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An Introduction to Sanitary Landfills

Instructor: J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
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1. INTRODUCTION

Options available to eliminate the quantity and specific types of refuse in sanitary landfills include incineration, recycling, composting yard wastes and landfills designed for a specific waste requiring permits (e.g. hazardous waste landfills, asbestos landfills, etc.). So there might be less transport of refuse, placement of landfills close to the center of population would be the most desirable situation for the designer. Adverse public sentiment and the cost and availability of land usually are the deciding factors for locating a landfill, which make transporting the refuse to a more advantageous location the preferred option for many authorities. New technologies that can produce a closed landfill system, a self contained system resulting in very little impact on the surrounding environment, have resulted in more restrictive legislation and regulations for sanitary landfills. Therefore, site selection and proper landfill design are considered the most important factors in the refuse disposal process.

1.1 Laws and Regulations. Representative laws and regulations controlling site selection and design of sanitary landfills include those indicated below. This is not a comprehensive list of federal, state and local laws, ordinances and regulations applicable to the site selection and design of sanitary landfills. Specific projects must be governed by the laws and regulations of the project site.

1.1.1 Federal.

1.1.1.1 *40 CFR 240 and 241.* For the design and operation of new landfill sites, 40 CFR 240 and 241 were implemented by the Solid Waste Disposal Act of 1965 as amended by the Resource Recovery Act of 1970. These regulations, which were promulgated by the U.S. Environmental Protection Agency (USEPA) and are mandatory and require control of leachate to prevent degradation of surface and groundwater quality.

1.1.1.2 *CFR 40, Part 257.* 40 CFR 257 provides guidance on evaluating existing landfill sites to determine if they are suitable for continued use. In essence, this regulation states that landfills that pollute surface waters or contaminate underground drinking water sources should be considered "open dumps" and therefore must be either upgraded or safely closed.

1.1.1.3 *40 CFR 258.* In September 1991, 40 CFR 258 was promulgated. It provided further location restrictions, operating criteria, design criteria, ground-water monitoring, corrective action requirements, and closure and post-closure care requirements. Specific requirements of 40 CFR 258 are explained in applicable chapters of this manual.

1.1.1.4 *Leachate.* Landfills that release leachate into surface waters or underground drinking water sources can also be subject to the provisions of either the Clean Water Act (CWA) or the Safe Drinking Water Act (SDWA). Contaminants entering the ground-water, which are determined to be priority hazardous pollutants, require remedial action under either SDWA or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), referred to as the "Superfund Law."

1.1.2 State.

1.1.2.1 Enforcement of Federal solid waste regulations is now delegated to many states. The law delineating state responsibilities is the Resource Conservation and Recovery Act (RCRA). The mechanism used to discharge this responsibility is the Solid Waste Management Plan, developed by a state and approved by USEPA. An outgrowth of these management plans is definitive state regulations that prescribe design and operating standards for landfills. Most state regulations also require that every landfill operator obtain a permit for each facility, and that a registered professional engineer design the disposal facilities.

1.1.2.2 A majority of states specifically require groundwater monitoring systems, and many of the remainder have general authority to impose groundwater monitoring on a site-specific basis. Almost all of the states have either requirements in their regulations, or have general authority to impose corrective action. Approximately half of the states require methane gas monitoring and/or surface water monitoring. While most states have general guidelines or requirements for facility closure and post-closure maintenance requirements, these requirements vary widely in stringency.

1.1.2.3 Most states have issued separate regulations on hazardous waste management. Consequently, whenever a leachate release contains a hazardous substance, corrective action will be required and will be guided primarily by these regulations.

1.2 Solid Waste Characteristics. In the past, lawn and garden trimmings have made up approximately 12% of the waste in municipal landfills. Also, many installations and municipalities are no longer disposing of yard or garden wastes in sanitary landfills; instead the waste is land farmed or disposed in non-sanitary landfills, such as approved fill areas. To further reduce the waste streams, many installations now burn wood, recycle metal and other materials, and use dirt, concrete, and brick for erosion control projects.

1.3 Alternate Disposal Methods.

1.3.1 Alternatives. The options generally available are contractual arrangements, sanitary landfills, and incineration, but new methods may be introduced as they become economically viable. The preferred method of solid waste disposal is to participate in a regional solid waste management system, if feasible. In the absence of a regional system, contractual arrangements for hauling and/or disposal with a public agency or a commercial entity may be practical. When contractual arrangements are impractical and where conditions are suitable, alternative methods to sanitary landfills may include incineration with energy recovery, recycling of suitable materials, and composting organic matter.

1.3.2 Comparison of Alternatives.

1.3.2.1 Sanitary landfilling is generally preferred over other alternatives, because there is less handling and processing of materials. However, a landfill may not be the most economical or environmentally preferred method. The rapid filling of available sites, and outdated containment systems of existing landfills have forced authorities to consider alternative disposal methods. A combination of the options listed above may be the best solution, but may depend on several factors at the installation, including: the type of refuse, availability of land for site selection, incinerator accessibility, economic feasibility for recycling usable materials, suitable locations for large quantity composting, and possible contractual arrangements that would combine several of these methods.

1.3.2.2 The main advantage of a sanitary landfill is that handling and processing of refuse is kept to a minimum. Handling is limited to the pickup and transport of the waste, the spreading of refuse, and covering with a suitable cover material. Composting requires more handling before it is stored to decompose, and may only be suitable for disposing of organic matter such as yard waste. Therefore, composting may not be a viable alternative for a majority of the situations. Recycling requires that only specific materials be processed, and requires more handling than most other methods, but can reduce solid wastes in a landfill by as much as 30%. After the material is collected, it may go through various changes and processes, at a substantial expenditure of energy, before it results in a reusable form. Recyclable materials include paper, plastics, glass, metals, batteries, and automobile tires. Incineration with energy recovery has been used for some time, but has come under increased scrutiny because of new laws and regulations aimed at reducing air pollution and the resulting products of incineration may be even more dangerous than originally thought. Clean air laws, and negative public sentiment may require additional expense and waste treatment that can make incineration the least favored alternative. Ash residue and bulky refuse which are not burned during incineration will still require disposal. The main advantage of incineration is the capability to reduce landfill use by 70-80%.

1.3.2.3 The critical factors which must be considered include: the possibility of surface and groundwater contamination, explosions from gases generated by waste decomposition, airborne ash from incineration, odors from the composting process, and the lack of suitable sites with the capacity for long term use are critical factors which must be considered. Design authorities must make decisions which are critical to the areas surrounding the proposed sanitary landfill. Selecting a method for proper and complete disposal can be a very intricate process.

1.4 Solid Waste Stabilization in a Sanitary Landfill.

1.4.1 Alternatives. While past designs required that landfills receive extended maintenance after closure, increasingly stringent regulations and the shrinking availability of suitable sites for landfills may force the designer to consider some of the new technologies that can speed up solid waste stabilization. Stabilization is achieved by the degradation of the deposited refuse, mainly through decomposition, which reduces the pile volume and can lead to surface subsidence. Landfill designs offer two options: dry or sealed landfills; and wet landfills.

1.4.2 Dry Landfills. Dry landfills are designed to seal off the solid waste in hopes of reducing leachate production, therefore decreasing the possibility of leachate leakage outside of the landfill system. Unfortunately, studies show that solid waste stabilization is limited with the “dry” system. Archaeological investigations have found 20 years old refuse in existing landfills which was preserved from the elements. Because the waste was sealed off, it was protected from the rotting influences of air and moisture. While this method may require low maintenance, it could possibly require maintenance for several decades, with little actual stabilization or decomposition of the solid waste.

1.4.3 Wet landfills.

1.4.3.1 Biodegradation. Current studies have shown that wet systems, or landfills that use leachate recirculation, are becoming the favored option when considering solid waste stabilization as a priority for the landfill. Since most biodegradation results from complex interactions of microbial bacteria, these “wet landfills” may also require the addition of air along with the recirculation of leachate. Lined landfills that have been properly designed and constructed provide leachate containment with a low risk of leakage.

1.4.3.2 Gas Generation. Methane gas generation is considered to be a problem at some landfills. Therefore, the production of methane and other gases should be considered in the design. The economics of extracting methane gas as an energy source makes accelerated methane gas production a benefit of wet landfill designs. This may require that containing and recovering the methane gas be made part of the landfill design.

1.4.3.3 Stabilization Time. The main advantage of a wet landfill is the increased rate of stabilization of the solid waste in the landfill. Studies show that the process of leachate recirculation can speed up the rate of waste decomposition, by an active biological process in a landfill from 50 or more years for a dry landfill, to just 5 or 10 years for a wet landfill. Long term financial savings through eliminated or reduced maintenance and long term monitoring may outweigh the initial start-up costs and requirements for leachate recirculation, and should be considered in the design of the sanitary landfill.

