, leads to predominately CO_2 emissions. In anaerobic conditions, as is typical of landfills, methane and CO_2 are produced in a ratio of 60:40. Methane (CH_4) is the important component of landfill gas as it has a calorific value of 33.95 MJ/Nm^3 which gives rise to energy generation benefits[4]. The amount of methane that is produced varies significantly based on composition of the waste. Most of the methane produced in MSW landfills is derived from food waste, composite paper, and corrugated cardboard which comprise 19.4 ± 5.5%, 21.9 ± 5.2%, and 20.9 ± 7.1% respectively on average of MSW landfills in the United States[5]. The rate of landfill gas production varies with the age of the landfill.

There are **four common phases** that a section of an MSW landfill undergoes after placement. Typically, in a large landfill, different areas of the site will be at various stages simultaneously. The landfill gas production rate will reach a maximum at around 5 years and start to decline. The Landfill Methane Outreach Program (LMOP) provides first order decay model (**LandGEM**) to

[4] Scottish Environment Protection Agency. Guidance on Landfill Gas Flaring. November 2002. Web. <http://www.sepa.org.uk/waste/waste_regulation/idoc.ashx?docid=d2a6df2b-8ea9-4326-af87-e6803f769d47&version=-1 Archived 2011-01-07 at the Wayback Machine>.

[5] Staley, Bryan, Morton Barlaz, and Morton Barlaz. "Composition of Municipal Solid Waste in the United States and Implications for Carbon Sequestration and Methane Yield." Journal of Environmental Engineering, 135.10 (2009): 901-909

aid in the determination of landfill gas production. Typically, gas extraction rates from a municipal solid waste (MSW) landfill range from 25 to 10000 m^3/h where Landfill sites typically range from 100,000 m^3 to 10 million m^3 of waste in place[6]. MSW landfill gas typically has roughly 45 to 60% methane and 40 to 60% carbon dioxide, depending on the amount of air introduced to the site, either through active gas extraction or from inadequate sealing (capping) of the landfill site. Depending on the composition of the waste in place, there are many other minor components that comprises roughly 1% which includes H_2S, NO_x, SO_2, CO, non-methane volatile organic compounds (NMVOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), etc. All of the aforementioned agents are harmful to human health at high doses. LFG compositions are provided in the following Table 2[7].

Table 2: Typical LFG composition

Compound	Percent		Compound	Percent
Methane	47.4		Paraffin hydrocarbons	0.1
Carbon-dioxide	47.0		Hydrogen	0.1
Nitrogen	3.7		Carbon monoxide	0.1
Oxygen	0.8		Hydrogen sulfide	0.01
Aromatic-cyclic hydrocarbons	0.2		Trace compounds	0.5

The four common phases that a section of an MSW landfill undergoes after placement and generate landfill gas are described and shown in Figure *44*:

STAGE I (Aerobic). Oxygen in the air that is trapped within the landfill is consumed during the aerobic decomposition of organic waste. This phase is relatively short, usually several weeks or months, depending on the limited quantity of oxygen present. The primary by-products of this exothermal process are carbon dioxide and water.

- ✓ Oxygen (O_2) depletion
- ✓ Temperature increase
- ✓ High CO_2 & H_2O production
- ✓ Minimal solids loss

[6] Scottish Environment Protection Agency. Guidance on Landfill Gas Flaring. November 2002. Web. <http://www.sepa.org.uk/waste/waste_regulation/idoc.ashx?docid=d2a6df2b-8ea9-4326-af87-e6803f769d47&version=-1 Archived 2011-01-07 at the Wayback Machine>.

[7] Ham, R. USEPA, Recovery Processing and Utilization of Gas from Sanitary Landfills, 1979.

STAGE II (Anoxic). In the second stage, as the oxygen is depleted, a different kind of bacteria, the anaerobic acid formers, perform decomposition under an anaerobic condition. Little amounts of carbon dioxide and some hydrogens are produced. Nitrogen begins to be displaced.

- ✓ No oxygen infiltration
- ✓ Acids accumulate → acidic pH
- ✓ Little CO_2, no CH_4 production
- ✓ Possibly some H_2
- ✓ Minimal solids loss

STAGE III (Unsteady methanogenic). The dominant methane-forming bacteria works slowly to form methane, carbon dioxide and water in the third stage. Methane is produced at an unsteady rate.