2. PLANNING

2.1 Feasibility Investigation. The feasibility report for a new sanitary landfill should summarize the findings from an investigation of factors discussed herein, and should include advantages and costs of waste recycling, volume reduction, and waste minimization. The options for a new landfill must be investigation; these options include prolonging the life of an existing landfill, alternate disposal methods, and use of regional or private facilities. In those cases where an installation sanitary landfill is recommended, plans will be included which show existing conditions and final conditions, the topography at the landfill site, surface drainage, quantity and location of cover material, supporting facility requirements, and recommended operational procedures. Most states also have their own procedures for documenting the feasibility of a landfill project and site.

2.2 Operational Data for Planning.

2.2.1 General. Every effort should be made to maintain design intent during the operation of the landfill. Operational data which will be provided by the using service will include a detailed description of mechanical equipment to be used for handling refuse and operating the landfill, and the methods of solid waste placement that will be used.

2.2.2 Waste Characteristics. The using service should have data on the solid waste for which disposal is required, including the types of waste, the amounts, and the variations in delivery rates. When possible, the information should be based on an analysis of solid wastes from the installation on which the project is to be located, or from a similar installation. For new installations, an analysis can be made based on the population to be served and other major sources of solid waste. The daily per capita quantity of solid waste for troop facilities is typically 4 to 6 pounds of combined refuse and garbage. This rate is based on effective population, which is the sum of the resident population plus one-third of the nonresident employees. For industrial facilities, an analysis of the operation is required.

2.2.3 Operational Equipment . The using service can provide information on the equipment to be used, both for collection and delivery, and sanitary landfill operation. This will include any planned changes in equipment. The capabilities of this equipment must be considered in evaluating factors such as access roads, grades, drainage, and operation in severe climates.

2.2.4 Operational Methods. The two most commonly used methods of operating a landfill are the area method and the trench method. Selection of the most appropriate method depends on local conditions. In the area method, waste is placed in a large open excavation, is spread and compacted, and then covered with suitable material. The trench method takes its name from the fact that waste is dumped into a trench and then covered with material from the trench excavation. Typical area and trench operations are shown in Figures 1 and 2. The expense of lining side slopes generally makes the trench method less desirable than the area method. The design presented in this manual is a combination of the area and trench methods.

2.3 Site Selection.

2.3.1 Planning. Site selection is very much a part of the design process, and could be considered the most critical step in establishing a landfill disposal facility. Landfill siting must be a balance between minimizing haul distances, which impacts the economics of the landfill, and maximizing distances from housing areas, inhabited buildings and other undesirable locations. Larger installations may require more than one landfill when justified by savings resulting from reduced haul distances. It is recommended that a preliminary closure plan be drafted prior to the site selection to ensure that the closure is considered. There are many uses for properly closed landfill sites. These include many areas of interest to an installation, such as recreational parks, parade grounds, and parking lots.

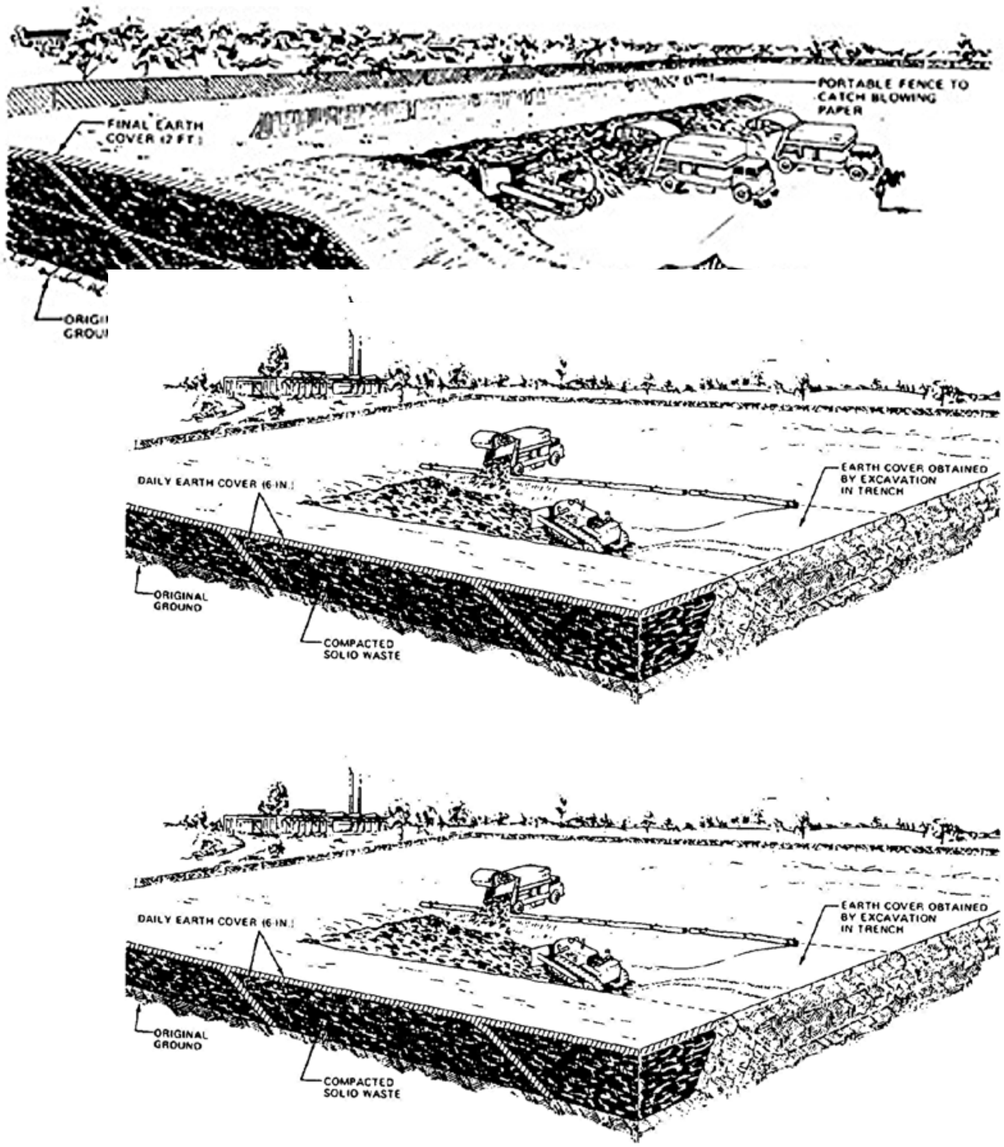

Figure 2
Typical Trench Landfill Operation

2.3.2 Other Considerations*.* The selection process must consider ground and surface water conditions, seismic impact zones and fault areas, geology, soils and topographic features, solid waste types and quantities, geographic factors, and aesthetic and environmental impacts. Environmentally sensitive areas, including wetlands, 100-years flood-plains, permafrost areas, critical habitats of endangered species, and recharge zones of sole source aquifers, should be avoided or receive lowest priority as potential locations for landfill disposal facilities. These areas might require a comprehensive study of the location with respect to environmentally sensitive conditions.

- ***Airports.*** No portion of a landfill can be within 10,000 feet of a runway end used by turbojet aircraft or 5,000 feet of runway end used by piston-type aircraft.
- ***Wetlands.*** All infringements into wetlands will be avoided. Restrictions and considerations for impacting wetlands are in 40 CFR 258, 33 CFR 320, and EO 11990.
- ***Seismic Impact Zones.*** Areas of high earthquake activity will be avoided. No portion of a landfill shall be in a seismic impact zone, as defined in 40 CFR 258, unless it is designed to resist the corresponding pressure.
- ***Unstable Areas.*** Karst terrain will be avoided. Before a landfill can be located in a geologically unstable area it must be demonstrated to the appropriate state agency that the integrity of the liner system and other structural components will not be disrupted.
- ***Cover.*** There should he a sufficient quantity of on-site soil suitable for use as cover material.
- ***Existing Site Utilities.*** Sites traversed by underground pipes or conduits (for sewage, storm water, etc.) must be rejected unless their relocation is feasible.
- ***Access.*** Preferred access to the site is over an existing secondary road net with all-weather capability and direct routes to the landfill. Use of primary roads, roads through housing areas or roads crossing major highways creates both a safety hazard and a nuisance.

3. DESIGN

Proper design is vital to the successful operation of a landfill disposal facility in even the most suitable location. All technological alternatives which meet requirements of the proposed landfill should be reviewed prior to incorporation into the design. The design should produce a landfill capable of accepting given solid waste materials for disposal. To serve as a basis for design, the types and quantities of all refuse expected to be disposed of at the landfill should be determined by survey and analysis.

3.1 Site Development Plans. In accordance with 40 CFR 241, site development plans should include:

- Initial and final topographic maps at contour intervals of 5 feet or less.
- Land use and zoning within one quarter of a mile of the site, and airports that could be affected by birds near the landfill. Land use drawings should include housing and other buildings, water wells, water courses, rock outcroppings, roads, and soil or rock borings.
- Utilities within 500 feet of the site.
- Buildings and facilities associated with the landfill.
- Groundwater monitoring wells.
- Provisions for surface water runoff control.
- Leachate collection and treatment or disposal system.
- Gas collection control and disposal system.
- Final cover system.
- Liner system.