- ✓ Gas composition → 50% / 50% CH_4/CO_2
- ✓ Steep increase in methane production
- ✓ Decreasing leachate BOD, COD
  - BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand
- ✓ pH ≈ 7
- ✓ Significant solids decomposition begins

STAGE IV (Steady methanogenic). During the last stage, as the carbon dioxide and hydrogen levels decrease, the percent by volume of methane increases. It generally takes one to two years for the anaerobic reaction to produce methane steadily after the placement of waste. After a period of time the production of methane begins to decline as the organics (food) supply dwindles. Some refer to this as Phase V, declining methanogenic.

- ✓ Gas composition → 50% / 50% CH_4/CO_2
- ✓ Asymptotic decrease in methane production
- ✓ Low leachate BOD, COD
- ✓ pH > 7
- ✓ Significant solids decomposition

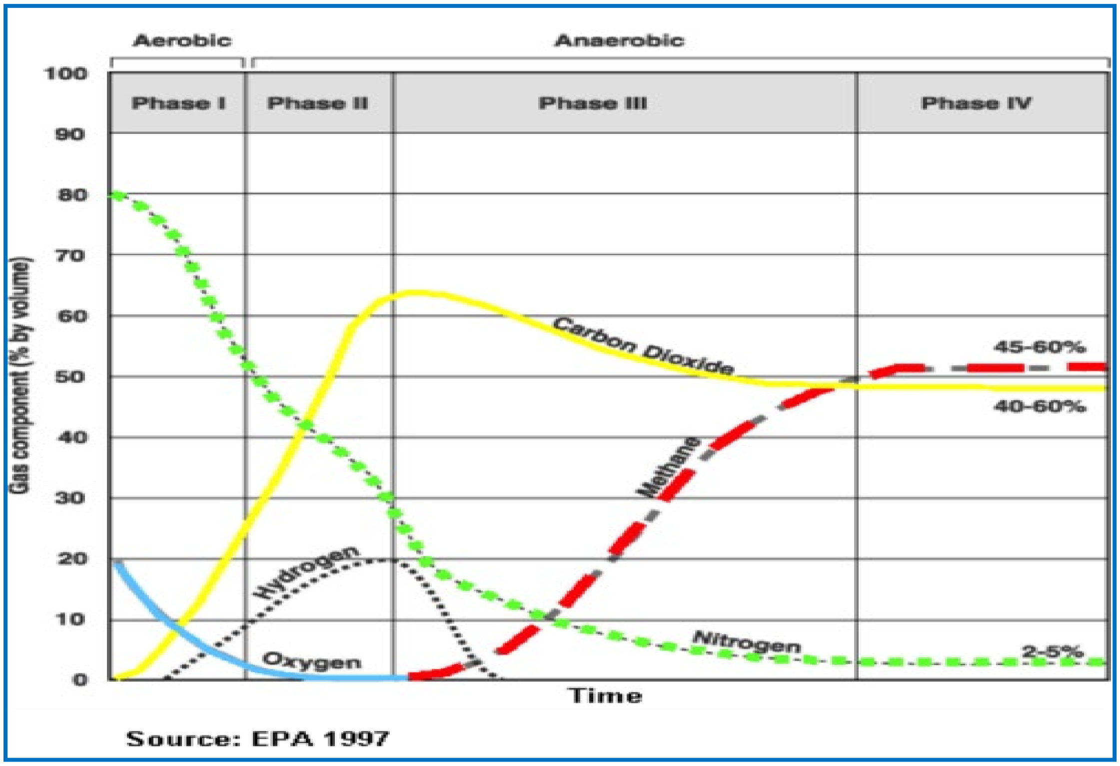


Figure 44: Percent composition of each major component of landfill gas with time[8]

12.6 Landfill Gas Estimate

Landfill gas generation rate is estimated using EPA suggested Equation and EPA landfill Gas Emission Model (**LandGEM**).

Estimation by Equation: Landfill gas generation follows first-order kinetic decay after decline begins with a *k*-value ranging 0.02/yr for arid conditions and 0.065/yr for wet conditions. The maximum landfill gas (LFG) generation rate occurs shortly after the time of closure (i.e., when the maximum mass of waste has been placed). The LFG generation rate is calculated using the following equation from 40 CFR 60.755(a)(1)(I):

$$Q_{LFG} = 2LoR(e^{-kc} - e^{-kt})$$

where:

Q_{LFG} = LFG generation rate at time t (m^3/year).

Lo = Methane generation potential (m^3 CH_4/ Mg refuse).

R = Average annual refuse accepted rate during active life (Mg/year).

[8] U.S. Environmental Protection Agency. https://www.sciencedirect.com/topics/earth-and-planetary-sciences/landfill-gas extracted April 2020.

k = Methane generation rate constant ($year^{-1}$).
c = Time since landfill closure (yr) [c = 0 for active landfills].
t = Time since initial refuse placement (year).