3.2 Additional Plans and Narratives. Plans should be accompanied by a narrative and drawings which describe:

- Planned or projected use of the completed site.
- Programs to monitor and control gases and leachate.
- Current and projected use of water resources.

- Elevation, movement, and initial quality of groundwater which may be affected by the landfill.
- Groundwater testing program.
- Description of soil and other geologic materials to a depth sufficient to determine the degree of ground-water protection provided naturally.
- Potential for leachate generation.
- Vector controls.
- Litter control program.
- Operating procedures.
- Closure.

3.3 Health and Safety. The design will produce a sanitary landfill which does not threaten the health and safety of nearby inhabitants, and which in general precludes the following:

- Pollution of surface and ground-waters from landfill generated leachate.
- Air pollution from dust or smoke.
- Infestation by rats, flies or other vermin.
- Other nuisance factors such as odors and noise.
- Fires and combustion of refuse materials.
- Explosive hazards from methane gas generated within the landfill.

3.4 Volume Minimization. Reducing the need for a landfill should be a priority for all installations. The type and extent of compaction should be considered in design to reduce landfill volume.

3.5 Site Layout.

The configuration of the landfill, supporting buildings, and access roads should be to facilitate effective stormwater drainage, erosion control, leachate collection, and operation at a minimum cost. The layout should make optimum use of the existing terrain to minimize excavation and construction costs. Supporting buildings should be near the landfill. If the waste is to be weighed, a truck scale should be adjacent to the access road and situated where all vehicles entering and exiting the landfill must pass directly in front of the scale. A typical site layout is shown in Figure 3.

3.6 Trench Design.

3.6.1 Capacity. Commonly 1,000 to 1,200 pounds of refuse requires 1 cubic yard of landfill volume. Under ideal conditions compaction rates, 1,800 pounds of refuse per cubic yard and higher have been achieved. Volume requirements for a new landfill should be determined by assessing operations at the landfill being closed or replaced. In the absence of existing data, the capacity will be based on 1,000 pounds of refuse per cubic yard of landfill volume.

3.6.2 Trenches. When designing the landfill the designer must consider the method of construction and operation. In the engineering report provided to the owner/operating agency, the designer must show location and orientation of the working face and explain how the landfill is to be operated and constructed. Considerations in design are:

3.6.2.1 Earth cover should be moved as little as possible, and over the shortest distance feasible. Use all excavated material continuously as cover to minimize stockpiling. However, provide one area for stockpiling material to be used for fire fighting.

3.6.2.2 Begin excavation and filling at the lowest point of the leachate system to facilitate gravity flow and to allow collection of all leachate from the very beginning of the landfill's life.

3.6.2.3 If feasible, lay out trenches such that refuse will be placed along the side of the trench facing the prevailing winds in order to reduce windblown litter. Indicate on the drawings the direction of prevailing winds, and where landfilling is to begin.

3.6.2.4 Do not allow surface stormwater to enter trenches.

3.6.2.5 The floor of the landfill must have a 2 to 5 percent slope to drain leachate toward the collection system. Follow the slope of the original grade to minimize excavation, and keep the depth uniform to minimize leachate pumping.

3.6.2.6 Provide side slopes of 3 feet horizontal to 1 foot vertical or flatter.

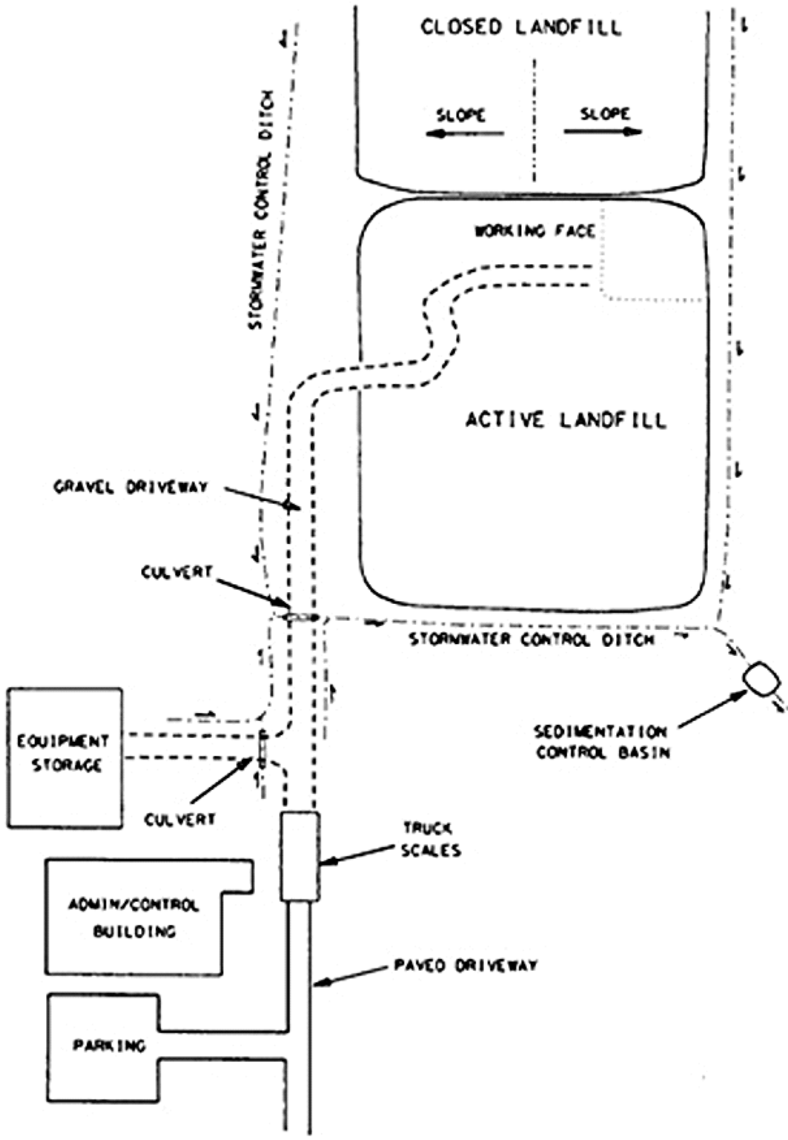

Figure 3
Typical Landfill Site Layout

3.6.2.7 Provide a roadway constructed so that wastes can be placed at the bottom of the working face during inclement weather. The road surface and slope are dependent on actual site conditions. A crushed stone surface and a maximum 6 percent slope are recommended. The minimum width must be sufficient for two trucks to pass in opposite directions unless anticipated traffic does not warrant it.

3.6.2.8 To minimize the amount of stormwater coming into contact with the waste, the trench can be constructed as a series of cells separated by berms or by alternating the direction of the bottom slope as shown in Figures 4 and 5. See Figure 6 for a typical berm detail.

3.6.2.9 Provide for simple construction and operation methods.

3.6.2.10 For simple and economical operation, all wastes should be placed in a single trench unless directions are given to segregate certain wastes.

3.6.3 Final Cover.

3.6.3.1 40 CFR 258 provides the following design criteria for final covers to minimize infiltration and erosion:

- Provide a hydraulic barrier of at least 18 inches of earthen material that has a permeability less than or equal to that of the bottom liner system or natural subsoil, but not greater than 1 x 10^{-5} cm/sec.

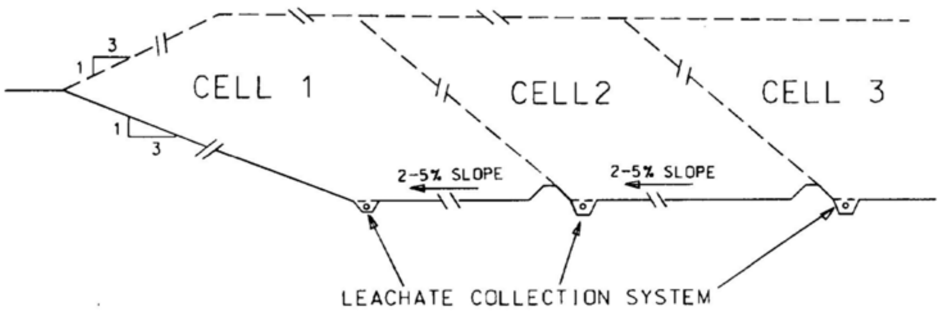

Figure 4
Typical Trench Bottom Separated by Berms

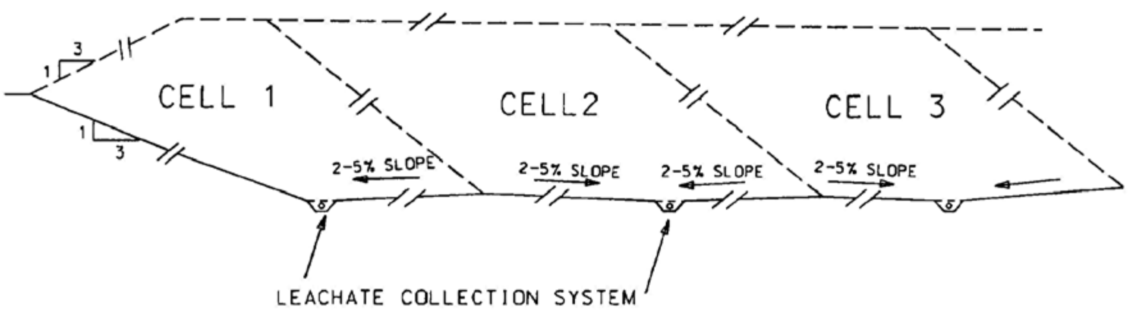

Figure 5
Alternate Trench Bottom Design

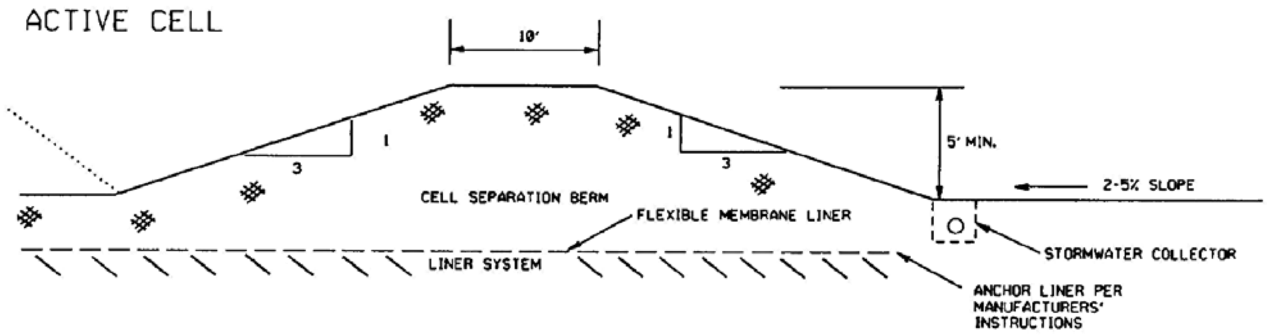

Figure 6
Typical Berm Detail

- Provide an erosion layer of at least 6-inches of earthen material capable of sustaining native plant growth.
- The designer can submit an alternative design which must be approved by the appropriate State or Federal agency.

3.6.3.2 The actual design, however, will be dependent on field conditions. A general design shown in Figure 7 consists of 12 inches or more of top soil, followed by a 12 inch drainage layer of sand, and a hydraulic barrier of 24 inches of compacted clay over a gas collection system. Drain tile or perforated pipe can be installed in the drainage layer to facilitate drainage, however, they must be designed to prevent crushing. There must be 12 to 24 inches of compacted soil between the gas collection system and the compacted waste. If a sufficient quantity of good quality clay is not available, a 40 mil thick flexible membrane liner (20 mil minimum) is recommended. In some states both a compacted clay layer and a flexible membrane liner are required. Grass or other native vegetation with finely branched root systems that will stabilize the soil without penetrating the hydraulic barrier must be planted. Trees must not be allowed to grow in the cover unless necessary for the planned final use of the landfill, and then must be enclosed in planters. Generally, a much thicker soil layer is required for planted trees.

3.6.3.3 Generally, the drainage layer will consist of course sand, but if there is concern that burrowing animals may penetrate the hydraulic barrier, the drainage layer should be comprised of aggregate.

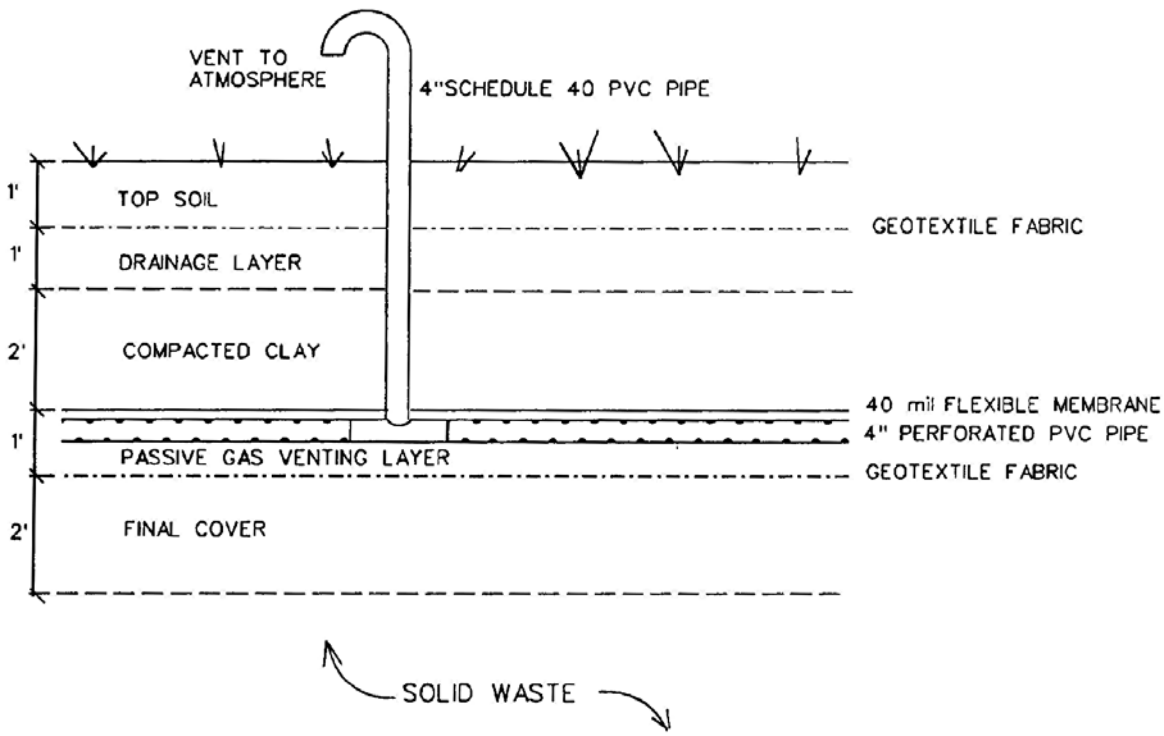

Figure 7
Typical Cover and Gas Venting System

The size of the selected aggregate is dependent on the types of burrowing animals found in the area. In most cases, size 357 per ASTM D 448 should be specified. Size 357 is comprised predominantly of 2-inch stone with a small percentage as small as 3/16 of an inch. However, to prevent undue stress on the liner the aggregate must be separated from the liner by a layer of sand or permeable soil.

3.6.3.4 To minimize erosion the top grade must be sloped in accordance with local design standards to form a crown (a 2 percent slope is common). Side slopes should be 3:1 or flatter. (See Figure 8). Drainage ditches around the perimeter of the landfill should carry stormwater away from the landfill quickly and should not cross over the landfill. Windbreaks at slopes facing prevailing winds can be used to minimize wind erosion.

3.6.4 Ultimate Use of a Landfill Site. The use which is to be made of the landfill site after closure should be decided during the initial planning stage. Uses which are typical are playgrounds, parks, and other recreational purposes during the near term, and parking areas or light industry following stabilization. Construction on a completed landfill should not be programmed until site and subsurface investigations have verified that damaging settlement or gas generation would not occur. Installation master plans will be used in siting a proposed sanitary landfill to assure that construction on the site is not contemplated before the refuse has fully stabilized.

3.6.5 Access Road. The access road should not cross completed cells. An all-weather road should not cross completed cells. An all-weather road should parallel the trench outside the landfill area. Branch roads should lead into the trench to the base of the working face. Generally, the branch road will come down the slope of the cell under construction and cross the berm to the working cell.