Parameter Values:

Lo = 100 m^3 CH_4/ Mg refuse [AP-42 recommended value]

R = 1.3 x 10^6 Mg/yr [Assuming 4,000 tons per day (tpd) intake and 359 days/yr in operation. (4,000 tpd) x (359 days/yr)/(1.10231 Mg/ton) = 1.3 x 10^6 Mg/yr.]

k = 0.05 yr^{-1} [AP-42 recommended value is 0.04 yr^{-1}].

c = 0 yr.

t = (22.4 x10^6 yd^3x 0.95 ton/yd^3)/(4000 tpd x 359 days/yr) = 14.8 years ≈ **15** years.

[Assumed 22.4x10^6 yd^3 is the landfill design capacity, 0.95 ton/yd^3 is the waste density, Therefore, Landfill Capacity = 22.4x10^6 yd^3 x 0.95 ton/yd^3 = 21.28x10^6 tons = 21.28x10^6 tons x 2000 lb/ton = 4.256x10^{10} lb].

Example Calculations:

$$Q_{LFG} = 2\text{x}100\ x(1.3x10^6)\text{x}(e^{-(0.05)(0)} - e^{-(0.05)(15)})$$

= 1.372 x 10^8 m^3/yr = 4.845 x 10^9 scf/yr.

= 0.114 scf/lb. MSW/yr [(4.845 x 10^9 scf/yr)/(4.256x10^{10} lb)]

= 9.218 x 10^3 scfm = <u>1.536 x 10^2</u> scfs.

Example 6: A landfill cell receives about 225,000 metric tons of MSW per year. Calculate the gas production for the first year, given a landfill gas emission constant of 0.0335 $year^{-1}$ and methane generation potential of 175 m^3/metric ton. [*1 Mega gram (Mg) = 1.1023 metric ton*].

$$Q_T = 2L_o R\left(e^{-kc} - e^{-kt}\right) \qquad Q_T = \sum_{i=1}^{n} 2kL_0 M_i e^{-kt}$$

Solutions:

Given,	M or R	225000	metric ton/yr =	204118.66	Mg/yr
	Lo =	175	m^3/metric ton =	192.9	m^3/Mg
	k =	0.0335	/year		
	t =	1	year	c = 0	for active landfill

Using the formula, $Q_T = \sum_{i=1}^{n} 2kL_0 M_i e^{-kt}$

= 2 x 0.0335 x 175 x 225000 x EXP(-0.0335 x 1)

= **2,551,212** m^3/year **ANS.**

Using the formula, $Q_T = 2L_o R\left(e^{-kc} - e^{-kt}\right)$

where, Lo = 192.90

R = 204118.66

***Q_T* =** 2 x 192.9 x 204118.66[EXP(-0.0335x0) - EXP(-0.0335x1)]

= **2,594,426** m^3/year **ANS.** More conservative

Landfill Gas Estimation by LandGEM:

Model Parameters:

- ✓ Annual waste input, M_i in Mg (megagram)
- ✓ Age of waste, t_i in year.
- ✓ Methane generation potential, *Lo* in m^3/Mg
- ✓ Refuse decay rate, k in yr^{-1}

Model Parameter Values:

- ✓ LandGEM developed for dry site (conventional landfill)
- ✓ M_i and t_i are site specific
- ✓ Lo = 100 to 170 m^3/Mg
- ✓ k = 0.02 to 0.05 yr^{-1} (conventional); rainfall dependent
- ✓ k = 0.1 to 0.5 yr^{-1} (bioreactor), derived from limited laboratory and pilot scale studies.

The model uses the following equation to estimate the gas:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10}\right) e^{-kt_{ij}}$$

where, $\boldsymbol{Q_{CH4}}$ = annual methane generation in the year of the calculation (m^3/year); ***i*** = 1 year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1-year time increment; ***k*** = methane generation rate ($year^{-1}$)
Lo = potential methane generation capacity (m^3/Mg)
M_i = mass of waste accepted in the *ith* year (Mg)
t_{ij}= age of the *jth* section of waste mass *Mi* accepted in the *ith* year (decimal years, e.g., 3.2 years)

The typical model run plots are shown in Figure *45* and Figure *46*.