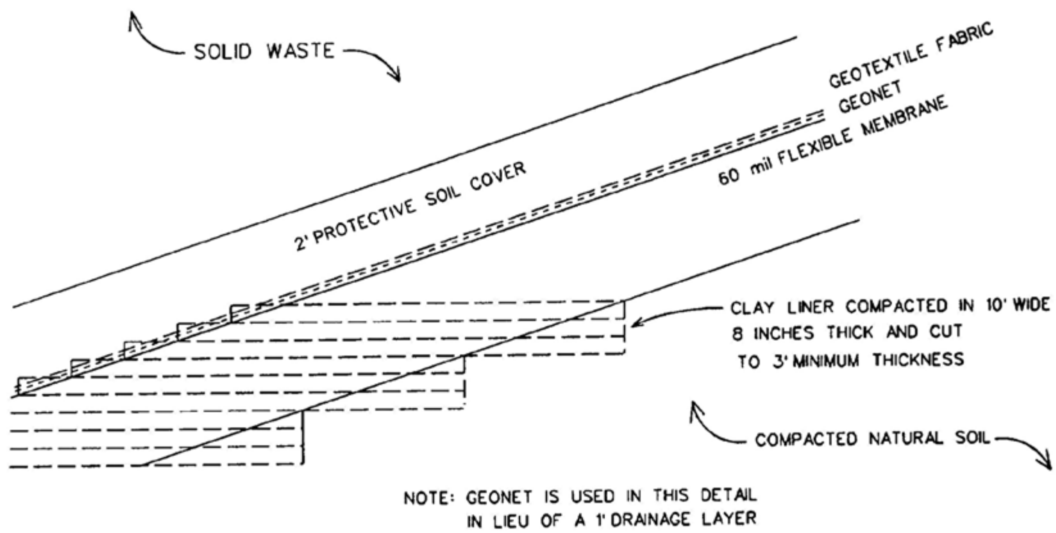

Figure 8
Typical Side Slope Construction Detail

3.7 Leachate Control.

3.7.1 General.

3.7.1.1 Leachate is a liquid generated as a result of percolation of water or other liquid through landfilled waste, and compression of the waste as the weight of overlying materials increases. Leachate is considered to be a contaminated liquid, since it contains many dissolved and suspended materials. Good management techniques that can limit adverse impact of leachate on ground and surface waters include control of leachate production and discharge from a landfill, and collection of the leachate with final treatment and/or disposal.

3.7.1.2 The minimization and containment of leachate within a landfill ultimately depends on the design of the landfill. Providing an impervious cover, minimizing the working face of the landfill, and limiting liquids to household containers and normal moisture found in refuse, are all methods that will minimize leachate production. Studies show that recycling leachate through the landfill can speed up stabilization.

3.7.2 Composition of Leachate.

3.7.2.1 The composition of leachate will determine the potential effect it will have on the quality of nearby surface and ground-water. Specific contaminants carried in leachate vary, depending on what is in the solid waste, and on the simultaneous physical, chemical, and biological processes occurring within the landfill.

3.7.2.2 The chemical and biological characteristics of leachate depend on constituents found in the solid waste, the age of the landfill, degree of compaction, and climatological conditions, which includes ambient temperature and rainfall. Young landfills, generally those less than 5 years old, produce leachate with a high organic content made up primarily of fatty acids. Leachate from older landfills may have only 10 percent organic content, which will be predominantly humic and fulvic acid. In some landfills the metals content in the leachate has decreased with age, but in many others it has greatly increased with age. Leachate from younger landfills generally has a higher pH than older landfills. Table 1 lists some of the characteristics and common constituents of leachate for municipal landfills.

3.7.2.3 Requirements for controlling leachate from sanitary landfills are based on Federal and state laws and regulations.

Constituent (in mg/L except where noted)	Concentration Range *	Typical Concentration Range
Biochemical Oxygen Demand, 5-day (BOD)	4-57,70	1,000-30,000
Chemical Oxygen Demand (COD)	31-89,520	1,000-50,000
Total Organic Carbon (TOC)	0-28,500	700-10,000
Total Volatile Acids (as acetic acid)	70-27,700	**
Total Kjeldahl Nitrogen (as N)	7-1,970	10-500
Nitrate (as N)	0-51	0.1-10
Ammonia	0-1,966	**
Total Phosphates	0.2-130	0.5-50
Orthophosphates	0.2-130	**
Total Alkalinity (as $CaCO_3$)	0-20,850	500-10,000
Total Hardness (as $CaCO_3$)	0-22,800	500-10,000
Total Solids	0-59,200	3,000-50,000
Total Dissolved Solids	584-44,900	1,000-20,000
Specific Conductance (umhos/cm)	1,400-17,100	2,000-8,000
pH (units)	3.7-8.8	5-7.5
Calcium	60-7,200	100-3,000
Magnesium	17-15,600	30-500
Sodium	0-7,700	200-1,500
Chloride	4.7-4,816	100-2,000
Sulfate	10-3,240	10-1,000
Chromium (total)	0.02-18	0.05-1
Cadmium	0.03-17	0-0.1
Copper	0.005-9.9	0.02-1
Lead	0.001-2	0.1-1
Nickel	0.02-79	0.1-1
Iron	4-2,820	10-1,000
Zinc	0.06-370	0.5-30
Methane Gas (percent composition)	(up to 60%)	**
Carbon dioxide (percent composition)	(up to 40%)	**

* Based on data collected by U.S. Army Corps of Engineers, Construction Engineering Research Laboratory

** No data presented

Table 1
Leachate Characteristics and Common Constituents

3.7.3 Leachate Collection.

3.7.3.1 Design of Collection Systems.

- The fundamental approach in controlling leachate is first to confine leachate to the limits of the landfill, then to collect and dispose of it safely.
- For collection techniques to be successful an impermeable soil barrier or artificial liner must be in place to confine the leachate, and to deliver it to the disposal site. The most common type of collection system utilizes gravity drainage and consists of a layer of sand and/or gravel underlain with perforated pipes that carry the leachate to a collection point. Figure 3-7 shows examples of collection systems.

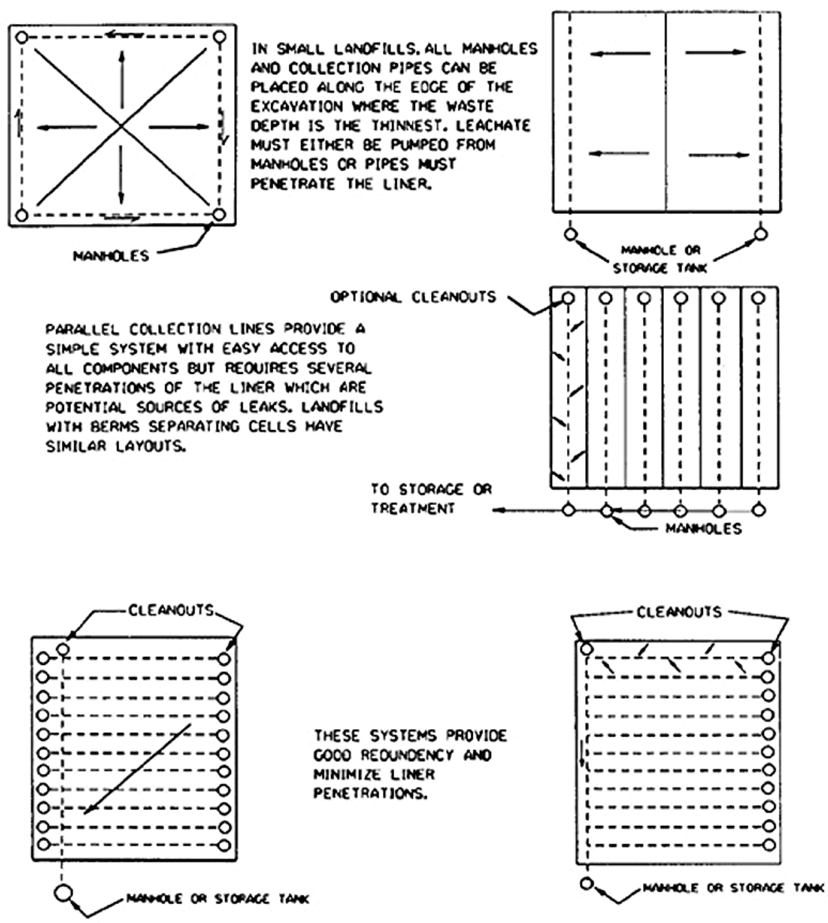

Figure 8
Leachate Collection Systems

- Underlying the leachate collection system must be a composite barrier consisting of a flexible membrane liner (FML), over a minimum depth of 2 feet of compacted soil having a hydraulic conductivity no greater than 1 x 10^{-7} cm/sec. In most cases, a layer of clay with a minimum 3-foot depth should be specified. While the USEPA has established a minimum FML thickness of 60-mil for high density polyethylene (HDPE), and 30-mil for other FML materials, a greater thickness is recommended. The type of material and its thickness must be selected based on the conditions anticipated. HDPE is more chemically resistant and stronger than PVC and other types of material due to its rigidity. However, PVC and more flexible materials conform better to settling and large deformations in the underlying material than does the rigid HDPE. Liner manufacturers should be consulted to determine acceptable materials. Generally, more than one material will be acceptable for each design. Figure 9 shows a typical liner system.

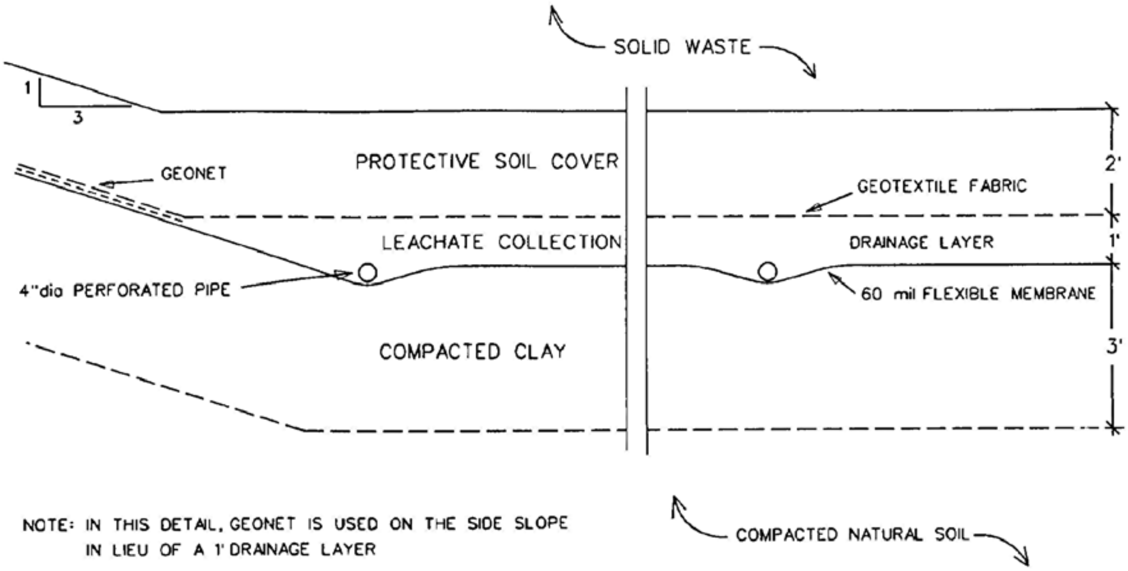

Figure 9
Typical Liner System

- *Liner Placement.* Where settlement is a concern or the underlying soil contains coarse material, a geonet layer can be used as a cushion under the liner. Geonet is a net-like product where strands are crossed to form a grid. It can serve as a protective layer or a drainage media. When placed over the liner, it protects the liner from gravel or crushed stone in the drainage layer and can replace all or part of the drainage layer. Geotextile fabric must be placed between the soil cover and the drainage layer and also between the soil or drainage layer and the geonet.

3.7.3.2 Pipe Location. Pipe location and placement are critical to leachate collection system performance. Failure of the collection system may result from crushing or displacement of pipe caused by equipment loading and/or differential settling. A pipe is best protected when it is placed in a trench, with careful consideration given to proper bedding and to solid waste loading conditions over the pipe. The trench provides added protection for the pipe, especially during placement of the first lift to waste when the pipe is most susceptible to crushing.

3.7.3.3 System Redundancy. Design redundancy is important to minimize the effect of any single failure. The system should be able to remove leachate from any point in the facility by more than one pathway, such as through the gravel bedding in the trench as well as the piping system. One of the primary ways to provide redundancy is to design collection laterals so that drainage requirements can be met by the gravel layer alone if flow through the pipe is restricted. Collection laterals are pipes and trenches that are placed parallel throughout the liner, at a spacing and slope determined by the designer. Collection laterals must be designed to discharge to treatment and/or disposal facilities. In addition, laterals should be spaced so that if one lateral is totally blocked, liquid can be removed through an adjacent lateral.

3.7.3.4 Maintenance.

- One of the most important considerations is to design the system to facilitate inspection and maintenance. There should be access to all parts of the system. This includes the placement of manholes and cleanouts so that maintenance equipment can reach any length of pipe. The design should consider minimum pipe sizes, distance between access points, and maximum pipe bends accessible by cleaning equipment. Pipes and manhole penetrations through the liner must be minimized. When the liner is penetrated, consideration should be given to making the penetrating material the same as the liner material. To avoid a penetration, riser pipes with a sump pump at the bottom can be laid on the side slopes above the liner. If a manhole is placed inside the liner a bed of soil must be placed between the manhole and the liner. All manholes must be vented to release landfill gases. (See Figures 10 and 11)
- It is extremely important to design a collection system to avoid clogging. For example, settling of solids can be avoided by properly selecting grain size distribution in the filter material to exclude solids. As the permeability of the drainer layer decreases the slope must increase. If a sufficient quantity of permeable material is not available, a synthetic geonet or drainage net can be used. The drainage layer should be at least one foot thick and be composed of fine gravel and course sand with a minimum hydraulic conductivity of

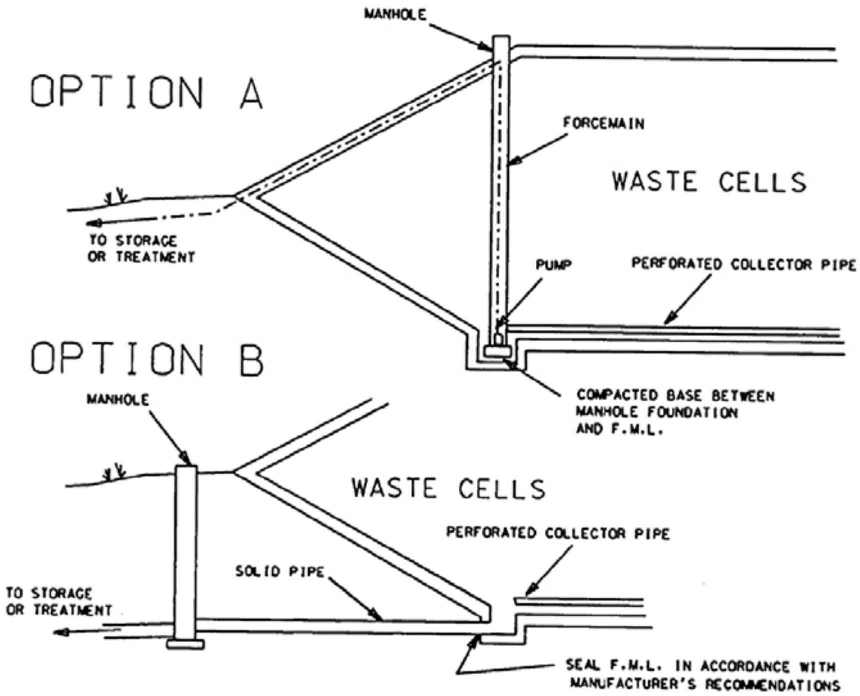

Figure 10

Collection Systems with Manholes

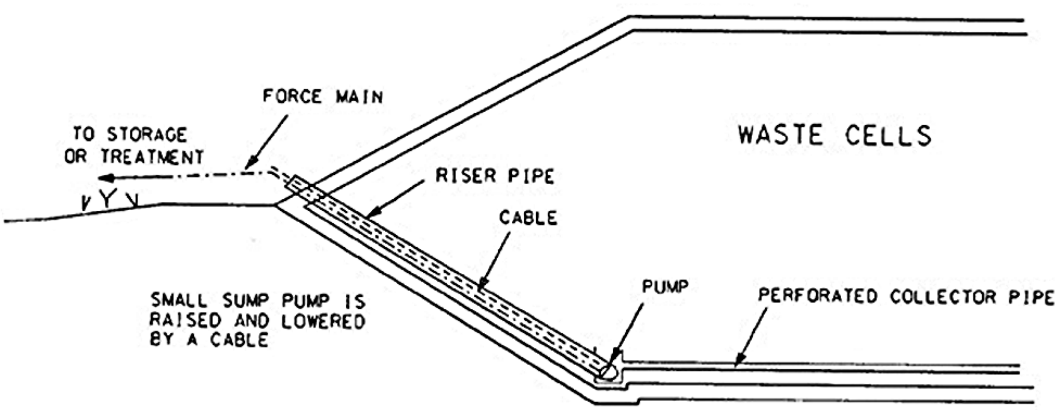

Figure 11

Collection Systems with Riser Pipes

1×10^{-2} cm/sec. A slope of 2 to 5 percent must be provided to maintain flow velocity during leachate collection so that solids do not settle out. Maintaining velocity will also help prevent biological and chemical processes that produce additional solids. Collection pipes should be placed in a trench where the top of the pipe is no more than one pipe diameter below grade, and the entire trench is wrapped in a geotextile blanket. (See Figure 12). Collection pipes should be situated where leachate will travel no more than 200 feet (preferably 100 feet or less) through the drainage layer before being intercepted.

3.7.3.5 Additional Protection. If leachate is expected to be extremely hazardous, or if the landfill is located in an environmentally sensitive area, then either a double composite liner with backup collection system, or a leak detection system will be required as determined by the responsible agency.

3.7.3.6 Transport for Treatment. The using service will determine the method of leachate disposal. Therefore, requirements for transporting leachate should be a part of that decision process.

3.7.4 Leachate Treatment.

3.7.4.1 Before a treatment plan can be formulated, the quantity and quality of leachate should be determined. Factors which influence leachate quality include:

- Refuse composition.
- Landfill age.
- Refuse depth.
- Refuse permeability.
- Ambient temperature.
- Available moisture from the surrounding environment.
- Molecular oxygen levels in the refuse. The three primary reasons for assessing leachate quality before determining the type of treatment required are to:
  - Identify whether the waste is hazardous.
  - Design or gain access to a suitable wastewater treatment plant.
  - Develop a list of chemicals for use in a ground-water monitoring program. See Table 1 for leachate characteristics and common constituents found in

landfill leachate. Leachate quantity is greatly dependent on the landfill design. A quantity estimate of leachate should be provided before deciding which treatment/disposal methods will be used.