Print out from Computer Model (LandGEM) Run

==

Model Parameters

==

Lo : 169.90 m^3 /Mg
k : 0.0500 1/yr.
NMOC : 4000.00 ppmv
Methane : 50.0000 % volume
Carbon Dioxide : 50.0000 % volume

==

Landfill Parameters

==

Year Opened : 1977 Current Year : 1977 Year Closed: 2008
Capacity : 880865 Mg
Average acceptance Rate Required from Current Year to Closure Year : 26693.20 Mg/Year

==

Model Results

==

Year	Refuse in Place (Mg)	Methane Emission Rate (Mg/yr)	Methane Emission Rate (Cubic m/yr)
1978	2.936E+04	1.664E+02	2.494E+05
1979	5.872E+04	3.247E+02	4.867E+05
1980	8.809E+04	4.753E+02	7.124E+05
1981	1.174E+05	6.185E+02	9.271E+05
1982	1.468E+05	7.547E+02	1.131E+06
1983	1.762E+05	8.843E+02	1.326E+06
1984	2.055E+05	1.008E+03	1.510E+06
1985	2.349E+05	1.125E+03	1.686E+06

2050	0.000E+00	1.125E+00	1.686E+00

==

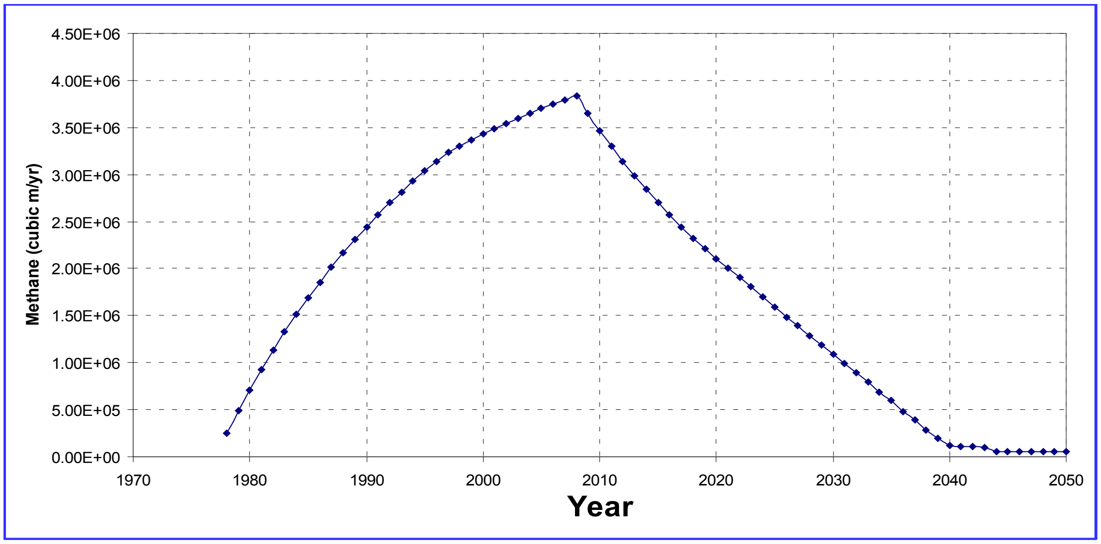
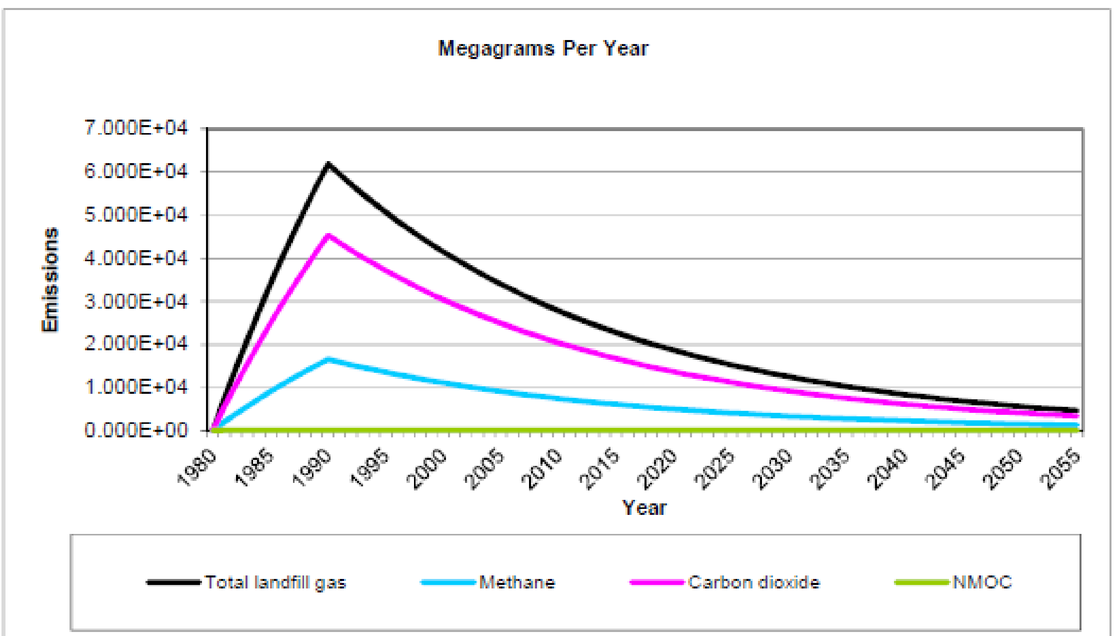
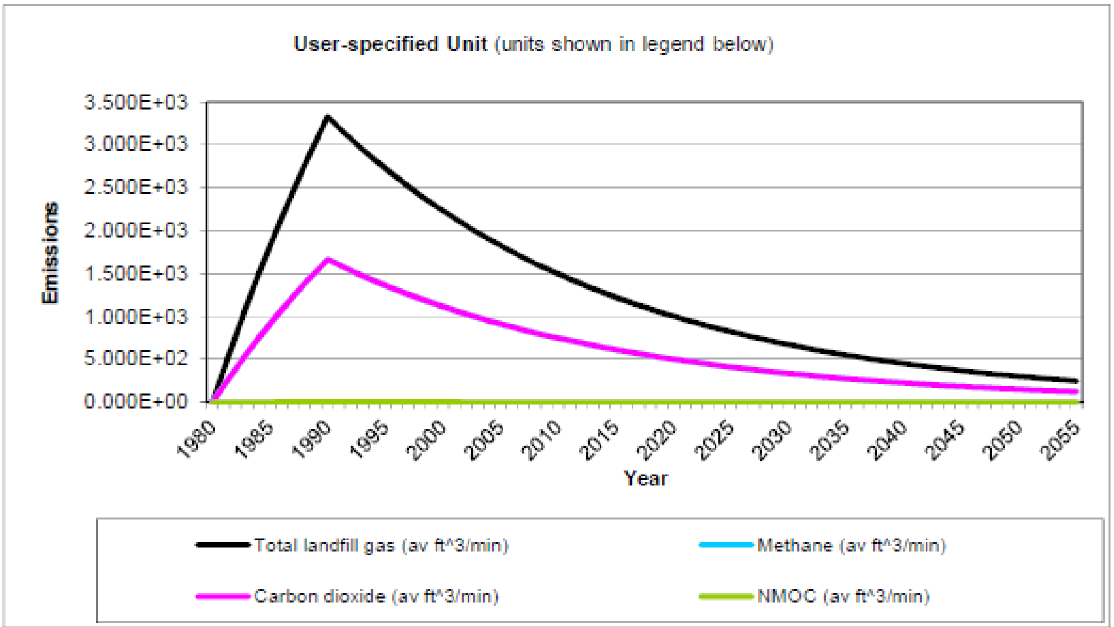