3.7.4.2 OffsiteTreatment. The most common and often the most economical method for treatment of leachate is to discharge to a municipal sewage treatment plant (STP) offsite. While there is little data available, some plants have accepted high strength leachate in quantities of 2 to 5 percent of the total daily flow to the plant, and have reported no adverse impact. However, moderate increases in oxygen uptake, foaming and odors may occur, in addition to increased sludge production and metals concentrations in the sludge. Treatment at a municipal STP avoids the cost of onsite facilities, the need for personnel to operate them, and future operational problems which can result when leachate characteristics change as the landfill ages, or leachate volume decreases below the design capacity of an onsite treatment system.

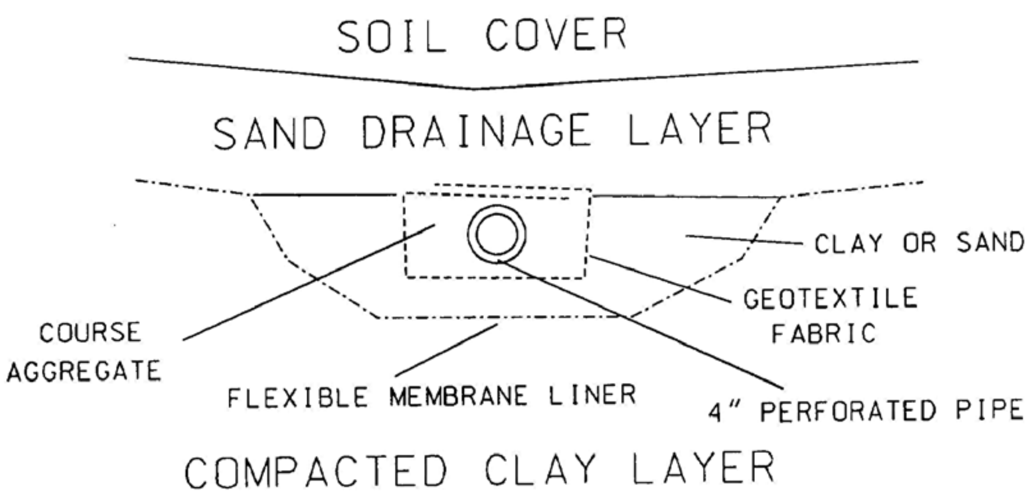

Figure 12
Collection Trench Detail

3.7.4.3 Onsite Treatment.

- Onsite treatment is generally used only at large, remote landfills. Biological treatment processes are most often used for leachate from landfills less than five years old, and physical/chemical treatment processes for landfills more than ten years old. Combinations of the two are necessary for landfills between five and ten years old.

- *Biological* treatment removes most dissolved organics, heavy metals, nutrients such as nitrogen and phosphorus, and colloidal solids. Typical biological processes include: activated sludge, stabilization ponds, rotating biological contactors, and trickling filters.
- *Physical/Chemical* processes include: ammonia stripping to reduce ammonia to nontoxic levels, carbon absorption to remove a variety of organic compounds, chemical oxidation (chlorination) for disinfection, ion exchange to remove soluble metallic elements and certain anions and acids, precipitation, flocculation and sedimentation to remove particulates and soluble heavy metals, reverse osmosis to separate out dissolved salts and organics, and wet air oxidation to remove highly toxic organics.

3.7.5 Final Disposal. Leachate may be (1) discharged to a surface water through a National Pollutant Discharge Elimination System (NPDES) permit, (2) discharged to a land application system, or (3) recirculated back to the landfill. Recirculation can accelerate waste stabilization in the land-fill, but does not eliminate the need for ultimate disposal of the leachate. The exception is arid regions where the soil and refuse attenuation capability eliminate leachate production. Discharge to a municipal STP eliminates the need for a separate NPDES permit for the leachate.

3.8 Gas Control

3.8.1 Production. Although gas generated within some types of landfills may be negligible, most landfills are expected to generate a significant quantity of gas. The quality of gas depends mainly on the type of solid waste. As with leachate, the quality and quantity of landfill gas both vary with time. The following discussion on gas quality and quantity pertains mainly to landfills with municipal type wastes, which would be expected at most installations.

3.8.1.1 Quality. Landfill gases, specifically methane gas, are natural by-products of anaerobic microbial activity in the landfill. The anaerobic process requires water and the proper mix of nutrients to maintain optimal conditions. The quality of gas varies with time, and may be characterized by four distinct phases. In the first phase, which may last several weeks under optimum conditions, aerobic decomposition takes place depleting the oxygen present and producing carbon dioxide. In the second phase, the percentages of both nitrogen and oxygen are reduced very rapidly, and anaerobic conditions lead to the production of hydrogen and carbon dioxide, the latter reaching its peak during this phase. Some experts consider the second phase to have started when the free oxygen is depleted. In the third phase, the percentages of carbon dioxide and nitrogen are reduced significantly, hydrogen and oxygen concentrations are reduced to zero, and the percentage of methane increases rapidly to reach a relatively constant level. The fourth phase which occurs after the landfill has become more stable, may be termed pseudo steady-state because the percentages of methane, carbon dioxide, and nitrogen all reach stable values. The time dependency of methane production is critical for landfill gas recovery and reuse projects. In most cases, over 90 percent of the gas volume produced from the decomposition of solid wastes consists of methane and carbon dioxide. The current procedure of sealing off landfills to maintain a dry environment significantly slows these four phases.

3.8.1.2 Quantity. The quantity of gas generated depends on waste volume, waste composition, and time since deposition of waste in the landfill, as summarized above. Methane production ranges from 0.04-0.24 cubic feet per pound of waste per year. Gas production may be increased by adding nutrients, such as sewage sludge or agricultural waste, the removal of bulky metallic goods, and the use of less daily and intermediate cover soil. Promoting stabilization in the landfill, such as designing for a "wet landfill", as discussed elsewhere in this manual, is a method for increasing the production of gases, specifically methane. The daily soil cover may inhibit gas movement and interaction, and create pockets of gas which restrict gas collection. Some authorities have used a spray-on foam to prevent the wind from scattering loose debris, thus reducing animal scavenging on the working face of the landfill. The foam dissipates when mixed in with the working portion of the landfill on the next day, so it will not restrict the flow of landfill gases, if that is a priority.

3.8.1.3 Regulations. The landfill authority should insure that all Federal, state, and local regulations are followed concerning gas collection and release, or recovery and reuse. Approximately half of the states and territories require methane gas monitoring. Monitoring is generally conducted at the periphery of the landfill site by selecting possible migration routes that could produce a safety hazard.

3.8.2 Collection. If gas is expected to be generated in a landfill, then arrangements should be made for proper venting or extracting the gas, and subsequent treatment provided where desired or required. Whether or not gas should be vented from a landfill depends on the following.

3.8.2.1 Venting Issues. The following issues should be considered before deciding on gas ventilation from a landfill:

- *Gas pressure.* A gas pressure build-up estimate should be made. The pressure generated by landfill gases should be low enough so as not to rupture the landfill cover. If gas generation is expected from waste biodegradation and/or from physical/chemical processes, then venting of the gas is recommended.
- *Stress on vegetation.* Landfill gases that diffuse upward through the landfill cover may have an effect on vegetation growing above. This stress may cause vegetation to deteriorate or die, which in turn will lead to increased erosion of the final cover.
- *Toxicity of the* gas. The toxicity of landfill gases should be studied. Release of gases by diffusion through the final cover is unavoidable without using a very high grade material. The diffusion rate, concentration of the gas, and its toxicity will determine whether such release will violate air quality regulations. In some cases a high grade, impervious cover may be required.
- *Location of the landfill.* Gases diffusing through a landfill cover may pose a health risk to the resident population in the immediate vicinity of the landfill. Proper monitoring should be provided.
- *Explosive potential.* The USEPA reinforced concerns about proper gas explosion control relative to landfill facilities and structures at the property boundary. These are addressed in 40 CFR 258.23.

3.8.2.2 Passive Venting. Passive venting systems are installed where gas generation is low and off-site migration of gas is not expected. Essentially passive venting is suitable for small municipal landfills (less than 50,000 cubic yards) and for most non-municipal, containment type landfills. A typical system may consist of a series of isolated gas vents that only penetrate as far as the top layer of landfill waste. No design procedure is available to calculate the number of vents required, but one vent per 10,000 cubic yards of waste may be sufficient. The more stringent requirements for landfill liners which exist today will help prevent gas movement away from the landfill site. Some techniques, such as gravel filled trenches and perforated pipes, not only help direct the flow of leachate, but assist in the passive venting of landfill gases. A passive gas vent is shown in Figure 7. A typical gas venting layer is composed of sand or fine aggregates. If fine aggregate is used, a layer of sand must be placed between it and the flexible membrane liner.

3.8.2.3 Active Venting. An active venting system consists of a series of deep extraction wells connected by header pipe to a mechanical blower, that either delivers the gas to a combustion boiler for energy reuse, transports it to an on-site waste burner, or simply releases it to the atmosphere. An active system is more effective for controlling gas movement than a passive system, but the layout and design of an active system is much more detailed. An active system will require as much engineering and design effort as other piping systems that contain or transport potentially hazardous materials.

3.8.2.4 Gas Release. Whether landfill gases can be released to the atmosphere either before or after burning depends on the following:

- *Chemical constituents* of *landfill gases.* Hazardous air contaminants such as vinyl-chloride or benzene may be present in landfill gases, and combustion may produce other harmful chemical by-products. Air quality regulations may not permit the release of these chemicals.
- *Landfill location.* If the landfill is located near or within a community or neighborhood, then gas collection and disposal techniques may be necessary to minimize the nuisance of odors, and the explosive potential of the gas.
- *Gas Disposal*. No one plan for gas disposal will be suitable for all landfill

situations. Each design will require different design decisions relative to acceptable landfill wastes, leachate control and treatment, liner design, and gas production expectations. The primary options for gas disposal include: venting to the atmosphere, collecting for transport and disposal off-site, collecting and burning, and finally collecting for beneficial energy reuse. Most decisions regarding landfill gas disposal will depend on local regulations.

3.9 Runoff Control.

3.9.1 General. Control of storm water runoff at a landfill disposal facility is necessary to minimize the potential of environmental damage to ground and surface waters. Direct surface water contamination can result when solid waste and other dissolved or suspended contaminants are picked up and carried by storm water runoff that comes into contact with the working face of the landfill. Uncontrolled surface water runoff can also increase leachate production, thereby increasing the potential for groundwater contamination. The resulting unwanted gas generation may also increase the potential for explosions.

3.9.2 Criteria. The USEPA requires a stormwater control system to prevent surface water discharge into the working portion of the landfill during a peak storm discharge, defined as a 25-year storm. Surface water runoff control should be accomplished at a landfill disposal facility in accordance with the following:

3.9.2.1 Landfill disposal facilities should be located and designed so that the potential for surface drainage from adjacent areas onto the landfill is minimal. Control is accomplished by constructing diversion structures to prevent surface water runoff from entering the working portion of the facility.

3.9.2.2 Landfill disposal facilities should be equipped with suitable channeling devices, such as ditches, berms or dikes, to divert surface water runoff from areas contiguous to the landfill.

3.9.2.3 Precipitation that falls on a landfill will either infiltrate into the soil, run off the site, or be reduced by evapotranspiration or direct evaporation. To control leachate generation the final cover on the landfill should inhibit moisture penetration and limit surface erosion. This can be done by sloping the final side grades at a maximum of 30 percent to enhance runoff.

3.9.2.4 Well-compacted, fine-grained soils should be used for the final cover to promote surface water runoff by minimizing infiltration.

3.9.2.5 Ground cover and plant growth should be included to aid in erosion control and to help dissipate moisture in the soil.

3.9.2.6 Runoff which does not come into contact with the working portion of the landfill, and thus is not contaminated, should be dispersed overland to reduce the flow rate and suspended solids load. Other sedimentation control measures such as retaining ponds may be equally effective.

3.10 Support Facilities

3.10.1 General. In planning a sanitary landfill, consideration will be given to support facilities, that are based primarily on the size of the operation and the climate. Support facilities must be tailored to the specific landfill. These facilities generally include the following:

3.10.2 Administration/Control and Storage Buildings. Control buildings, administrative offices, and storage areas are designed to meet the needs of the user. Showers and lockers should be provided for operators if feasible, and if not readily available elsewhere. At a minimum, a small building or semi-portable shed with sanitary facilities should be provided. If trucks entering the landfill are to be weighed or monitored, a control room is needed adjacent to the truck scales and roadway. It can be a separate building or part of the administration building. The control room operator must be able to see down the roadway in both directions. A typical floor plan is shown in Figure 13.

3.10.3 Truck Scales. Truck scales are readily available commercially and should be designed based on the size and type of trucks to be used. Scales can be low profile and installed on top of the ground. High profile scales are generally installed in pits. If drainage is such that water may collect in the pit, low profile scales are recommended. A straight truck approach is needed and in most cases a concrete approach ramp is required. This will prevent the scale from being covered with mud during wet periods.

3.10.4 Utilities. Power for lighting and water for employee use should be provided when feasible. However, these are not essential and extremely long utility runs are rarely justified. Fire protection is to be based on user requirements. However, in most cases the high cost of fire protection at remote sites is not justified since buildings in this size range are relatively inexpensive.

3.10.5 Processing Equipment. Refuse handling and processing equipment has not typically been provided at military installations. There may be specific cases where the type of waste present or the local climate make it desirable to shred the waste or use a solid waste baler. Prior to using this type of equipment at a military installation, the regional office of USEPA should be contacted for approval.

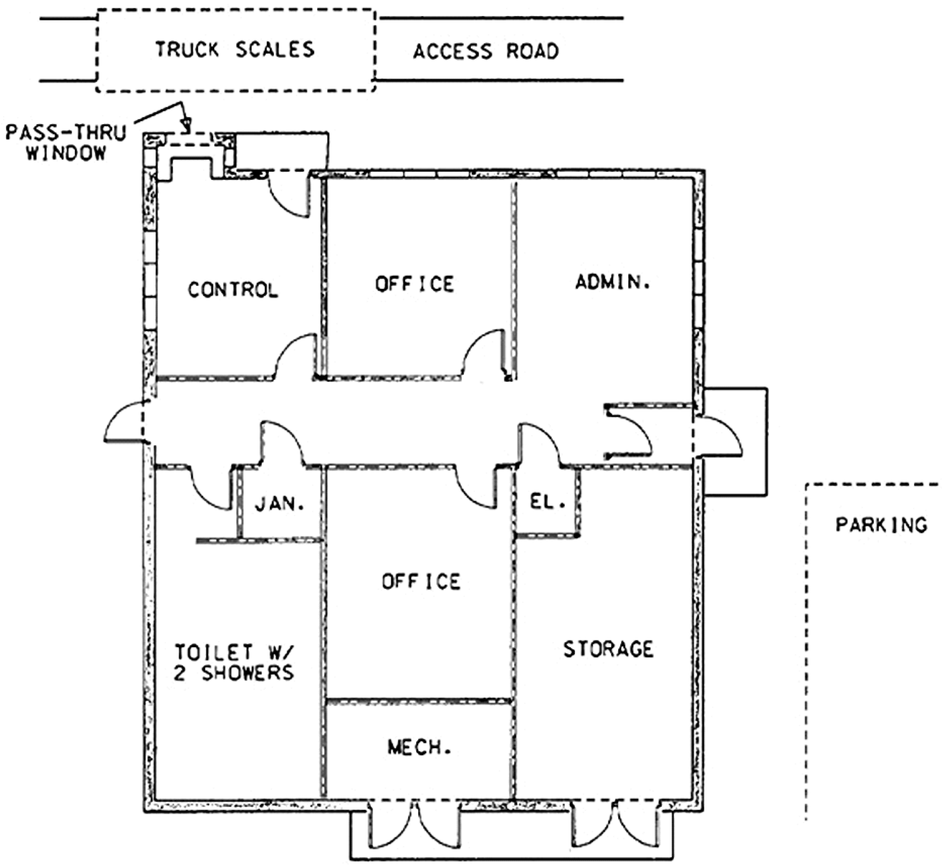

Figure 13
Typical Administration/Control Building Floor Plan

3.11 Closure.

3.11.1 Before closing a landfill, the final cover must be installed as described in as approved by the state regulatory agency. Closure activities must begin no later than 30 days after the last waste is received unless it is reasonable to expect additional waste. However, even if additional waste is expected, the landfill must be closed if no waste is received for one year (longer periods must be approved by the state).

3.11.2 In accordance with 40 CFR 258, post-closure care must be provided the landfill for a period of 30 years after closure. Each component of the landfill must be designed to maintain its integrity and effectiveness for the operating life of the landfill plus 30 years. Post-closure activities must not disturb or alter these systems. At a minimum, post-closure care includes maintaining the final cover, operating and maintaining systems for leachate collection, leachate treatment (if installed), gas collection, monitoring and disposal, and groundwater monitoring. The design must include a permanent access road.

3.11.3 Prior to receiving waste at the landfill, a post-closure plan must be prepared and maintained on file. The plan can be prepared by the designer of the landfill. At a minimum, the plan must include:

- A description of the monitoring program.
- The point-of-contact for the closed landfill (with title, office, address, and phone number).
- A description of the planned use of the site.