Figure 45: Methane generation rate with time plotted from LandGEM run data





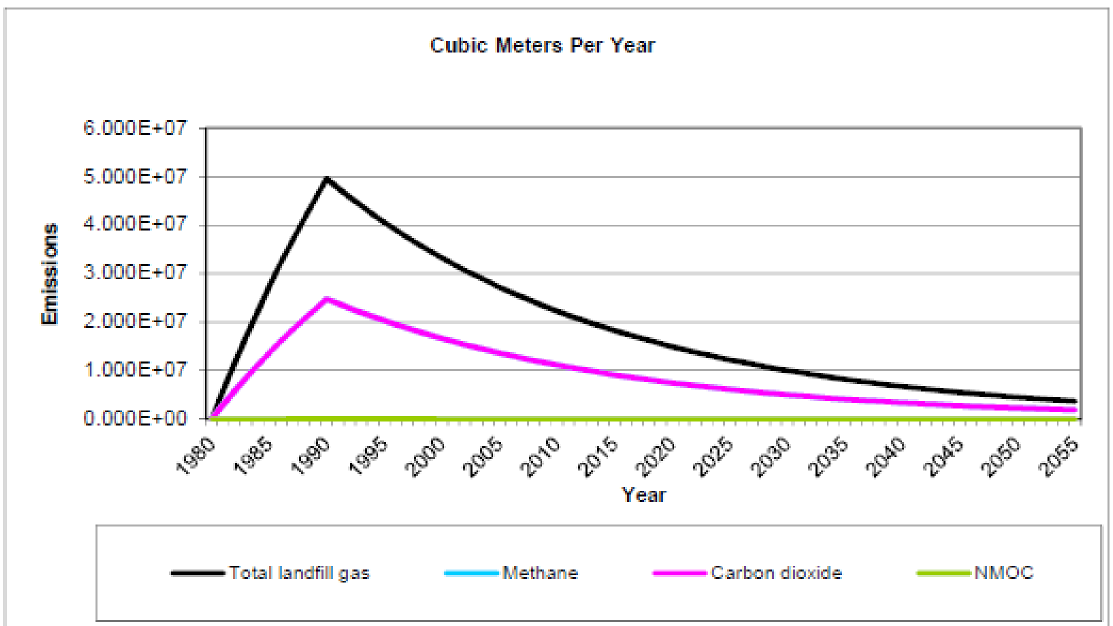


Figure 46: Typical graphs (3 graphs above) generated by the LandGEM run for gases

12.7 Beneficial Use of Landfill Gas

- The LFG can be passed through filters to remove moisture and possible hydrogen sulfide, and then injected into the furnace in combination with the regular boiler fuel, which may be coal, oil or natural gas (Figure *47*).
- Boiler fuel is perhaps the simplest approach to using LFG, but availability of a boiler near a landfill is not common. When deciding how far to transport the gas, the cost of

constructing a pipeline between the site and the boiler must be compared with the gas's value.

- If a boiler is not available, LFG can be directed to an engine-generator system for electricity production.
- Almost all landfills have electrical service, and the generated power can be put back into the electric grid.
- A typical turbine generator system (Figure *48*) will produce 3.3 megawatts of electricity, consuming 1,600 standard cubic feet per minute of 500 BTUs per cubic foot of LFG.
- Internal combustion engines also are being used to operate the generators. Because the gas methane content will directly affect the turbine's performance, it is important that site operators tightly regulate the gas collection system. Electricity generation from LFG is expected to increase greatly in the near future.
- Other LFG use options include vehicle fuel. Experiments currently are being conducted on fuel cells.

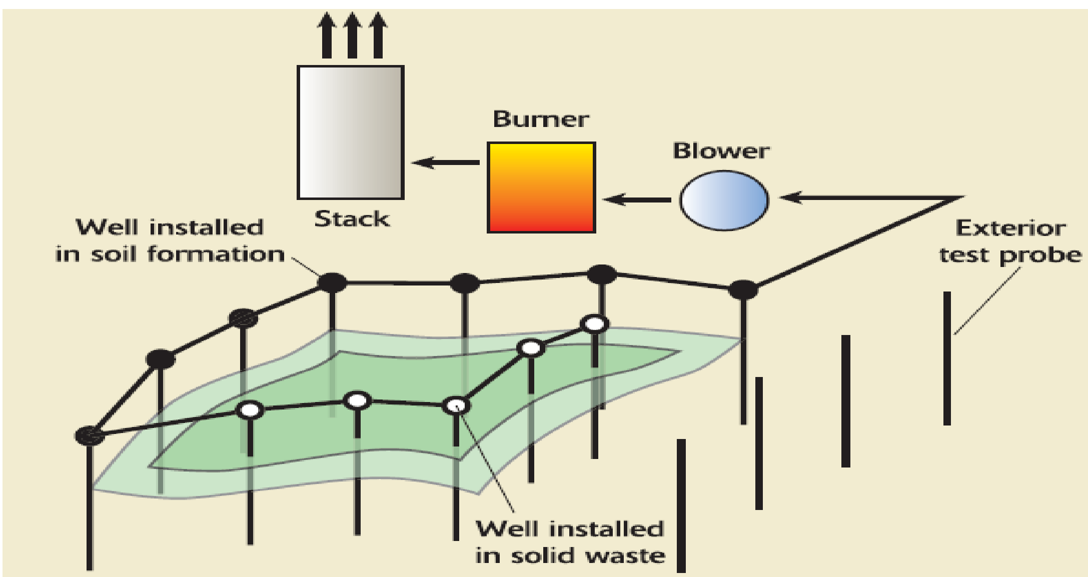


Figure 47: Landfill gas collection and burning system

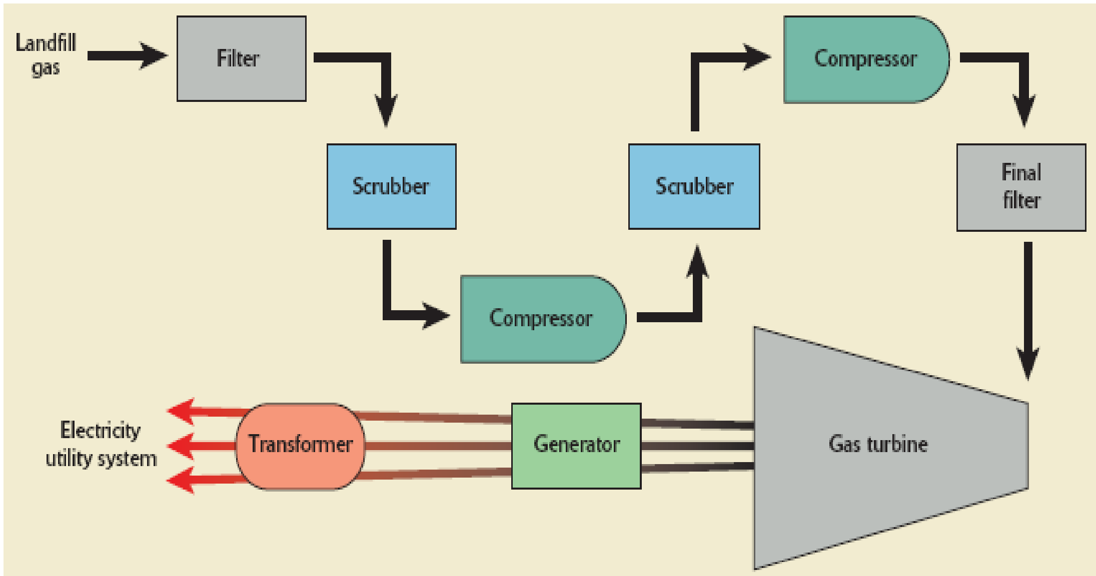


Figure 48: A typical electricity generation flowchart from LFG

13.Summary

In this course we discussed and understood processes and needs of Solid Waste Landfills, Site Selection, Site Preparation, Equipment, Operation, Environmental Considerations, Bioreactor Landfill, Landfill Design, Completed Solid Waste Landfills, Beneficial Use of Solid Waste By-Products such as leachate and gas. We solved several problems as well as reviewed HELP Model and LandGEM run results to understand the extent of solid waste landfill design and related issues.

14. References

1. Personal work experience and open source from internet.
2. Other references are shown as footnotes.

+++++++++++++++ **The End** ++++++++++++++

Any questions please contact the instructor at makarim@juno.com

QUIZ for Overview of Solid Waste Landfill

1. The solid waste by-products are:
a. leachate and gas
b. electricity and gas
c. all of the above
d. none of the above

2. In order to select a site for a solid waste landfill, consideration should be given to Public opposition, Proximity of major roadways, Speed limits and _______________.
a. Load limits on access roadways
b. Bridge capacities
c. Underpass limitations
d. all of the above
e. none of the above

3. The 3 basic types of solid waste landfill are: sanitary (municipal), CDD, and Industrial Landfills.
a. True
b. False

4. A solid waste landfill must comply with the following criteria:
a. Certain distance (5 miles) from airport
b. Should not be on the flood plain
c. Should not be on fault areas
d. all of the above
e. none of the above

5. A SW LF should be located more than ___________ from drinking water wells.
a. 300 ft
b. 500 ft
c. 700 ft
d. 900 ft

6. A SW LF should be located more than ___________ from airport runways.
a. 5300 ft
b. 10,000 ft
c. 12,000 ft
d. 15,000 ft

7. Selecting the type, size, quantity, and combination of machines required to move, spread, compact and cover waste in a solid waste landfill depends on:

a. Waste amount and type
b. Weather conditions
c. Site and soil conditions: topography, soil moisture and difficulty of excavation
d. all of the above
e. none of the above

8. There are two basic techniques that are involved in landfill operation and these are: area method and trench method
a. True
b. False

9. ***Daily cover*** consisting of ______ inches of compacted soil or other approved material shall be placed upon all exposed solid waste prior to the end of each operating day.
a. 4
b. 5
c. 6
d. 8

10. If any area of a landfill attains final elevation, within ________ days after such elevation is reached, the ***final cover*** construction will be initiated in accordance with the requirements of Closure Regulations.
a. 30
b. 60
c. 90
d. 120

11. There is a probability that diseases may be spread by vectors and air and water may be polluted from landfill operations due to the ______ emission and _______ disposal.
a. gas leachate
b. leachate gas
c. water leachate
d. radiation water

12. There are 3 types of Bioreactor Landfill and these are: Aerobic, Anaerobic, and Hybrid
a. True
b. False

13. In anaerobic bioreactor landfill, biodegradation occurs in the absence of ________ and produces landfill gas.
a. oxygen
b. carbon dioxide
c. nitrogen
d. hydrogen

14. Landfill gas, primarily ________, can be captured to minimize greenhouse gas emissions and for energy projects.
a. oxygen
b. methane
c. hydrogen
d. nitrogen

15. The primary by-products of the aerobic (Stage I) process are ____________.
a. oxygen and water
b. carbon dioxide and water
c. hydrogen and water
d. nitrogen and water

16. The ___________hybrid bioreactor landfill accelerates waste degradation by employing a sequential aerobic-anaerobic treatment to rapidly degrade organics in the upper sections of the landfill and collect gas from lower sections.
a. aerobic
b. anaerobic
c. hybrid
d. all of the above
e. none of the above

17. The bioreactor landfill ______________accelerates the decomposition and stabilization of waste.
a. accelerates
b. decelerates
c. stop
d. none of the above

18. The bioreactor technology relies on maintaining optimal moisture content near field capacity, approximately _________ and adds liquids when it is necessary to maintain that percentage.
a. 35 – 65%.
b. 40 – 65%.
c. 50 – 60%.
d. 30 – 40%.

19. Leachate recirculation and/or liquid addition to bioreactor landfill can be achieved with:
a. Ponding
b. Spraying
c. Horizontal Wells
d. all of the above
e. none of the above

20. Regulations require that at least _____ upgradient and ________ downgradient monitoring wells shall be required within a compliance network for a solid waste landfill.
a. 2 3
b. 1 3
c. 3 4
d. 3 1

21. Regulations require that the owners or operators of sanitary landfills must perform _________ ground water monitoring.
a. monthly
b. quarterly
c. yearly
d. bi-yearly

22. The leachate collection system shall be designed and placed:
a. to prevent causing failure of the liner;
b. to filter and prevent migration of fines to the drainage layer from above; and
c. so that no more than one foot head of leachate may accumulate over the liner at its lowest point excluding manifold trenches and sumps
d. all of the above
e. none of the above

23. A flexible membrane liner (FML), at least ____-mil thick if linear low-density polyethylene (LLDPE) is used or at least ____-mil thick if high density polyethylene (HDPE) is used
a. 20 50
b. 30 60
c. 40 70
d. 50 80

24. In a sanitary landfill, a minimum ____-inch thick compacted clay layer with a permeability of $k \leq 1.0 \times 10^{-7}$ cm/sec needs to be used.
a. 12
b. 24
c. 30
d. 36

25. The final cover system in a sanitary landfill shall be designed and constructed to have an _____**-inch** infiltration layer with a hydraulic conductivity less than or equal to the hydraulic conductivity of any bottom liner system or natural subsoils present, or a hydraulic conductivity no greater than 1.0×10^{-5} cm/sec, whichever is less.
a. 12
b. 18
c. 24
d. 30

26. In a solid waste landfill, side slopes of ________ will be allowed provided that adequate runoff controls are established.
a. 11%
b. 30%
c. 33%
d. 40

27. A run-off control system must be able to manage at least the volume of water that results from a ___**-hour, ___-year** storm over the active portion of the landfill.
a. 12 15
b. 15 25
c. 24 25
d. 30 25

28. Completed landfills generally require maintenance for __________ (called post-closure care period) because of uneven settlement, final cover maintenance, groundwater monitoring, and leachate and gas management
a. 60 years
b. 50 years
c. 40 years
d. 30 years

29. The CQA program shall address the six physical components and these are: Foundations; Low-hydraulic conductivity soil liners; Synthetic membrane liners; Leachate collection and removal systems; Gas management components; and Final cover systems.
a. True
b. False

30. A run-on control system should prevent liquid from flowing onto the active portion of the landfill during the peak discharge from a ________ storm event.
a. 25-year
b. 35-year
c. 40-year
d. 100-year

31. A bioreactor landfill is defined as a containment structure in which reactions are initiated and controlled to optimize a desired outcome.
a. True
b. False

32. The major parameters that are used to characterize leachate include:
a. BOD_5 and COD
b. TOC and pH

c. Total Alkalinity
d. all of the above
e. none of the above

33. Leachate quantity is estimated using EPA _______________ Model.
a. LandGEM
b. HELP
c. MultiMed
d. PCSTABL

34. Landfill gas generation rate is estimated using EPA _____________ Model.
a. LandGEM
b. HELP
c. MultiMed
d. PCSTABL

35. Groundwater contamination for alternate liner is estimated using EPA ___________ Model.
a. LandGEM
b. HELP
c. MultiMed
d. PCSTABL

36. If a boiler is not available, landfill gas (LFG) can be directed to an engine-generator system for ___________ production.
a. electricity
b. heat
c. steam
d. magnet

37. Which one is NOT one of the 4 common phases that a section of an MSW landfill undergoes after placement and generate landfill gas.
a. aerobic
b. anaerobic
c. anoxic
d. unsteady methanogenic
e. steady methanogenic